STRANDED ASSETS PROGRAMME

SMITH SCHOOL OF ENTERPRISE AND THE ENVIRONMENT

UNIVERSITY OF OXFORD

# Stranded Assets and Thermal Coal

## An analysis of environment-related risk exposure

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# About the Stranded Assets Programme

The Stranded Assets Programme at the University of Oxford's Smith School of Enterprise and the Environment was established in 2012 to understand environment-related risks driving asset stranding in different sectors and systemically. We research how environment-related risks might emerge and strand assets; how different risks might be interrelated; assess their materiality (in terms of scale, impact, timing, and likelihood); identify who will be affected; and what impacted groups can do to pre-emptively manage and monitor risk.

We recognise that the production of high-quality research on environment-related risk factors is a necessary, though insufficient, condition for these factors to be successfully integrated into decision-making. Consequently, we also research the barriers that might prevent integration, whether in financial institutions, companies, governments, or regulators, and develop responses to address them. We also develop the data, analytics, frameworks, and models required to enable integration for these different stakeholders.

The programme is based in a world leading university with a global reach and reputation. We are the only academic institution conducting work in a significant and coordinated way on stranded assets. We work with leading practitioners from across the investment chain (e.g. actuaries, asset owners, asset managers, accountants, investment consultants, lawyers), with firms and their management, and with experts from a wide range of related subject areas (e.g. finance, economics, management, geography, anthropology, climate science, law, area studies) within the University of Oxford and beyond.

We have created the Stranded Assets Research Network, which brings together researchers, research institutions, and practitioners working on these and related issues internationally to share expertise. We have also created the Stranded Assets Forums, which are a series of private workshops to explore the issues involved. The Global Stranded Assets Advisory Council that guides the programme contains many of the key individuals and organisations involved in developing the emergent stranded assets agenda. The council also has a role in helping to informally co-ordinate and share information on stranded assets work internationally.

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# Global Advisory Council

The Stranded Assets Programme is led by Ben Caldecott and its work is guided by the Global Stranded Assets Advisory Council chaired by Professor Gordon L. Clark, Director of the Oxford Smith School. The Council is also a high-level forum for work on stranded assets to be co-ordinated internationally. Members are:

**Jane Ambachtsheer**, Partner and Global Head of Responsible Investment, Mercer Investment
**Rob Bailey**, Research Director, Energy, Environment and Resources, Chatham House
**Vicki Bakhshi**, Head of Governance & Sustainable Investment, BMO Global Asset Management (EMEA)
**Morgan Bazilian**, Affiliate Professor, The Royal Institute of Technology of Sweden
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**James Mitchell** is a Researcher at the Stranded Assets Programme. He is concurrently a Senior Associate at the Carbon War Room, where he leads engagement with maritime financial institutions on stranded assets and financial decision-making.

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## University of Oxford Disclaimer

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# Executive Summary

The principal aim of this report is to turn the latest research on environment-related risk factors facing thermal coal assets into *actionable* investment hypotheses for investors. By examining the fundamental drivers of environment-related risk, creating appropriate measures to differentiate the exposure of different assets to these risks, and linking this analysis to company ownership, debt issuance, and capital expenditure plans, our research can help to inform specific investor actions related to risk management, screening, voting, engagement, and disinvestment. To our knowledge, this report contains the most comprehensive and up-to-date analysis of the environment-related risks facing thermal coal companies that is publicly available.

Our approach is a departure from how the vast majority of analysis concerning environment-related risks is usually undertaken. Researchers and analysts typically take a 'top down' approach. They look at company-level reporting and focus on measures of carbon emissions and intensity. Even if company-level reporting is accurate and up-to-date (in many cases it is not), this is an overly simplistic approach that attempts to measure a wide range of environment-related risk factors (often with widely varying degrees of correlation) through one proxy metric (carbon). While this might be a useful exercise, we believe that more sophisticated 'bottom up' approaches can yield improved insights for asset performance and if appropriately aggregated, company performance. In this report, we conduct a bottom up, asset-specific analysis of the thermal coal value chain and we look well beyond the relative carbon performance of different assets.

We have examined the top 100 utilities by coal-fired power generation capacity, the top 20 thermal coal mining companies by revenue (for companies with ≥30% revenue from thermal coal), and the top 30 coal processing technology companies by normalised syngas production. In the case of coal-fired utilities, we examine their coal-fired power stations. The top 100 coal-fired power utilities own 42% of the world's coal-fired power stations, with 73% of all coal-fired generating capacity. In the case of thermal coal miners, we examine their mines. The top 20 thermal coal miners account for approximately 60% of listed coal company revenue (see Section 6). In the case of coal-to-gas and coal-to-liquids companies, we examine their processing plants. The top 30 coal-to-gas and –liquids companies own 34% of all coal processing plants, with 63% of all fuel product capacity. We also look at the capital expenditure plans of these companies and their outstanding debt issuance.

Our approach requires granular data on the specific assets that make up a company's portfolio. For each sector we have attempted to find and integrate data to secure enough information on asset characteristics to enable an analysis of environment-related factors. Our approach also requires us to take a view on what the environment-related risks facing thermal coal assets could be and how they could affect asset values. We call these Local Risk Hypotheses (LRHs) or National Risk Hypotheses (NRHs) based on whether the risk factor in question affects all assets in a particular country in a similar way or not. For example, water stress has variable impacts within a country and so is an LRH, whereas a country-wide carbon price is an NRH. The list of LRHs and NRHs considered in this report can be found in Table 1 below.

As part of the process we have undertaken an assessment of how these environment-related risk factors, whether local or national, might affect assets over time. We find that the environment-related risks facing the thermal coal value chain are substantial and span physical environmental impacts, the transition risks of policy and technology responding to environmental pressures, and new legal liabilities that may arise from either of the former. These environment-related factors have the potential to create stranded assets, which are assets which have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities[1].

[1] See Caldecott, B., Howath, N., & McSharry, P. (2013). Stranded Assets in Agriculture: Protecting Value from Environment-Related Risks. Smith School of Enterprise and the Environment, University of Oxford (Oxford, UK).

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For each of the environment-related risk factors we examine in this report, we identify appropriate measures that could indicate levels of exposure and assess how each specific asset (i.e. power station, coal mine, or processing plant) is exposed to these measures. We have then linked these assets back to their company owners. This allows us to see which companies have portfolios that are more or less exposed, and allows investors to interrogate individual company portfolios for environment-related risks.

***Table 1:*** *Local risk hypotheses (LRHs) and national risk hypotheses (NRHs)*

| # | Name | Source |
|---|---|---|
| Coal-Fired Power Utilities | | |
| LRH-U1 | Carbon Intensity | CARMA/CoalSwarm/WEPP/Oxford Smith School |
| LRH-U2 | Plant Age | CARMA/CoalSwarm/WEPP |
| LRH-U3 | Local Air Pollution | Boys et al. (2015)/NASA's SEDAC |
| LRH-U4 | Water Stress | WRI's Aqueduct |
| LRH-U5 | Quality of Coal | CoalSwarm/WEPP |
| LRH-U6 | CCS Retrofitability | CARMA/CoalSwarm/WEPP/Geogreen |
| LRH-U7 | Future Heat Stress | IPCC AR5 |
| NRH-U1 | Electricity Demand Outlook | IEA |
| NRH-U2 | 'Utility Death Spiral' | Oxford Smith School |
| NRH-U3 | Renewables Resource | Lu et al. (2009)/ McKinsey & Co/SolarGIS |
| NRH-U4 | Renewables Policy Support | EY's Renewables Attractiveness Index |
| NRH-U5 | Renewables Generation Outlook | BP/REN21 |
| NRH-U6 | Gas Resource | BP/IEA |
| NRH-U7 | Gas Generation Outlook | IEA |
| NRH-U8 | Falling Utilisation Rates | Oxford Smith School |
| NRH-U9 | Regulatory Water Stress | WRI's Aqueduct |
| NRH-U10 | CCS Legal Environment | Global CCS Institute |
| Thermal Coal Mining Companies | | |
| LRH-M1 | Proximity to Populations and Protected Areas | NASA's SEDAC/UNEP-WCMC |
| LRH-M2 | Water Stress | WRI's Aqueduct |
| NRH-M1 | Remediation Liability Exposure | Oxford Smith School |
| NRH-M2 | Environmental Regulation | Oxford Smith School |
| NRH-M3 | New Mineral Taxes or Tariffs | Oxford Smith School |
| NRH-M4 | Type of Coal Produced | IEA |
| NRH-M5 | Domestic Demand Outlook | IEA |
| NRH-M6 | Export Sensitivity | IEA |
| NRH-M7 | Protests and Activism | CoalSwarm |
| NRH-M8 | Water Regulatory Stress | WRI's Aqueduct |

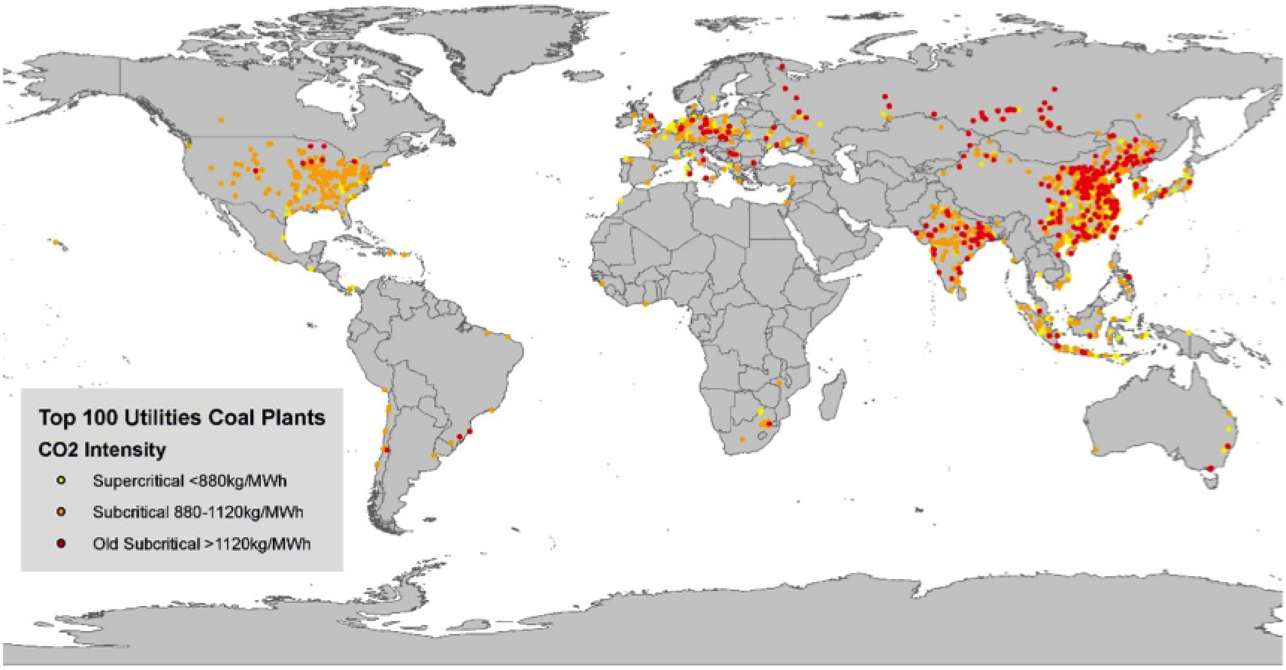
*Table 1: (Continued)*

| Coal Processing Technology Companies | | |
|---|---|---|
| LRH-P1 | Plant Age | World Gasification Database |
| LRH-P2 | Water Stress | WRI's Aqueduct |
| LRH-P3 | CCS Retrofitability | World Gasification Database/GeoGreen |
| NRH-P1 | CPT Policy Support | Oxford Smith School |
| NRH-P2 | Oil and Gas Demand Outlook | IEA |
| NRH-P3 | Oil and Gas Indigenous Resources | BP |
| NRH-P4 | Other Local Environmental | Oxford Smith School |
| NRH-P5 | Regulatory Water Stress | WRI's Aqueduct |
| NRH-P6 | CCS Policy Outlook | Global CCS Institute |

# Coal-fired power utilities

Figure 1 shows the location and carbon intensity of the power stations of the world's top 100 coal-fired power utilities.

***Figure 1:** Coal-fired power stations of the top 100 coal-fired power utilities*



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Exposure to environment-related risk of the top 100 coal-fired power utilities is summarised in Figure 2 below. Companies from the United States carry the most exposure to ageing plants (LRH-U2), CCS retrofitability (LRH-U6), and future heat stress (LRH-U7). Companies in China and India are most exposed to conventional air pollution concentration (LRH-U3) and physical water stress (LRH-U4). Table 62 in Appendix A provides further details of company exposure to all LRHs and NRHs.

***Figure 2:*** *LRH rankings for coal-fired utilities*

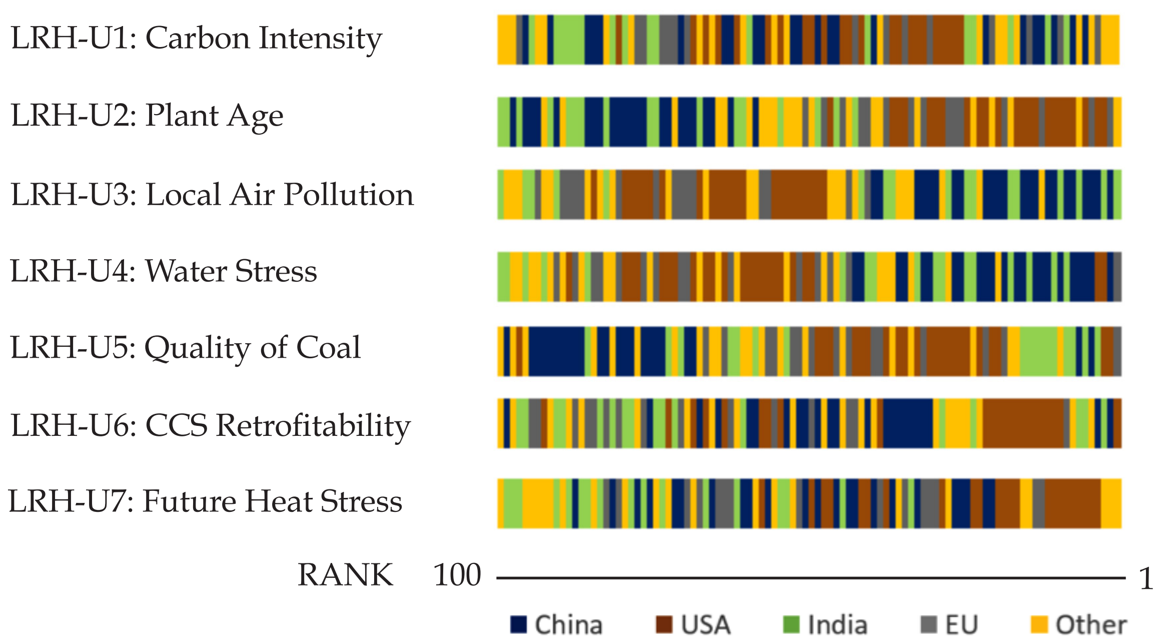

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Table 2 below shows the top 20 coal-fired utilities ranked by coal-fired generation capacity. The top 100 list can be found in Appendix A.

***Table 2:** Summary of top 20 coal-fired power utilities*

| # | PARENT OWNER | COUNTRY | Coal-Fired Electricity: Generation [GWh] | Coal-Fired Electricity: Capacity OPR [MW] | Coal-Fired Electricity: Capacity CON [MW] | Coal-Fired Electricity: Capacity PLN [MW] | DEBT/EQUITY | CURRENT RATIO | (EBITDA-CAPEX)/INTEREST | LRH-U1 'Carbon Intensity' [RANK]* | LRH-U2 'Plant Age' [RANK]* | LRH-U3 'Local Air Pollution' [RANK]* | LRH-U4 'Water Stress' [RANK]* | LRH-U5 'Quality of Coal' [RANK]* | LRH-U6 'CCS Retrofitability' [RANK]* | LRH-U7 'Future Heat Stress' [RANK]* | ASSET BASE | NRH-AGGREGATE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CHINA HUANENG GROUP CORP | China | 471,139 | 160,212 | 5,360 | 91,968 | 3.28 | 0.45x | 0.42x | 57 | 53 | 37 | 25 | 27 | 83 | 51 | CH-100% | 60% |
| 2 | CHINA GUODIAN CORP | China | 455,038 | 148,539 | 20,140 | 111,360 | 3.38 | 0.24x | 0.85x | 53 | 52 | 33 | 21 | 32 | 78 | 37 | CH-100% | 60% |
| 3 | CHINA DATANG CORP | China | 415,118 | 123,635 | 12,230 | 89,521 | 3.69 | 0.47x | 1.16x | 45 | 100 | 39 | 18 | 35 | 90 | 43 | CH-100% | 60% |
| 4 | CHINA HUADIAN GROUP CORP | China | 369,511 | 119,808 | 21,101 | 95,628 | 3.22 | 0.37x | 3.02x | 63 | 100 | 41 | 20 | 39 | 84 | 54 | CH-100% | 60% |
| 5 | CHINA POWER INVESTMENT CORP | China | 293,658 | 82,819 | 16,028 | 35,590 | - | - | - | 50 | 100 | 49 | 14 | 16 | 76 | 44 | CH-99% | 60% |
| 6 | SHENHUA GROUP CORP LTD | China | 292,107 | 89,021 | 42,520 | 67,710 | 0.49 | 0.96x | 0.62x | 87 | 100 | 42 | 29 | 30 | 96 | 47 | CH-100% | 60% |
| 7 | ESKOM HOLDINGS SOC LTD | South Africa | 214,924 | 36,678 | 19,375 | 3,000 | 1.69 | 1.09x | -10.67x | 20 | 36 | 92 | 100 | 100 | 1 | 27 | SA-100% | 55% |
| 8 | NTPC LTD | India | 208,588 | 41,532 | 46,520 | 91,056 | 1.24 | 1.16x | -0.48x | 80 | 49 | 40 | 40 | 24 | 71 | 65 | IN-100% | 45% |
| 9 | CHINA RESOURCES POWER HOLDINGS | China | 171,178 | 55,342 | 13,410 | 24,340 | 1.12 | 0.58x | 3.65x | 40 | 100 | 25 | 16 | 36 | 85 | 61 | CH-100% | 60% |
| 10 | KOREA ELECTRIC POWER CORP | Korea | 128,189 | 23,481 | 30,459 | 7,880 | 0.92 | 1.03x | 1.68x | 38 | 46 | 14 | 48 | 42 | 1 | 48 | OTHER | - |
| 11 | GUANGDONG YUDEAN GROUP CO LTD | China | 126,689 | 43,441 | 9,850 | 13,300 | - | - | - | 69 | 100 | 36 | 100 | 34 | 1 | 66 | CH-100% | 65% |
| 12 | NRG ENERGY INC | USA | 99,685 | 29,576 | - | - | 1.66 | 1.86x | 1.76x | 30 | 8 | 78 | 100 | 31 | 1 | 42 | US-94%, AU-6% | 60% |
| 13 | STATE GRID CORP OF CHINA | China | 97,603 | 22,218 | - | 10,000 | 0.53 | 0.39x | 0.00x | 15 | 48 | 32 | 11 | 14 | 66 | 30 | CH-100% | 60% |
| 14 | GDF SUEZ SA | France | 89,977 | 20,424 | 1,715 | 5,059 | 0.69 | 1.06x | 4.67x | 76 | 37 | 59 | 42 | 20 | 91 | 80 | NOTE-1 | 47% |
| 15 | VATTENFALL GROUP | Sweden | 83,646 | 15,719 | 1,730 | - | 0.97 | 1.35x | -1.16x | 84 | 47 | 53 | 100 | 9 | 79 | 57 | CH-81% | 60% |
| 16 | SOUTHERN CO | USA | 71,669 | 27,819 | 600 | - | 1.23 | 0.65x | -0.15x | 49 | 21 | 87 | 100 | 40 | 69 | 53 | US-100% | 60% |
| 17 | DUKE ENERGY CORP | USA | 67,730 | 22,492 | - | - | 1.07 | 0.97x | 1.68x | 51 | 17 | 71 | 100 | 41 | 67 | 50 | US-99% | 60% |
| 18 | PT PLN PERSERO | Indonesia | 66,467 | 16,763 | 6,730 | 18,350 | 3.42 | 0.84x | 0.88x | 19 | 100 | 30 | 33 | 33 | 87 | 89 | ID-100% | 40% |
| 19 | ENEL SPA | Italy | 62,916 | 17,937 | - | 2,900 | 1.03 | 0.99x | 2.65x | 37 | 24 | 68 | 46 | 23 | 1 | 56 | OTHER | - |
| 20 | AMERICAN ELECTRIC POWER CO INC | USA | 60,917 | 22,577 | - | - | 1.14 | 0.64x | 0.76x | 35 | 13 | 80 | 100 | 38 | 1 | 17 | US-100% | 60% |

*: Companies are ranked by exposure, with 1 being the most at risk.

**: NRHs have been aggregated to a single outlook percentage based on the sum of high risk (+2) and medium risk (+1) evaluations relative to the maximum possible and weighted by asset locations.

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Figure 3 and Figure 4 show planned and under construction new coal-fired generating capacity as a proportion of existing capacity. Utilities in the United States have largely abandoned new coal-fired capacity. Utilities in China and India continue to build and plan power stations. Seven of the 16 Indian utilities in the top 100 are more than doubling their current coal-fired generating capacity. Other outliers include J-Power, Gazprom, Inter RAO UES, Taiwan's Ministry of Economic Affairs, Elektroprivreda Srbije, and Electricity of Vietnam.

***Figure 3:*** *Planned coal-fired capacity as a percentage of current capacity*

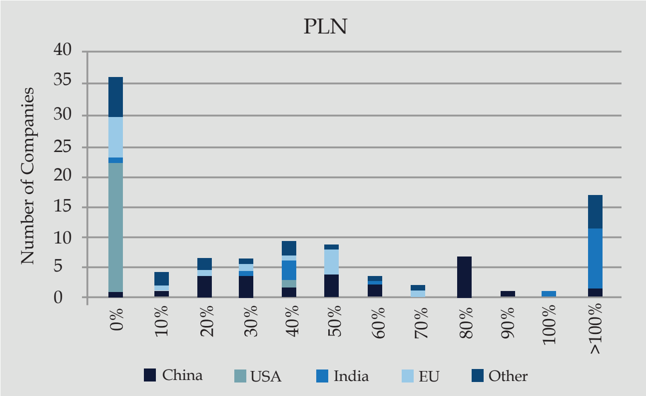


***Figure 4:*** *Coal-fired capacity under construction as a percentage of current capacity*

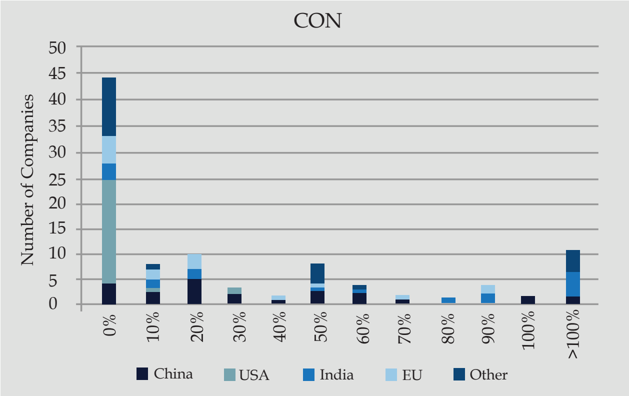


Figure 5 shows the ratios of (EBITDA less CAPEX) / debt repayment for the top 100 coal-fired power utilities. Companies with a ratio less than unity cannot currently service their existing debt. Companies with a negative ratio are expending CAPEX in excess of EBITDA. The five companies with a ratio less than -1 are Vattenfall Group, Eskom Holdings SOC Ltd, Comision Federal de Electricidad, Tauron Polska Energia SA, and Andhra Pradesh Power Gen Corp.

***Figure 5:*** *Histogram of (EBITDA-CAPEX)/Interest*

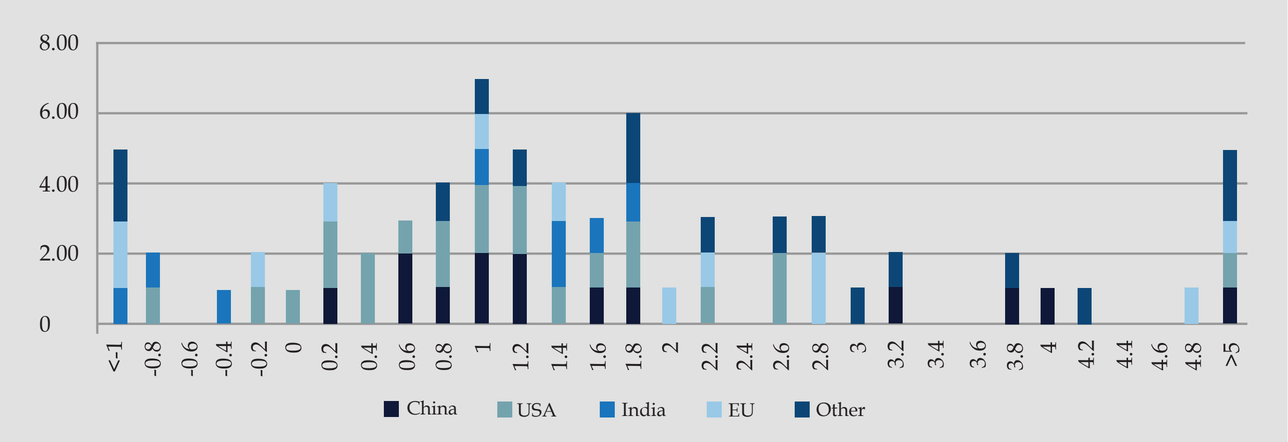

Figure 6 shows the current ratios of the top 100 coal-fired power utilities. European coal-fired utilities have higher current ratios than coal-fired utilities in the United States, which in turn have higher current ratios than Chinese coal-fired power utilities.

***Figure 6:*** *Histogram of current ratios*

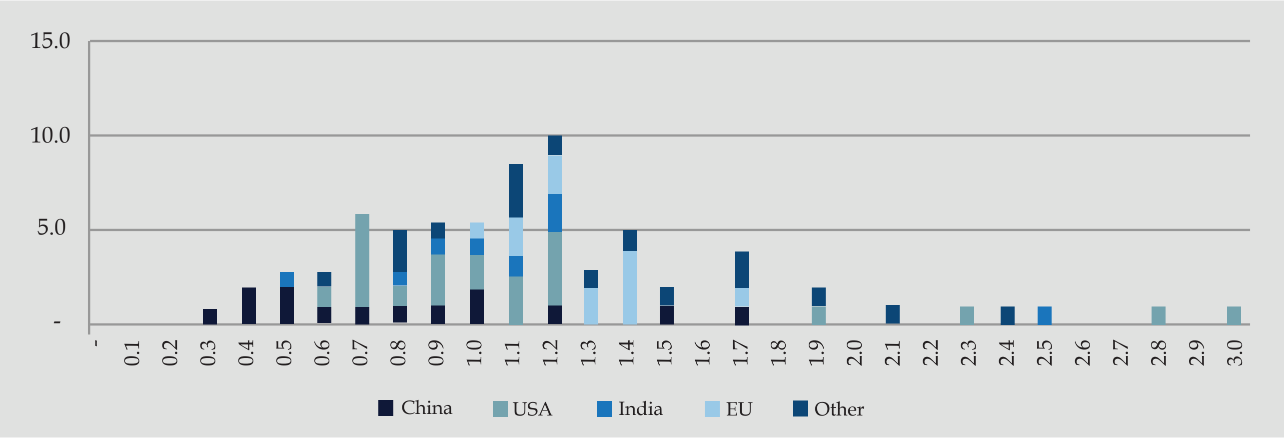


Figure 7 shows the debt-to-equity (D/E) ratios of the top 100 coal-fired power utilities. Utilities in the US are generally more leveraged than utilities in China or Europe. Outliers include Tohoku Electric Power Corp and AES Corp, the only public companies with D/E ratios over 300%.

***Figure 7:*** *Histogram of D/E ratios*

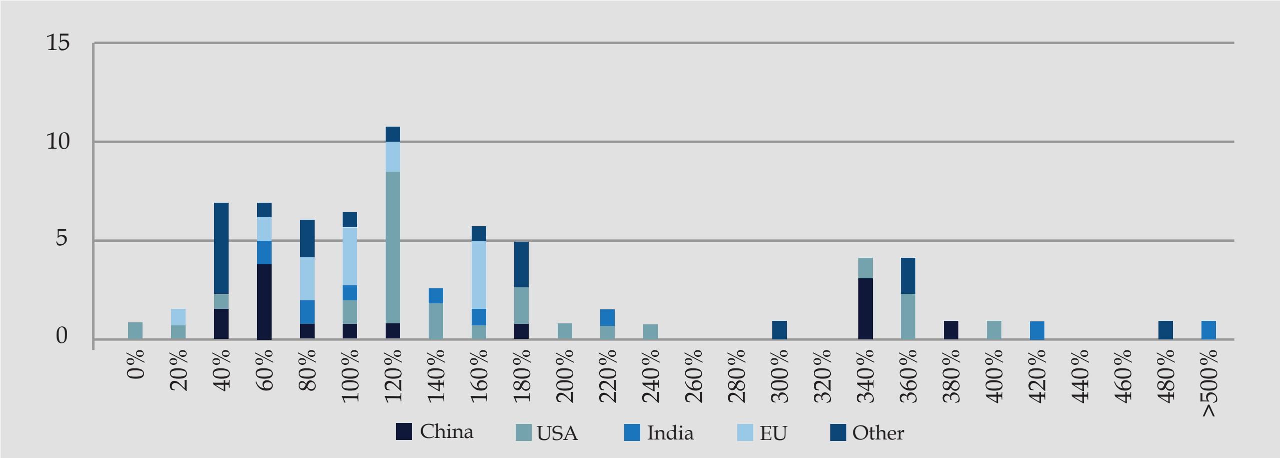

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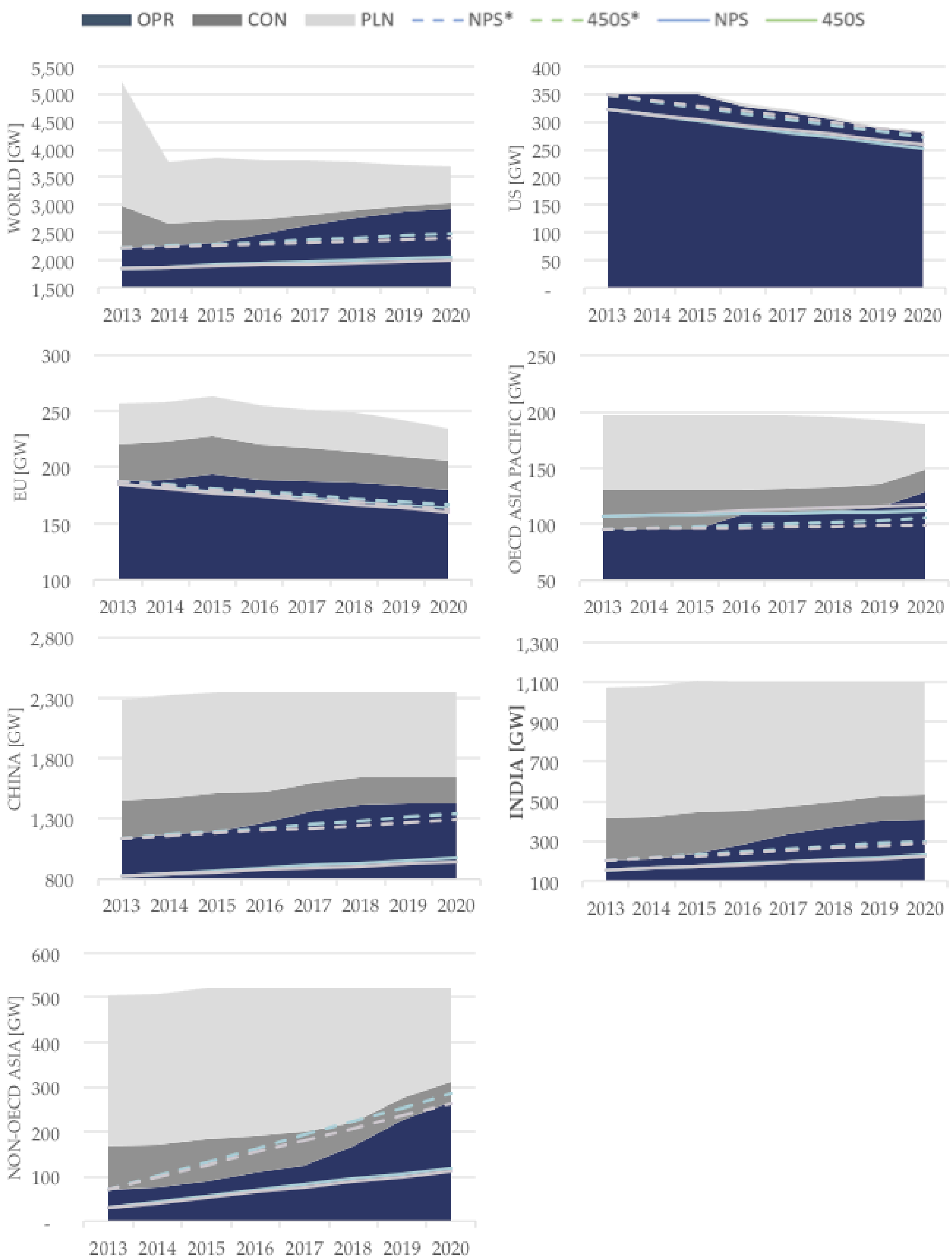
Figure 8 shows global and regional projected coal-fired power generating capacity, operating, in construction, and planned from datasets compiled by the Oxford Smith School. Generating capacity from this new dataset is compared with scenarios from the IEA WEO 2015. Because of differences in database coverage, IEA projections have also been benchmarked to 2013 data, shown in the dashed series denoted by "*". Plant life is assumed to be 40 years on average.

***Figure 8:*** *Projection of operational, in construction, and planned coal-fired power stations, all companies, from composite database with comparison to IEA projections*

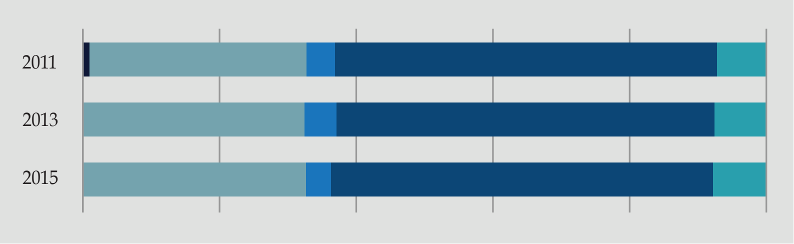


The ownership of coal-fired power utilities is shown for selected regions in Figure 9. Widely-held public companies are likely to have different decision-making processes than entirely state-owned companies.

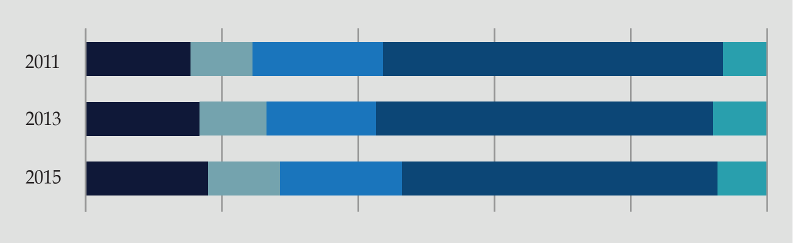
***Figure 9:** Coal-fired power utility ownership changes by region*[2]

■ Individuals/Insiders ■ Corporates ■ Institutions ■ ESOP ■ State ■ Pubic/Other

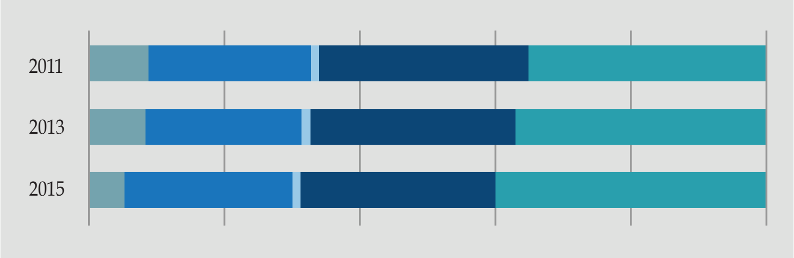
**China** – Ownership of coal-fired utilities is dominated by the state and has remained stable for the last five years. Investors owning portions of Chinese utilities are often ultimately state-owned.



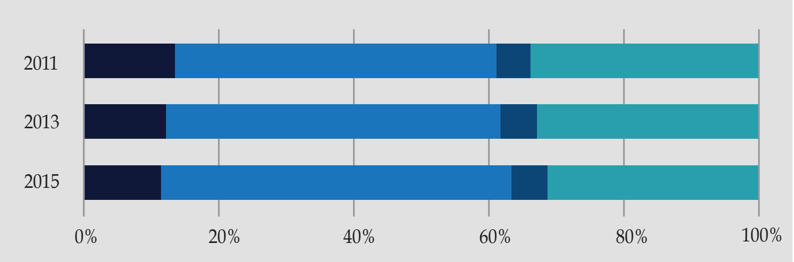

**India** – Ownership of coal-fired utilities has growing insider/ individual ownership. The state also owns a significant and stable portion of coal-fired power utilities.




**EU** – European coal-fired power utilities still retain a significant portion of state ownership. They are otherwise owned by institutional and retail investors.




**US** – Coal-fired power utilities in the United States are mostly widely-held public companies. Individual and insider ownership tends to be dominated by the executives of the companies.




[2] Data from Standard & Poor's Capital IQ, November 2015.

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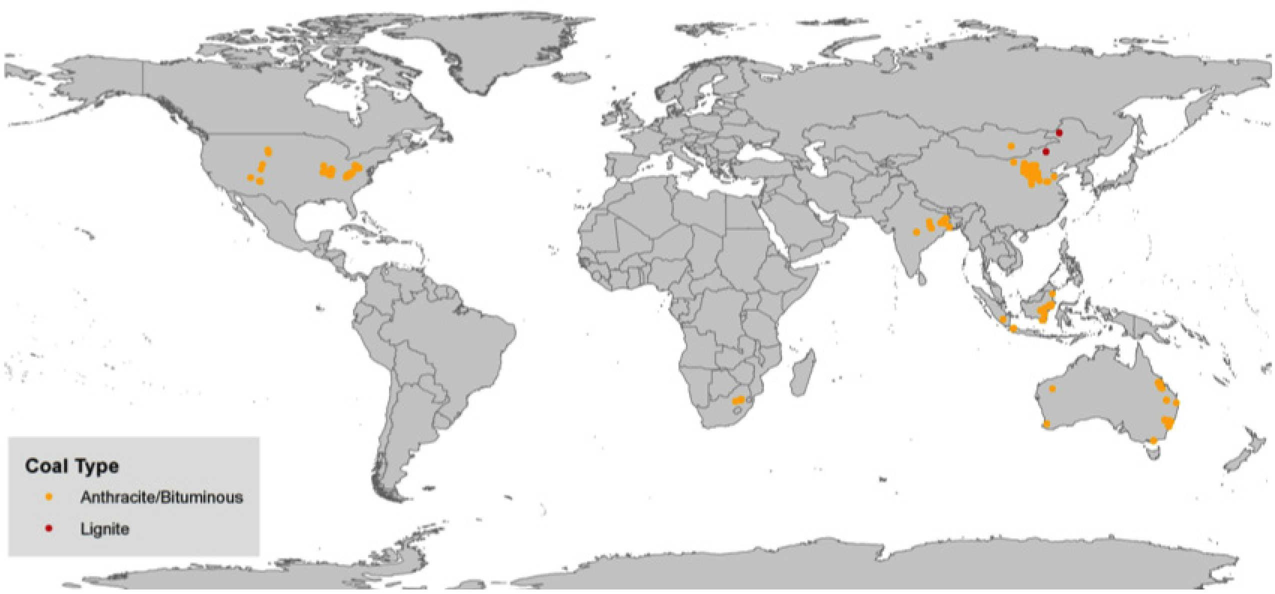
# Thermal coal miners

Figure 10 shows the location of the mines of the world's top 20 thermal coal mining companies with ≥30% revenue from thermal coal.

***Figure 10:*** *Mines of the world's top 20 thermal coal mining companies with revenue ≥30% from thermal coal*




The capital expenditure projections of the top 20 thermal coal mines is shown in Table 65 in Appendix B. Emerging environment-related risks may expose capital spending to risk of stranding. Table 66 in Appendix B shows ownership information for the 20 top thermal coal mining companies.

*Table 3: Summary of top 20 thermal coal miners with revenue ≥30% from thermal coal*

| # | PARENT OWNER | COUNTRY | 2014 THERMAL COAL REV [US$mn] | NUMBER OF MINES | PRODUCTION [Mt (#)] | Diversification [% rev from coal] | Projected Capex / EBITDA | Debt/EQUITY | Current Ratio | (EBITDA-CAPEX) /Interest | LRH-M1: 'Proximity to Populations and Protected Areas' [RANK]* | LRH-M2: 'Water Stress' [RANK]* | ASSET BASE | NRH-ALL** [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CHINA SHENHUA ENERGY CO | China | 14,006 | 23 | 305 (23) | 35% | 45% | 28% | 1.30x | 7.66x | 9 | 6 | CH-100% | 31% |
| 2 | SASOL | South Africa | 11,050 | 6 | 41 (6) | 58% | 75% | 22% | 2.58x | 7.10x | 14 | 14 | SA-100% | 44% |
| 3 | COAL INDIA LTD | India | 10,251 | 13 | 494 (8) | 89% | 46% | 1% | 3.15x | 1,728.94x | 2 | 17 | IN-100% | 31% |
| 4 | CHINA COAL ENERGY COMPANY | China | 5,966 | 11 | 107 (6) | 52% | 201% | 113% | 1.36x | - | 6 | 1 | CH-100% | 31% |
| 5 | ADANI ENTERPRISES LTD | India | 5,068 | 6 | 8 (2) | 55% | 28% | 142% | 1.08x | 2.71x | 12 | 15 | Note 1 | 38% |
| 6 | PEABODY ENERGY CORPORATION | USA | 4,890 | 28 | 232 (28) | 72% | 31% | 481% | 1.02x | 0.23x | 16 | 13 | AU-39%, US-61% | 49% |
| 7 | INNER MONGOLIA YITAI COAL CO., LTD. | China | 3,397 | 13 | 51 (13) | 85% | 282% | 109% | 1.63x | -6.26x | 10 | 5 | CH-100% | 31% |
| 8 | YANZHOU COAL MINING COMPANY LIMITED | China | 3,045 | 23 | 73 (19) | 31% | 150% | 119% | 1.21x | -1.34x | 8 | 7 | AU-43%, CH-57% | 42% |
| 9 | PT ADARO ENERGY TBK | Indonesia | 2,909 | 4 | 56 (4) | 91% | 23% | 49% | 2.10x | 5.34x | 13 | 19 | ID-100% | 44% |
| 10 | ALPHA NATURAL RESOURCES | USA | 2,837 | 3 | 84 (3) | 66% | 163% | 141% | 0.40x | -0.28x | 19 | 9 | US-100% | 44% |
| 11 | PT UNITED TRACTORS | Indonesia | 2,826 | 1 | 6 (1) | 66% | 39% | 7% | 1.90x | 105.39x | 20 | 20 | ID-100% | 44% |
| 12 | BANPU PUBLIC COMPANY LIMITED | Thailand | 2,638 | 10 | 39 (9) | 85% | 69% | 156% | 1.23x | 1.38x | 7 | 10 | ID-70%, CH-30% | 40% |
| 13 | ARCH COAL | USA | 2,350 | 12 | 264 (11) | 80% | 32% | -849%* | 2.66x | 0.59x | 18 | 8 | US-100% | 44% |
| 14 | YANG QUAN COAL INDUSTRY (GROUP) CO., LTD. | China | 2,337 | 25 | 13 (4) | 70% | 113% | - | - | - | 5 | 1 | CH-25% | 31% |
| 15 | PINGDINGSHAN TIANAN COAL MINING CO | China | 2,324 | 10 | 6 (1) | 45% | - | 114% | 0.85x | -0.34x | 21 | 26 | CH-100% | 31% |
| 16 | SHANXI LU'AN ENVIRONMENTAL ENERGY DEVELOPMENT | China | 2,301 | 5 | 30 (5) | 90% | 162% | 69% | 0.89x | -2.66x | 3 | 1 | CH-5% | 31% |
| 17 | ALLIANCE RESROUCE PARTNERS | USA | 1,861 | 13 | 41 (11) | 100% | 29% | 92% | 1.01x | 18.26x | 17 | 18 | US-13% | 44% |
| 18 | THE TATA POWER COMPANY | India | 1,741 | 3 | 27 (1) | 31% | 19% | 195% | 0.69x | 2.40x | 1 | 11 | ID-3% | 44% |
| 19 | INDO TAMBANGRAYA MEGAH TBK PT | Indonesia | 1,600 | 6 | 29 (6) | 94% | 39% | 0% | 1.88x | 121.77x | 4 | 12 | ID-6% | 44% |
| 20 | CONSOL ENERGY INC | USA | 1,356 | 5 | 32 (5) | 46% | 67% | 76% | 0.52x | -1.11x | 15 | 16 | US-5% | 44% |

Note 1: ID-17%, AU-17%, IN-66%

*: Companies are ranked by exposure, with 1 being the most at risk

**: NRHs have been aggregated to a single outlook percentage based on the sum of high risk (+2) and medium risk (+1) evaluations relative to the maximum possible and weighted by asset locations.

Thermal coal miners might be more resilient to environment-related risks if their business activities are diversified. The revenue sources of 18 of the top 20 thermal coal miners (by ultimate corporate parent) have been obtained from Trucost and weighted by company EBITDA, see Figure 11.

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*Figure 11:* *Coal mining diversification trends*[3]

**China** (6/7*) – Chinese coal miners have made the mainstay of their revenue from underground coal mining and a small portion of coal-fired power generation. Petrochemical and surface mining activities are slowly emerging.

*Number of companies for which data was available

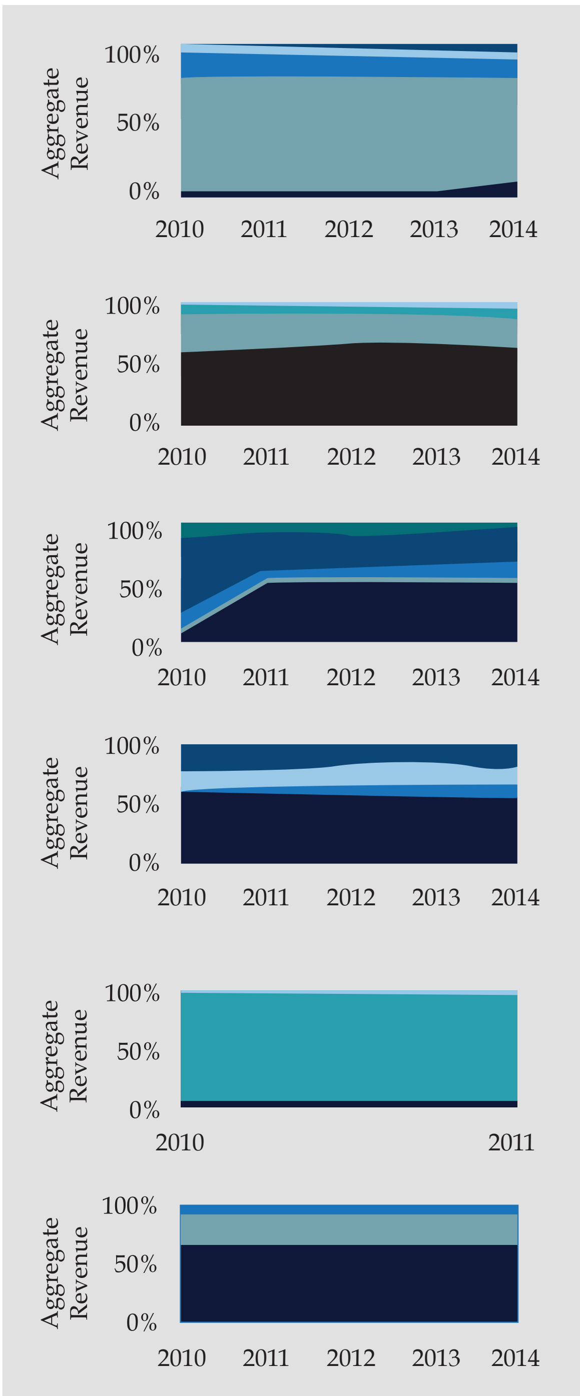
**US** (4/5) – Underground mining is giving way to surface mining in the United States. Coal mining companies are also becoming increasingly involved in petrochemical activities.

**India** (3/3) – Indian thermal coal miners for which data are available have diversified activities: power generation, coal-fuelled or otherwise, and other activities. Most coal is surface mined.

**Indonesia** (3/3) – Indonesia's thermal coal miners conduct surface mining almost exclusively and are diversified into power generation with fuels other than coal and non-related business activities. Coal power generation activities have begun recently.

**South Africa** (1/1) – Most of the revenue of South Africa's thermal coal miners is derived from petrochemical processing activities. These companies are therefore highly exposed to the CPT risks discussed below.

**Thailand** (1/1) – The revenue of Banpu Public Company ltd has been shifting slowly from surface coal mining to underground coal mining, with consistent power generation revenue.




[3] Data from Trucost, November 2015; and MSCI, October 2015.

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# Coal processing technology companies

Coal processing technologies (CPTs) are a suite of technologies used to convert coal into a wide range of useful fuels. These technologies have had a nascent presence for decades, but interest has recently grown, based on policy objectives for energy security and reducing conventional air pollutants, and economic opportunities for arbitrage with gas or liquid fuels. Common CPTs include coal to gas technology (CTG), coal to liquids (CTL) including Fisher-Tropsch synthesis, and underground coal gasification (UCG), also called coal seam methanation. Figure 12 shows the location of the plants of the global top 30 CPT companies.

***Figure 12:*** *Top 30 coal processing technology plants*

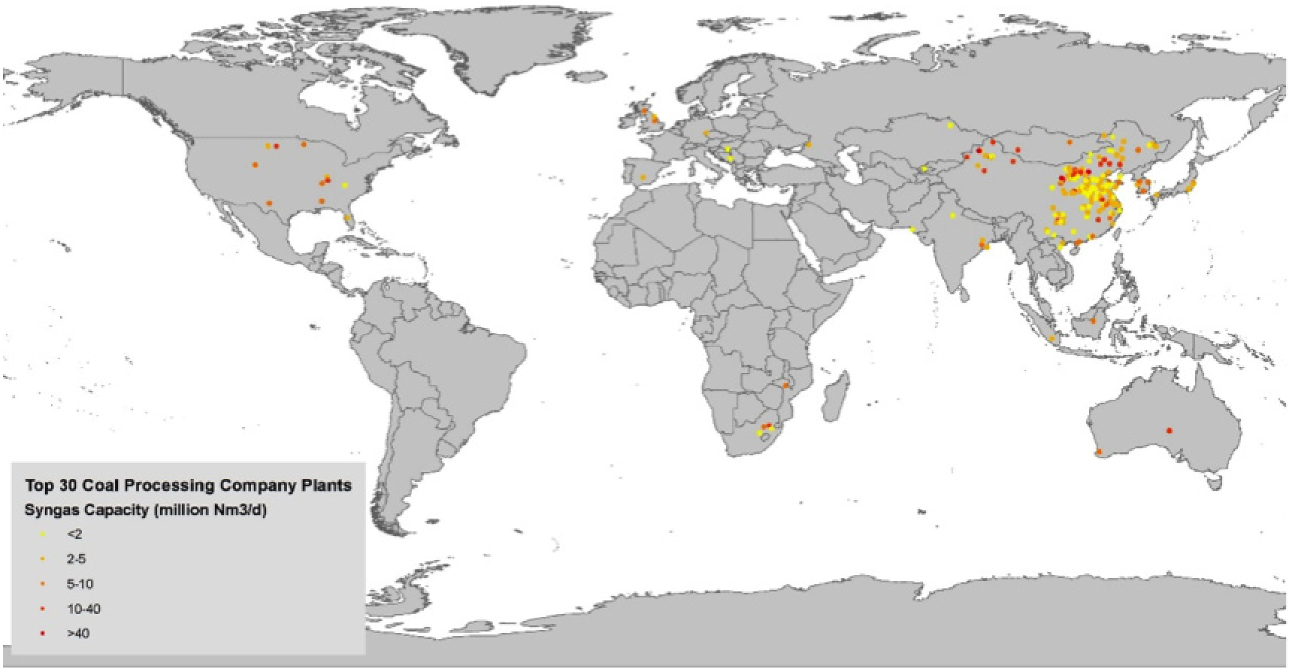

Table 4 below shows the top 20 coal processing technology companies ranked by normalised syngas capacity. The top 30 list can be found in Appendix C.

***Table 4:*** *Top 20 coal processing technology companies*

| # | PARENT OWNER | COUNTRY | CAPACITY [kNm³/day] OPR | CON | PLN | DEBT/EQUITY | CURRENT RATIO | (EBITDA – CAPEX) INTEREST | LRH-P1: 'Plant Age' [RANK]* | LRH-P2: 'Water Stress' [RANK]* | LRH-P3: 'CCS Retrofitability' [RANK]* | NRH-ALL** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SASOL | South Africa | 90,260 | - | 2,046 | 0.22 | 2.58x | 7.10x | 1 | 27 | 1 | 29% |
| 2 | DATANG | China | 48,550 | - | - | 2.71 | 0.34x | 0.91x | 10 | 13 | 17 | 43% |
| 3 | SHENHUA GROUP | China | 43,360 | - | - | 0.49 | 0.96x | 0.62x | 12 | 8 | 20 | 43% |
| 4 | YITAI COAL OIL MANUFACTURING CO (INNER MONGOLIA YITAI GROUP | China | 33,700 | 9,420 | 113,080 | - | - | - | 30 | 10 | 30 | 43% |
| 5 | SINOPEC | China | 29,481 | 8,400 | - | 0.32 | 0.76x | 3.90x | 9 | 19 | 19 | 43% |
| 6 | CHINACOAL GROUP | China | 24,100 | 3,336 | 73,442 | - | - | - | 20 | 16 | 30 | 43% |
| 7 | DAKOTA GASIFICATION CO | USA | 13,900 | - | - | - | - | - | 2 | 22 | 30 | 29% |
| 8 | QINGHUA GROUP | China | 13,860 | - | - | - | - | - | 17 | 5 | 1 | 43% |
| 9 | YANKUANG GROUP | China | 13,415 | - | - | - | - | - | 4 | 15 | 1 | 43% |
| 10 | GUANGHUI ENERGY CO | China | 12,600 | 840 | 63,400 | 1.79 | 0.41x | -1.86x | 15 | 7 | 1 | 43% |
| 11 | PUCHENG CLEAN ENERGY CHEMICAL CO | China | 12,100 | - | - | - | - | - | 21 | 17 | 1 | 43% |
| 12 | XINHU GROUP | China | 12,000 | 68,000 | - | - | - | - | 22 | 11 | 30 | 43% |
| 13 | WISON (NANJING) CLEAN ENERGY CO | China | 11,932 | - | - | - | - | - | 14 | 29 | 30 | 43% |
| 14 | TOKYO ELECTRIC POWER COMPANY (TEPCO) | Japan | 11,566 | - | - | 2.86 | 1.17x | 4.79x | 26 | 25 | 1 | 21% |
| 15 | CHINA NATIONAL OFFSHORE OIL CORPORATION (CNOOC) | China | 9,975 | - | 72,000 | 0.43 | 1.18x | 0.00x | 24 | 26 | 1 | 43% |
| 16 | SANWEI RESOURCE GROUP | China | 9,744 | - | - | - | - | - | 6 | 9 | 18 | 43% |
| 17 | INNER MONGOLIA ZHUOZHENG COAL CHEMICAL CO | China | 9,040 | - | - | - | - | - | 16 | 12 | 30 | 43% |
| 18 | TIANJIN BOHAI CHEMICAL GROUP | China | 8,787 | - | 3,125 | - | - | - | 5 | 4 | 30 | 43% |
| 19 | KOREA SOUTH EAST POWER CO (KOSEP) | South Korea | 8,400 | - | - | 0.88 | 1.03x | 4.11x | 27 | 1 | 1 | - |
| 20 | KOREA SOUTHERN POWER CO (KOSPO) | South Korea | 8,400 | - | - | 1.3 | 0.98x | -6.41x | 28 | 21 | 1 | - |

*: Companies are ranked by exposure, with 1 being the most at risk.
**: NRHs have been aggregated to a single outlook percentage based on the sum of high risk (+2) and medium risk (+1) evaluations relative to the maximum possible and weighted by asset locations.

The ownership trends of coal-based energy processing companies vary significantly by country. The majority of CPT plants are either in planning or under construction. Several projects have faced funding shortages or the withdrawal of companies due to low financial returns on trial projects, bureaucratic hurdles during planning and permitting stages, regulatory uncertainty, and environmental liabilities. A summary of key capital projects and their owners and funders is provided in Table 5.

### *Table 5: CPT capital projects*

| Country | Demonstration / operating projects | Pipeline projects | Key companies | Funding source |
|---|---|---|---|---|
| Australia | Monash Energy (CTL), Arckaringa (CTL), Chinchilla (UCG) - closed down in 2013 | Additional CTM project for Arckaringa | Anglo Coal, Shell, Altona Energy, Linc Energy | Private sector funding and government subsidies |
| China | Several CTG/CTL/UCG demonstration projects in place since 2010 | 50 new CTG plants in Northwestern China | Datang, China Guodian Corporation, China Power Investment, CNPC, CNOOC and Sinopec | Subsidies from local governments and loans from the Chinese Development Bank |
| India | UCG plant applications for Katha (Jharkhand), Thesgora (Madya Pradesh)<br>Tata Group's application for a CTL plant in Odisha rejected by government | New UCG pilot projects for West Bengal and Rajasthan | Coal India Limited, Tata Group, the Oil and Natural Gas Corporation Ltd (ONGC) and the Gas Authority of Indian Ltd. | Subsidies from local government, and private funding |
| South Africa | Operating 6 coal mines producing feedstock for Secunda Synfuels and Sasolburg Operations | New growth plans for the Project 2050, replacing 4 old coal mines for CTL projects | Sasol Ltd | Public and private funding; investment and pension funds |
| United States | Great Synfuels CTG Plant in North Dakota | 12 new CTL project proposals in Wyoming, Illinois, Arkansas, Indiana, Kentucky, Mississippi, Missouri, Ohio and West Virginia | Shell, Rentech, Baard, DKRW | Public and private funding |

Table 71 in Appendix C shows ownership information for the 30 coal-processing technology companies.

# Scenarios

The IEA's WEO scenarios are referenced in this report to provide consistency with the broader literature. While organisations have critiqued a number of assumptions that underlie the IEA scenarios, including technology penetration rates, world growth rates, and future energy demand, the IEA's WEO scenarios are widely referenced in industry and policymaking and are used as the primary reference scenarios in this study. We find that:

- Policy actions by key countries in the thermal coal value exceed the New Policies Scenario (NPS) in the reduction of coal in global total primary energy demand.
- The Paris Agreement offers a strong indicator that the direction of policy and technology deployment will continue to exceed the NPS in ambition to mitigate climate change.

# Carbon Capture and Storage

It is our view that CCS is unlikely to play a significant role in mitigating emissions from coal-fired power stations. Deployment of CCS has already been too slow to match IEA and IPCC scenarios. CCS compares unfavourably with other power sector mitigation options, especially considering that CCS also reduces plant efficiency, exacerbating existing merit-order challenges for conventional generators. CCS should remain an attractive option for industrial and process emitters that have few other mitigation options, and may be significant as a long-term option for delivering negative emissions with BECCS.

# Implications for reporting and disclosure

We have undertaken a comprehensive data integration process, bringing together a wide range of different datasets and sources for the first time. This is a work in progress, but our work to date has highlighted some of the challenges associated with turning an understanding of environment-related factors facing particular sectors into analysis that is decision-relevant for financial institutions. These experiences are germane to extant processes on disclosure and corporate reporting, particularly the Task Force on Climate-related Financial Disclosures (TCFD) chaired by Michael Bloomberg, that was launched at COP21 in Paris during December 2015.

To take one specific example, without accurate geo-location data for assets it is very hard to accurately overlay spatial datasets or to use remote sensing and satellite data to further research assets. Existing datasets for coal-fired power stations only have precise geo-location data for 30% of power stations and city level geo-location data for the remaining power stations. This means that spatial datasets representing certain types of risk (e.g. air pollution) are not uniformly accurate – and become less useful for power stations with inaccurate geo-location data. It also means that when, for example, we wanted to use satellite imagery to identify the type of cooling technology installed on a power station (for assets where cooling data was missing from existing datasets), we could only do this for assets with exact coordinates. Unfortunately, tracking down power stations on satellite imagery when the geo-location data is inaccurate is challenging and time consuming. This means that we have only been able to secure 71% coverage for the type of cool technology installed on coal-fired power stations, though we aim to improve this through further work.

One simple way around this particular problem would be for companies that are signed up to voluntary or mandatory reporting frameworks to disclosure the precise coordinates of their key physical assets. But a more general principle would be for companies, especially those with portfolios of large physical assets, to disclose asset specific characteristics so that researchers and analysts can undertake their own research on the risks and opportunities facing company portfolios. Natural resources companies, particularly those involved in upstream fossil fuel production, appear reluctant to disclose any asset specific information, instead suggesting that their investors should simply trust their judgement[4]. We would suggest that this is a highly questionable approach and one that the TCFD and other related processes should take on. Introducing a new 'Principle of Asset-level Disclosure' into reporting frameworks would significantly enhance the ability of investors to understand the environmental performance of companies.

More generally, it is noteworthy that very little of our analysis has actually depended on existing corporate reporting or data disclosed through voluntary disclosure frameworks. This is both a cause for hope and concern. It demonstrates that significant strides can be made to understand company exposure to environment-related risks even in the absence of consistent, comprehensive, and timely corporate reporting on these issues. But it also highlights how existing frameworks on environment-related corporate disclosure might be asking the wrong questions – they generally attempt to support and enable top down analysis, but might not do enough to support a bottom up, asset-specific approach. Reporting needs to link back to a fundamental understanding of risk and opportunity and to specific assets within company portfolios, especially for companies with portfolios of large physical assets (e.g. power stations, mines, oil and gas fields, processing plants, and factories). In the absence of that, what is reported may not be actionable from an investor perspective.

The other task is to reduce the cost of accessing and using data that can underpin the analytical approach we have used here. Where possible we use non-proprietary datasets, but this is insufficient. The cost is really the cost of data integration – to have all the relevant data points on asset characteristics merged from a variety of data sources, as well as overlays that allow us to measure the relative exposure of assets to different risks and opportunities. The costs associated with assuring datasets and finding novel datasets are also significant. Fortunately, these are all areas where costs can be reduced and this could be a significant public good.

# Company Data Intelligence Service

An initiative to find and integrate all the relevant asset-specific data points for companies in key sectors would almost certainly yield much more (and probably more accurate) investor-relevant information than what is currently disclosed. The initiative, call it the Company Data Intelligence Service (CDIS), would have the benefit of transcending mandatory and voluntary schemes as all companies would be in scope. CDIS would seek out data on company assets in key sectors, make this public where possible, and give companies the opportunity to correct mistakes and provide enhanced disclosure. It would operate in a completely transparent and accountable way and could collaborate with researchers and civil society to track down, assure, and release data on company assets.

[4] See Rook, D. & Caldecott, B.L. (2015) Evaluating capex risk: new metrics to assess extractive industry project portfolios. Working Paper. Smith School of Enterprise and the Environment, University of Oxford. Oxford, UK.

Critically, CDIS would not be dependent on companies disclosing data. Such a public goods initiative focused on putting into the public domain accurate and relevant information to improve the analysis of company environmental performance, would not be particularly costly – it would certainly be much cheaper, quicker, and more plausible than all companies actually disclosing all the asset specific data needed for bottom analyses of environment-related factors.

CDIS could support the development of new techniques and approaches to secure data that was hard to get or inaccessible due to cost or other barriers, whether through 'big data' or remote sensing, and foster the developments of new techniques to analyse data. CDIS could also have the task of integrating all existing corporate reporting into one system, allowing for analysis of data provided via a wide range of initiatives. The development of a CDIS type initiative is something that the TFCD should consider recommending as part of its deliberations.

# 1 Introduction

The principal aim of this report is to turn the latest academic and industry research on environment-related risk factors facing thermal coal assets into *actionable* investment hypotheses for investors. By examining the fundamental drivers of environment-related risk, creating appropriate measures to differentiate the exposure of different assets to these risks, and linking this analysis to company ownership, debt issuance, and capital expenditure plans, our research can help to inform specific actions related to risk management, screening, voting, engagement, and disinvestment. This report contains a thorough and up-to-date assessment of the key environment-related risk factors facing thermal coal assets and may also be of use for policymakers, companies, and civil society. The typology of environment-related risks is described in Table 6. Another aim of this work is for the datasets that underpin our analysis, as well as the analysis itself, to enable new lines of academic research and inquiry.

***Table 6:** Typology of environment-related risks*

| Set | Subset |
|---|---|
| Environmental Change | Climate change; natural capital depletion and degradation; biodiversity loss and decreasing species richness; air, land, and water contamination; habitat loss; and freshwater availability. |
| Resource Landscapes | Price and availability of different resources such as oil, gas, coal and other minerals and metals (e.g. shale gas revolution, phosphate availability, and rare earth metals). |
| Government Regulations | Carbon pricing (via taxes and trading schemes); subsidy regimes (e.g. for fossil fuels and renewables); air pollution regulation; voluntary and compulsory disclosure requirements; changing liability regimes and stricter licence conditions for operation; the 'carbon bubble' and international climate policy. |
| Technology Change | Falling clean technology costs (e.g. solar PV, onshore wind); disruptive technologies; GMO; and electric vehicles. |
| Social Norms and Consumer Behaviour | Fossil fuel divestment campaign; product labelling and certification schemes; and changing consumer preferences. |
| Litigation and Statutory Interpretations | Carbon liability; litigation; damages; and changes in the way existing laws are applied or interpreted. |

The vast majority of analyses that concern environment-related risks facing different sectors of the global economy are 'top down'. They look at company-level reporting and usually focus on measures of carbon intensity or carbon emissions. Even if this company level reporting is accurate and up-to-date (in many cases it is not), this is an overly simplistic approach that attempts to measure a wide range of environment-related risk factors (often with widely varying degrees of correlation) through one proxy metric (carbon). While this might be a useful exercise, we believe that more sophisticated 'bottom up' approaches can yield improved insights for asset performance and, if appropriately aggregated, company performance. In this report, we apply this bottom up, asset-specific approach to the thermal coal value chain.

The approach we use here is a significant extension of work pioneered in a previous report completed by the Stranded Assets Programme at the University of Oxford's Smith School of Enterprise and the Environment (the 'Oxford Smith School') from March 2015 entitled, 'Stranded Assets and Subcritical Coal: The Risk to Companies and Investors'.

Our methodology attempts to understand how specific assets could be affected by a wide range of environment-related risk factors and then to aggregate that analysis up to the level of the company portfolio. This is not particularly novel, but surprisingly, has not been applied to the questions we attempt to answer in this report. We believe that this is a much more promising approach for investors interested in understanding and anticipating the real risks and opportunities that companies face from environment-related factors.

The approach requires data on the specific assets that make up a company's portfolio. In this report we focus on companies involved in producing and using thermal coal. In the case of coal-fired utilities, we examine their coal-fired power stations. In the case of thermal coal miners, we examine their mines. And in the case of coal-to-gas and coal-to-liquids companies, we examine their processing plants. These different assets have different characteristics and for each sector we have attempted to find and integrate data that provide enough information on asset characteristics relevant to our analysis of environment-related factors. We also look at the capital expenditure pipeline of companies and their outstanding debt issuance.

Our approach also requires us to take a view on what the environment-related risks facing thermal coal assets could be and how they could affect asset values. We call these Local Risk Hypotheses (LRHs) or National Risk Hypotheses (NRHs) based on whether the risk factor in question affects all assets in a particular country in a similar way or not. For example, water stress has variable impacts within a country and so is an LRH, whereas a country-wide carbon price is an NRH.

It then requires an assessment of how these environment-related risk factors, whether local or national, might affect assets over time. We find that the environment-related risks facing the thermal coal value chain are substantial and span physical environmental impacts, the transition risks of policy and technology responding to environmental pressures, and new legal liabilities that may arise from either of the former. These environment-related factors may create stranded assets, which are assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities[5].

For each of the environment-related risk factors we examine in this report, we identify appropriate measures that indicate levels of exposure and assess how each specific asset (i.e. power station, coal mine, or processing plant) is exposed to these measures. We have then linked these assets back to their company owners. This allows us to see which companies have portfolios that are more or less exposed, and allows investors to interrogate individual company portfolios for environment-related risks. In this report we examine the top 100 utilities by coal-fired power generation capacity, the top 20 coal mining companies by revenue (for companies with ≥30% revenue from thermal coal), and the top 30 coal processing technology companies by production.

We believe this bottom up analysis is preferable to a top down one and can be replicated in a wide range of other sectors. The extent to which this type of analysis could improve investment decisions and result in better financial performance could be significant, but is unknown and could be a topic of future research.

[5] See Caldecott, B., et al. (2013). Stranded Assets in Agriculture: Protecting Value from Environment-Related Risks.

As part of our research we have undertaken a comprehensive data integration process, bringing together a wide range of different datasets and sources for the first time. This is a work in progress, but our work to date has highlighted some of the challenges associated with turning an understanding of environment-related factors facing particular sectors into analysis that is decision-relevant for financial institutions. These experiences are germane to extant processes on disclosure and corporate reporting, particularly the Task Force on Climate-related Financial Disclosures (TCFD) chaired by Michael Bloomberg, that was launched at COP21 in Paris during December 2015.

It is noteworthy that very little of our analysis has depended on existing corporate reporting or data disclosed through voluntary disclosure frameworks. This is both a cause for hope and concern. It demonstrates that significant strides can be made to understand company exposure to environment-related risks even in the absence of consistent, comprehensive, and timely corporate reporting on these issues. But it also highlights how existing frameworks on environment-related corporate disclosure might be asking the wrong questions – they try to enable top down analysis, but do little to support a bottom up one. Reporting needs to link back to a fundamental understanding of risk and opportunity and to specific assets within company portfolios. In the absence of that, what is reported may not be actionable from an investor perspective.

The report is accompanied by two technology briefings. The first addresses a clear gap in the available literature on existing and emerging coal processing technologies (CPTs). Ambitious deployment of CPTs would impact future coal demand, but the state of these technologies is largely uncertain.

The second briefing emerges out of the necessity to address the role of carbon capture and storage (CCS) in the future of coal. The rapid deployment of cost-efficient CCS could alter possible future coal demand pathways. CCS has particular technical synergies with CPTs and the role that each may play in the future of the other has been scarcely discussed.

Sections 2 and 3 are the briefings of CPTs and the role of CCS respectively. Section 4 presents policy summaries of the selected countries heavily involved in the global coal value chain. Section 5 presents analysis of the top 100 coal-fired utility companies. Section 6 presents analysis of the top 20 thermal coal miners with thermal coal revenue ≥30%. Section 7 presents analysis of identified CPT companies. Section 8 considers potential impact the future of thermal coal will have on other industries and markets. Section 9 concludes and identifies the implications of our research for extant corporate reporting and disclosure processes.

## 1.1 Coal Value Chain

Coal is a combustible sedimentary rock that provides 30% of the world's primary energy supply, fuels 40% of the world's electricity, and is used to produce 70% of the world's steel[6]. The coal value chain is described in Figure 13.

***Figure 13:** Coal value chain*

| Prospecting | Mining | Preparation | Transportation | End Market |
|---|---|---|---|---|
| • Securing mineral rights from government or land owners<br>• Exploration and surveying | • Open Cast' surface mining<br>• Underground 'deep' mining | • Optional step to remove impurities and improve material consistency<br>• Also called 'beneficiation', washing | • By rail<br>• By ship | • See Table 7 |

Table 7 describes coal types and their various end uses. Coal is standardised by ASTM International according to energy, carbon, and volatile compound contents[7].

***Table 7:** Coal types and uses*

| Coal Type | | Primary Use |
|---|---|---|
| Black/Hard Coal | Anthracite | Domestic and industrial uses, especially as a low-smoke fuel |
| | Bituminous | Metallurgical/coking coal for manufacture of iron and steel |
| Brown Coal | Sub-bituminous | Thermal/steam coal for power generation, industrial boilers, and cement production |
| | Lignite | Predominantly power generation in close proximity to the coal mine |

[6] World Coal Institute (2013). The Coal Resource. London, UK.

[7] See ASTM International (2015). ASTM D388-15: Standard Classification of Coals by Rank. West Conshohocken, US.

Major coal exporting countries include Australia, Indonesia, South Africa, and the United States. Coal is traded worldwide in two dominant regional markets – Pacific and Atlantic. Terminals in South Africa act as transfer points between the two markets. Most traded coal is thermal coal, and lignite is seldom transported large distances due to its low energy content. Coal reserves for selected countries are shown in Table 8.

***Table 8:*** *Proven coal reserves for select countries*[8]

| Country | Anthracite and Bituminous [Mt] | Sub-bituminous and Lignite [Mt] | Share of World Total |
|---|---|---|---|
| Australia | 37,100 | 39,300 | 8.6% |
| China | 62,200 | 52,300 | 12.8% |
| Germany | 48 | 40,500 | 4.5% |
| Indonesia | - | 28,017 | 3.1% |
| India | 56,100 | 4,500 | 6.8% |
| Japan | 337 | 10 | 0% |
| Poland | 4,178 | 1,287 | 0.6% |
| South Africa | 30,156 | - | 3.4% |
| United States | 108,501 | 128,794 | 26.6% |
| United Kingdom | 228 | - | 0% |

[8] BP plc (2015). Statistical Review of World Energy 2015. London, UK.

## 1.2 Scenario Development

The International Energy Agency (IEA) was founded by the OECD in response to the first oil shock in the 1970s. The IEA publishes the annual World Energy Outlook (WEO) of energy market projections and analysis. The WEO provides a third-party alternative to corporate and national publications, though it is informed by these studies. The IEA scenarios below are widely used as benchmarks for private and public planning and are used in this study. Table 9 describes the three IEA scenarios from the IEA World Energy Outlook 2015, published in November 2015.

***Table 9:*** *IEA scenarios*

| Scenario | Description |
|---|---|
| Current Policies (CPS) | The conservative scenario of the WEO, the CPS projects energy markets based on existing and implemented policy only. |
| New Policies (NPS) | The central scenario of the WEO, the NPS projects energy markets based on all current existing and committed policy measures. |
| 450S | A scenario used to illustrate the policy necessary to achieve a peak atmospheric concentration of 450ppm $C^{O2}e$, limiting long-term climate change to 2°C of warming with 50% likelihood. |

This study briefly references two other scenario sets in the outlook for CCS: the IEA's Energy Technology Perspective (ETP) scenarios, which include the 2°C Warming Scenario (2DS), 4°C Warming Scenario (4DS), and 6°C Warming Scenario (6DS), and the Intergovernmental Panel on Climate Change's (IPCC) aggregate scenarios for mitigation and technology pathways. The Carbon Tracker Initiative (CTI)[9] has critiqued a number of assumptions which underlie the IEA's and corporate scenarios, including technology penetration rates, world growth rates, and future energy demand. The IEA's WEO scenarios are, however, widely referenced in industry and policymaking and are used as the primary reference scenarios in this study.

[9] The Carbon Tracker Initiative (CTI) (2015). Lost in Transition. London, UK.

***Table 10:** 2020 Coal demand IEA scenarios*[10]

| | | | | | Coal-Fired Electricity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Total Primary Energy Demand – Coal [Mtoe] | | | | Capacity [GW} | | | | Generation [%][iv,v] | | | |
| | 2013 | CPS | NPS | 450S | 2013 | CPS | NPS | 450S | 2013 | CPS | NPS | 450S |
| Australia[i] | 46 | 46 | 45 | 43 | 27 | 33 | 33 | 30 | 75% | | | |
| China | 2,020 | 2,144 | 2,060 | 1,906 | 826 | 1,030 | 979 | 941 | 75% | 65% | 63% | 61% |
| Germany[ii] | 81 | 73 | 69 | 63 | 49 | 44 | 43 | 42 | 44% | | | |
| Indonesia[iii] | 34 | 41 | 40 | 47 | 18 | 32 | 30 | 28 | 50% | | | |
| India | 341 | 499 | 476 | 442 | 154 | 238 | 230 | 223 | 73% | 72% | 69% | 65% |
| Japan | 117 | 114 | 111 | 103 | 50 | 51 | 49 | 49 | 32% | 30% | 29% | 28% |
| Poland[ii] | 53 | 47 | 45 | 41 | 31 | 28 | 27 | 27 | 90% | | | |
| South Africa | 99 | 96 | 94 | 91 | 39 | 46 | 44 | 43 | 94% | 88% | 87% | 86% |
| United States | 430 | 421 | 368 | 303 | 322 | 281 | 252 | 259 | 40% | 36% | 33% | 28% |
| United Kingdom[ii] | 36 | 32 | 31 | 28 | 22 | 20 | 20 | 19 | 30% | | | |
| IEA World | 3,929 | 4,228 | 4,033 | 3,752 | 1,851 | 2,168 | 2,064 | 1,997 | 41% | 39% | 37% | 35% |

i: Imputed from IEA OECD Asia Pacific; ii: Imputed from IEA European Union; iii: Imputed from IEA Non-OECD Asia; iv: See Table 11 for references; v: due to imputation from IEA regions, no 2020 generation % is available for Australia, Germany, Indonesia, Poland, or the United Kingdom.

# 1.3 Scenario Outlook

This report examines environment-related risks to thermal coal utility, mining, and coal-processing technology assets. Where possible these environment-related risks are presented in the context of the IEA WEO scenarios for consistency with analysis in the broader literature. An opinion is developed in this section regarding the most probable IEA scenario and the general 'direction of travel' of policy development.

## *1.3.1 Coal in 2015*

According to the IEA's Coal Medium-Term Market Report (MTMR)[11], world thermal coal consumption peaked in 2013. China, the consumer of over half the world's coal, has experienced slowing growth and decoupling of energy consumption from GDP. The only regions where coal use grew was in India and the Association of South East Asian Nations (ASEAN) countries including Indonesia. Coal use in Europe and the US continued structural decline.

[10] International Energy Agency (IEA) (2015). World Energy Outlook (WEO) 2015. Paris, France.

[11] IEA (2015). Coal Medium-Term Market Report (MTMR). Paris, France.

The global coal market has been substantially affected by falling demand and over-supply. Since 2011, coal prices have fallen from over US$120/t to less than US$60/t[12]. Despite low commodity prices, coal power generation has faced difficulty expanding. Direct climate change policies like carbon pricing or emissions trading have negatively impacted plant profitability. Competition from gas and renewables has led both to decreasing utilisation rates and lower wholesale electricity prices. In some countries distributed energy resources have combined with efficiency improvements leading to lower overall power demand.

The IEA's MTMR estimates that OECD coal demand will continue to fall by 1.5% per year through 2020. Coal demand will increase in China by 0.9%, India by 3.7%, ASEAN by 7.7%, and other non-OECD 1.9% per year. World coal demand will increase by 0.8%, which is slightly more than the IEA's WEO 2015 NPS outlook of 0.4% annual growth through 2020.

***Table 11:*** *2014 Coal production, trade, consumption, and power generation for selected countries*[13]

| Country | Production | | Trade | Consumption | | | Coal-fired Electricity | |
|---|---|---|---|---|---|---|---|---|
| | Hard [Mt] | Brown [Mt] | (Exports) [Mt] | Hard [Mt] | Brown [Mt] | Change in 2015 [%][i] | Capacity [GW][ii] | Generation [%] |
| Australia | 431 | 61 | (376) | 55 | 61 | +0.3% | 27 | 75% |
| China | 3650 | - | 271 | 3921 | - | -6% | 826 | 75% |
| Germany | 8 | 178 | 51 | 59 | 177 | -3% | 49 | 44% |
| Indonesia | 471 | - | (409) | 62 | - | -2% | 18 | 50% |
| India | 621 | 47 | 238 | 859 | 47 | +3 to 6% | 154 | 73% |
| Japan | 0 | - | 187 | 187 | - | -5% | 50 | 32% |
| Poland | 73 | 64 | 0 | 73 | 64 | ND* | 31 | 90% |
| South Africa | 253 | - | (75) | 178 | - | -2.1% | 39 | 94% |
| United States | 844 | 72 | (79) | 765 | 70 | -11% | 322 | 40% |
| United Kingdom | 12 | - | 36 | 48 | - | -16% | 22 | 30% |

* No Data
i) Data from Institute for Energy Economics and Financial Analysis (IEEFA) (2015) *Past Peak Coal in China*.
ii) Data from IEA (2013) *World Energy Atlas; Australian Electricity Regulator* (AER) (2014) *State of the Electricity Market 2014;* Sakya, I. (2012) *Electricity Power Developments in Indonesia*, PT PLN; EMIS (2014) *Electricity Sector Poland;* Federal Ministry for Economic Affairs and Energy (BMWi) (2015) *An electricity market for Germany's energy transition;* Department of Energy & Climate Change (DECC) (2015) *Digest of UK Energy Statistics (DUKES)* 2015.

[12] IEA (2015). MTMR.
[13] Data from IEA (2015). MTMR unless otherwise noted.

### 1.3.2 COP21 and the Paris Agreement

The validity and relevance of these scenarios is increased by the Paris Agreement, which was adopted on 12th December 2015. The agreement calls on parties to the UNFCCC to hold warming levels substantially below 2°C, while aligning finance flows with sustainable and climate-resilient development. To meet the 2°C commitment, the agreement calls on countries to achieve net-zero global greenhouse gas emissions by the second half of the 21st century. The Paris Agreement also calls on nations to 'pursue efforts' to limit warming to 1.5°C and a coalition of higher-ambition countries, both developed and developing, emerged during the conference in support of the more stringent target. For a 50% chance of meeting this more ambitious target, countries would need to limit cumulative emissions from 2011 to 550 $GtC^{O2}eq$[15], less than half the emissions budget for 2°C of warming. The concentration of greenhouse gases would need to be limited to <430ppm by 2100, with emissions reductions of 70% to 95% below 2010 levels by 2050[16].

A departure from previous top-down 'grand coalitions' to limit climate change, the agreement takes a 'bottom up' approach. Countries remain responsible for setting their own greenhouse gas mitigation targets, called Intended Nationally Determined Contributions (INDCs). By the end of COP21, 185 countries representing 97% of global population and 94% of global emissions had submitted INDCs. Climate Action Tracker estimates that the current INDCs collectively limit warming to 2.7°C, with upper and lower bounds of 3.4°C and 2.2°C respectively[17]. To meet warming limit targets, the agreement establishes an 'ambition mechanism' for countries to increase their INDC commitments every five years beginning in 2020. A 'global stocktake' of emissions reduction progress will occur two years preceding each recommitment, providing a recurring time period for countries to negotiate their new INDCs. A transparency framework was agreed to in principle which will allow countries to observe their mutual mitigation efforts, discouraging hollow commitments and free-riding. The negotiation of this framework will be one of the key tasks of the UNFCCC.

### 1.3.3 WEO Scenario Alignment

The WEO scenarios provide a static snapshot of energy demand, technology development, and relevant policy. The CPS and NPS are benchmarked to implemented and emerging policies, and are thus only descriptive of existing policies. The 450S prescribes a policy pathway that limits end-of-century warming to 2°C. The IEA currently has no scenario which describes alignment with the higher-ambition 1.5°C warming limit.

Figure 14 shows the change of the IEA World Energy Outlook scenarios over time. Actual coal demand exceeded projections in 2010 to 2013, however, taken over time, the IEA scenarios indicate a tightening policy environment for coal as a primary energy source. Since WEO 2011, the NPS compound annual growth rate (CAGR) for coal total primary energy demand (TPED) through 2020 has fallen every year from 2.0% in 2011 to 0.3% in 2015. Significant policy developments took place between WEO 2014 and WEO 2015 and the 2014 NPS 2020 projection is now the 2015 CPS 2020 projection, showing how new policy can create a year-on-year change in scenario projections.

[15] Intergovernmental Panel on Climate Change (IPCC) (2014). Climate Change 2014 Synthesis Report. Geneva, Switzerland.
[16] Ibid.
[17] Climate Action Tracker (2015). Tracking INDCs. http://climateactiontracker.org/indcs.html.

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*Figure 14: IEA world energy outlook historic scenarios*[18]

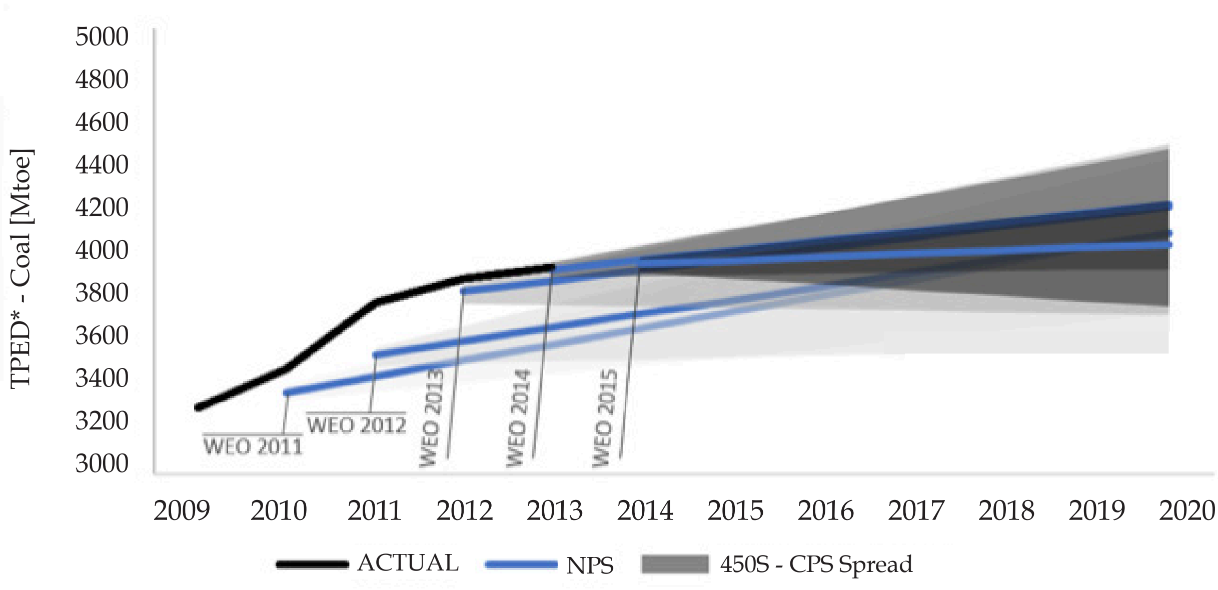


Table 12 benchmarks recent policy developments against selected policy measures from the IEA's WEO 2015. More details regarding policy developments in scope countries is available in Section 4. An opinion is provided on which scenario best describes the direction of policy development for each jurisdiction. Taken in aggregate, it is clear that the ambitions of policymakers now likely exceed the WEO NPS and are approaching the 450S. Several critical uncertainties remain, which are discussed in Box 1.

In the remainder of this report, IEA scenario projections are used to inform the development of hypotheses of environment-related risks. Based on the evidence in the preceding sections, the IEA 2015 NPS is referred to as the lower bound of policy action on climate change. The hypotheses developed in this report using the 2015 NPS thus underestimate the materiality of environment-related risks on the thermal coal value chain. This has been done to provide a conservative outlook and to reflect the IEA's consideration of the NPS as their central scenario.

[18] Data from IEA (2011). WEO 2011; IEA (2012). WEO 2012; IEA (2013). WEO 2013; IEA (2014). WEO 2014; IEA (2015). WEO 2015.

## *Table 12: Selected policy measures cross-referenced with IEA scenario assumptions*[19]

| Region | Scenario | Assumptions | Evaluation | Outlook Opinion |
|---|---|---|---|---|
| All OECD | 450S | Staggered introduction of CO2 prices in all countries<br>US$100bn in annual financing provided to non-OECD countries by 2020 | CO2 pricing growing, see below<br>US$100bn included in Paris Agreement | 450S |
| All Non-OECD | NPS | Fossil-fuel subsidies are phased out within the next ten years in net-importing countries | G20 commitment to phase out fossil fuel subsidies, see below | NPS |
| | 450S | Fossil-fuel subsidies are phased out within the next twenty years for net-exporting countries | | |
| United States | NPS | Clean Power Plan<br>Carbon Pollution Standards | Carbon Pollution Standards Rule and Clean Power Plan launched August 2015[20][21]<br>US wind production tax credit and solar investment credit extended through to 2019 and 2021 respectively[22] | 450S |
| | 450S | Extended support for renewables, nuclear, and CCS<br>Efficiency and emissions standards close plants<br>CO2 pricing implemented from 2020 | | |
| Japan | NPS | Achieve 2030 renewables power generation target of 22-24%, with nuclear generating 20-22%.<br>Harmonised support for renewables generation | Government targets on track for 23% renewables, 21% nuclear generation by 2030[23]<br>CO2 pricing pilot programmes established[24] | NPS |
| | 450S | CO2 pricing implemented from 2020<br>Share of low-carbon electricity generation to increase by 2020 and expand by 2030<br>Introduction of CCS | | |
| EU | NPS | Removal of barriers to CHP<br>2030 Climate and Energy framework<br>Partial implementation of the Energy Efficiency Directive reducing primary energy consumption by 20% by 2020<br>EU ETS reducing GHG emissions by 43% below 2005 level | Member states mostly on track with renewable energy deployment, energy efficiency improvement, and greenhouse gas reductions[25]<br>ETS revisions issued July 2015 in line with 2030 framework and 2050 roadmap[26] | 450S |
| | 450S | EU ETS strengthened in line with 2050 roadmap<br>Reinforcement of government support for renewables<br>Expanded support for CCS | | |

[19] IEA (2015). WEO 2015.
[20] US Environmental Protection Agency (EPA) (2015). Clean Power Plan for Existing Power Plants. Washington, US.
[21] US EPA (2015). Carbon Pollution Standards for New, Modified and Reconstructed Power Plants. Washington, US.
[22] Crooks, E. (2015). 'Wind and solar groups cheer US budget tax breaks', Financial Times. New York, US.
[23] Iwata, M., & Hoenig, H. (2015). 'Japan struggles to find balanced energy strategy', Wall Street Journal. Tokyo, Japan.
[24] Tokyo Metropolitan Government (2015). Tokyo Cap and Trade, https://www.kankyo.metro.tokyo.jp/en/climate/cap_and_trade.html
[25] European Environment Agency (2015). Trends and projections in Europe 2015. Copenhagen, Denmark.
[26] European Commission (2015). Questions and answers on the proposal to revise the EU ETS. Brussels, Belgium.

| Region | Scenario | Assumptions | Evaluation | Outlook Opinion |
|---|---|---|---|---|
| China | NPS | Restructuring of the economy away from investment and export growth towards services and domestic consumption<br>ETS covering power and industry from 2017<br>Expended use of natural gas<br>Energy price reform – increase in natural<br>gas prices and oil product price adjustments<br>Exceed 12th FYP renewables targets<br>Establishment of ETS<br>Emissions from coal new-builds of 300 g/kWh<br>By 2020: 58GW nuclear, 420GW hydro, 200GW wind, 100GW solar, and 30GW bioenergy | $C^{O2}$ pricing pilot programmes established<br>12th FYP 2015 targets (260GW hydro, 100GW wind, 10GW solar) exceeded by 2014 (280GW hydro, 114GW wind, 28GW solar)<br>Natural gas pricing reform was introduced in 2013, energy pricing reform will continue as part of nation-wide changes to market economy[27]<br>Nationwide ETS expected 2017-2020[28] | 450S |
| | 450S | Strengthen power and industry ETS<br>Reduce local air pollution by 2015 (8% $SO_2$, 10% $NO_x$)<br>ETS in accordance with overall targets<br>Enhanced support for renewables and nuclear<br>Deployment of CCS from 2020 | | |
| India | CPS | National Solar Mission, aiming to deploy 20GW by 2022<br>National Clean Energy Fund based on coal levy of INR 100/tonne of coal | 20.2GW PV expected by the end of 2017[29]<br>February 2015 Minister of Finance proposed to double the coal levy to 200 INR/tonne to increase National Clean Energy Fund[30]<br>Privatisation of coal mining met with labour resistance in 2015[31]<br>Planned and in-construction coal power stations have lower emissions intensity (902 kg/MWh) relative to existing fleet (1100 kg/MWh)[32] | NPS |
| | NPS | Increase in the National Clean Energy Fund<br>Open the coal sector to private and foreign investors<br>By 2022: competitive bidding for 100GW solar, 75GW non-solar<br>Increased uptake of supercritical coal-fired power plants<br>Strengthen grid and electricity markets; reduce losses | | |
| | 450S | Renewables reach 15% of installed capacity by 2020<br>Extended support for renewables, nuclear, efficient coal<br>Deployment of CCS from 2025 | | |

[27] Paltsev, S., & Zhang, D. (2015). 'Natural Gas Pricing Reform in China', Energy Policy, 86:43-56.
[28] Shu, W. (2015). Update on Chinese National-Wide ETS Development, National Development and Reform Commission. Beijing, China.
[29] Ministry of New and Renewable Energy (2015). Status of implementation of various schemes to achieve 1,00,000 MW Solar Plan. New Delhi, India.
[30] Jaitley, A. (2015). Minister of Finance Speech: Budget of 2015-16. New Delhi, India.
[31] Australian Government (2015). Coal in India, Department of Industry and Science. Canberra, Australia.
[32] Smith School Analysis, see Section 5.

## **Box 1:** *Critical uncertainties from WEO policy tables*

- *US$100bn in financing* – Continuing from the Copenhagen Accord, the provision of US$100bn per year for climate change mitigation and adaptation is referred to in the text of the Paris Agreement, but uncertainty remains regarding the source and additionality of the funding. A report by the OECD in advance of COP21 estimated that US$62bn per year in climate finance was already being provided by developed countries[33]. This caused controversy as developing countries, India in particular, critiqued the estimation methodology. The provision of this financing is not directly material to all aspects of the energy transition, just to developments in international climate policy.

- *Fossil-fuel subsidy phase-out* – The IMF estimates that, excluding externalities, over US$480bn is spent by governments each year on oil, gas, coal, and electricity subsidies, 40% in developed countries and 33% in oil exporting countries[34]. In 2009, G20 members agreed to phase out all fossil-fuel subsidies, which includes all the scope countries of this study. India and Indonesia have the largest fossil fuel subsidies of the scope countries, and Indonesia made substantial progress in 2014 reducing fuel and electricity subsidies. With continuing low oil prices, an opportunity exists for countries to accelerate their subsidy reductions without damaging social interests[35].

- *Carbon pricing* – Carbon pricing, from either a tax or quota, now covers approximately 12% of the world's emissions[36] and is present in 30% of the world's jurisdictions, weighted by emissions[37]. Total and jurisdictional emissions coverage is set to double with the inclusion of the Chinese ETS and the US Clean Power Plan. The Chinese ETS is expected to be designed for potentialfuture linkage with the EU ETS, establishing the beginnings of a global carbon price and beginning to capture emissions leakage from international trade[38]. What remains uncertain is the speed at which carbon pricing coverage will be able to extend to sectors beyond power generation and heavy industry.

- *CCS deployment* – CCS deployment to date has not been consistent with the low-warming scenarios of the IEA or the IPCC. Because CCS has implications for negative emissions technology and industrial process mitigation, the deployment of CCS can be a critical parameter in outlook scenarios. Mixed perspectives on the significance of CCS as a technology for power sector mitigation warranted the inclusion of a separate briefing on the subject, see Section 3.

- *Coal-processing technology deployment* – Coal-processing technologies (CPTs) have yet to be accommodated into energy, technology, and climate scenarios. CPTs offer an arbitrage opportunity between coal and gas or liquid fuels, or can be used for power generation without certain conventional air pollution drawbacks. There is little literature available on CPTs and their role in scenario projections, a briefing is included in this report in Section 2.

[33] OECD, Climate Policy Initiative (CPI) (2015). Climate finance in 2013-14 and the USD 100 billion goal. London, UK.
[34] International Monetary Fund (IMF) (2013). Energy Subsidy Reform: Lessons and Implications. Washington, US.
[35] Van der Hoeven, M. (2015). Fossil Fuel Subsidy Reform: Recent Trends, IEA. Paris, France.
[36] World Bank Group (2015). State and Trends of Carbon Pricing. Washington, US.
[37] Whitmore, A. (2015). 'The spread of carbon pricing and other climate legislation', On Climate Change Policy. https://onclimatechangepolicydotorg.wordpress.com/carbon-pricing/the-spread-of-carbon-pricing/
[38] Carbon Market Watch (2015). Towards a global carbon market. Brussels, Belgium.

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## 1.4 Data Availability

This report uses a number of data sources to provide analysis of coal-fired power utilities, thermal coal mining companies, and coal processing technologies. Table 13 summarises the main sources of data. Where the data was not available for all plants and mines, the remainder was either estimated from available data or completed by the Oxford Smith School as noted. For example, 74% of all coal-fired generating assets had generation data (in MWh) from CARMA, and the remaining 26% was estimated by the Oxford Smith School.

***Table 13:** Data sources and completeness*

| Data | Data Source (in order of seniority) | Completion % | Notes |
|---|---|---|---|
| Number of Coal-Fired Generating Assets (N = 1,445 coal-fired power stations) | | | |
| Location | CoalSwarm's Global Coal Plant Tracker (CoalSwarm, Q4 2015), Enipedia, Carbon Monitoring for Action Database (CARMA, v3.0 released Jul 2012), Platts' World Electric Power Plant Database (WEPP, Q4 2015) | 100% | |
| Capacity [MW] | CoalSwarm, WEPP, Enipedia, CARMA | 100% | |
| Generation [MWh] | Enipedia, CARMA, Oxford Smith School | 100% | 26% estimated by regression |
| Plant Age | CoalSwarm, WEPP, Enipedia, CARMA, Oxford Smith School | 100% | 31% estimated by regression |
| CO2 Intensity | CoalSwarm, WEPP, CARMA, Oxford Smith School | 100% | 22% estimated by regression |
| Cooling Technologies | WEPP, Oxford Smith School | 71% | 12 percentage points added from GoogleEarth searching |
| Pollution Abatement Technologies | WEPP | 73% | |
| Coal Type | CoalSwarm, WEPP, Oxford Smith School | 71% | 29 percentage points estimated based on proximity to reserves |
| Number of Thermal Coal Mining Assets (N = 274 thermal coal mines) | | | |
| 'Top 20' coal mining companies | MSCI | - | |
| % Rev by Activity | MSCI, Trucost | 97% | Data unavailable |
| Mine Production | Oxford Smith School | 69% | Data unavailable |
| Location | Oxford Smith School | 100% | |
| Number of Coal Processing Technology Assets (N = 63 coal processing technology plants) | | | |
| Location | World Gasification Database (Nov 2015) | 100% | |
| Capacity [$Nm^3$/day] | World Gasification Database, Oxford Smith School | 100% | 14% estimated from product energy content |
| Plant Age | World Gasification Database | 100% | |
| Market Analysis | | | |
| General Information | S&P CapitalIQ, Trucost | - | |
| Capital Spending Trends | S&P CapitalIQ | - | |
| Bond Issuances | S&P CapitalIQ | - | |
| Ownership Trends | S&P CapitalIQ | - | |

| Data | Data Source (in order of seniority) | Completion % | Notes |
|---|---|---|---|
| Local Risk Hypotheses | | | |
| $PM_{2.5}$ Emissions 2012-2014 Average | Atmospheric Composition Analysis Group, Dalhousie University | Global | |
| $NO_2$ Emissions 2015 | NASA GES DISC OMNO2 | Global | |
| Mercury Emissions 2010 | AMAP, UNEP 2010 | Global | |
| Water Stress 2015 | WRI Aqueduct | Global | |
| Water Stress Change 2016-2030 | WRI Aqueduct | Global | |
| Heat Stress Change 2016-2035 | IPCC AR5 WGII | Global | |
| CCS Geologic Suitability | Geogreen | Global | |
| Population Density 2015 | NASA SEDAC GPWv3 2015 | Global | |
| Protected Areas 2015 | UNEP-WCMC | Global | |
| National Risk Hypotheses | | | |
| Water Regulatory Risk 2015 | WRI Aqueduct | 10/10 Scope Countries | |
| CCS Legal Environment | Global CCS Institute Legal and Regulatory Indicator | 10/10 Scope Countries | |
| Energy Scenario Projections | International Energy Agency World Energy Outlook | Note | |
| Renewables Outlook | EY Renewable Energy Country Attractiveness Index | 10/10 Scope Countries | |
| Renewables Policy | REN21 Global Status Report | See NRHs for details | |

Note: Germany, Poland, UK comingled among EU; Indonesia comingled among Non-OECD Asia; Australia comingled among South Korea and New Zealand.

## 1.5 Dataset Preparation

Individual power station information is taken from the most recent version (v3) of the Carbon Monitoring for Action (CARMA) database, Enipedia, and CoalSwarm's Global Coal Plant Tracker (CPT). These databases are merged, and when power station matches occur, we preferentially use fields from CoalSwarm, then Enipedia, and finally CARMA. The Platts World Electric Power Plants Database (WEPP) is used to exclude power stations that have been closed, but not reported as such in CARMA, Enipedia, or CPT. We also use WEPP to identify non-coal-fired power stations that are operational, but not included in CARMA.

CARMA contains data on existing and planned plants and was last systematically updated to the end of 2009, CPT has data on coal-fired power plants planned and added to the global stock since the start of 2010 onwards (we currently used the most recent December 2015 update), and Enipedia is continuously updated on an individual power plant basis. WEPP is updated quarterly (we currently use data from the Q4 2015 release). The merger between these datasets has produced a database that effectively defines the locations of all the world's power plants, their ownership, the annual megawatt hours of electricity produced, plant age, fuel type, capacity, and carbon intensity. It is particularly current and comprehensive for coal-fired power stations.

Information on the accuracy of the CoalSwarm, Enipedia, and WEPP databases are not available, but the CARMA data has a number of caveats that are thoroughly enumerated on its website (carma.org), two of which are particularly relevant to this database. The first is that CARMA estimates electricity generation and CO2 emissions using statistical models that have been fitted from detailed US plant data. CARMA reports that fitted CO2 emissions values are within 20% of the true value 60% of the time, and that electricity generation is within 20% of the true value 40% of the time. Second, CARMA geographical location data varies in its degree of precision. For almost all power plants the state/province location is known, for 80% of power plants at least the city location is known, for 40% county/district data is known, and for 16% of power stations a unique postal code is assigned. Comparisons of approximate and precise coordinates suggest that the average spatial error is about 7 km, which is well within the bounds of all our geographical analyses (scales of 40km and 100km used).

International Securities Identification Numbers (ISINs) which uniquely identify securities have been matched to the equities of top coal-fired utilities, thermal coal miners, and coal processing technology companies where possible. Equity ISINs are not available for private companies. Multiple bond ISINs could be matched to each company, however that has not been completed at this time. ISINs were acquired directly from the public database[39] and through internet research.

[39] Accessible at http://www.isin.org

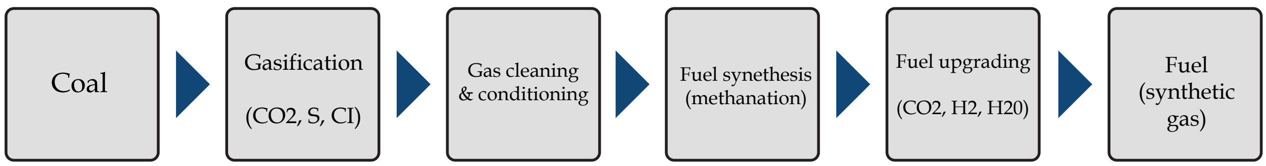
# 2 Briefing: Coal Processing Technologies

Coal processing technologies (CPTs) are a suite of technologies used to convert coal into a wide range of useful fuels. These technologies have had a nascent presence for decades, but interest has recently grown, based on policy objectives for energy security and reducing conventional air pollutants, and economic opportunities for arbitrage with gas or liquid fuels. Common CPTs include coal to gas technology (CTG), coal to liquids (CTL) including Fisher-Tropsch synthesis, and underground coal gasification (UCG), also called coal seam methanation. Some authors refer to CTG, CTL, and UCG collectively as 'CTX'. We use CPT in this report.

## 2.1 Technology Summary

Coal to gas (CTG) produces synthetic/substitute natural gas through a four-step process, see Figure 15[40]. First, coal is gasified with the addition of steam and/or oxygen, producing what is known as producer gas. Second, this gas is cleaned and conditioned, removing impurities such as sulphur and chlorine. Methanation[41] follows, at low temperature, high pressure, and with the addition of a catalyst. The final step is fuel upgrading, which removes water and carbon dioxide to fulfil required quality specifications. A major advantage of CTG is the generation of a concentrated stream of carbon dioxide as a by-product from the fuel-upgrading step. This can be utilised in other processes without the additional costs that are associated with carbon dioxide separation in coal-fired power stations[42].

***Figure 15:*** *CTG four-step process chain from coal to synthetic gas*[43]




Coal to liquids (CTL) are produced through two major methods – direct and indirect coal liquefaction[44]. Direct liquefaction (DCL) converts (see Figure 16) coal to liquid fuels, requiring high heat, high pressure, and a catalyst to initiate hydro-cracking[45]. This takes place in two stages, and has a liquid yield of up to 70% of the dry weight of the coal. These liquids can be directly utilised in power generation or petrochemical processes, but require further refining before use as transport fuel. Indirect liquefaction (ICL) converts coal to a mixture of carbon monoxide, and hydrogen, known as syngas, and from this intermediate step, to liquid hydrocarbons. Fuels produced through this process, a.k.a. Fischer-Tropsch synthesis (see Figure 17), do not require further refining for use.

[40] Kopyscinski, J., Schildhauer, T., & Biollaz, S. (2010). 'Production of Synthetic Natural Gas (SNG) from Coal and Dry Biomass', Fuel 89:1763-1783.

[41] Methanation process converts carbon oxides and hydrogen from syngas to methane and water through chemical catalysts in fixed-bed reactors. See US Department of Energy (DOE) (2010). Hydrogen and synthetic natural gas from coal. Washington, US.

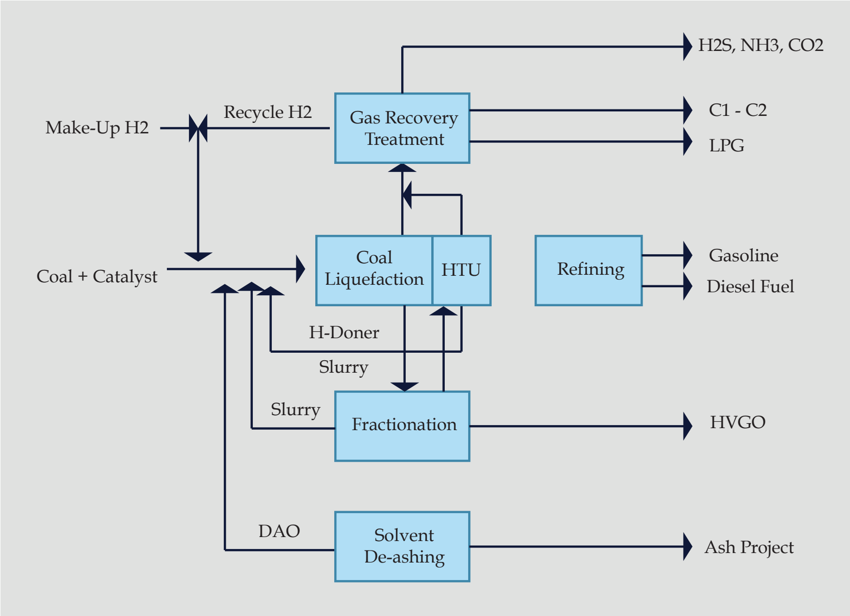
[42] Kopyscinski et al. (2010). Op. Cit.

[43] Adapted from Kopyscinski et al. (2010). Op. Cit.

[44] Höök, M., Fantazzini, D., Angelantoni, A., et al. (2014). 'Hydrocarbon Liquefaction: Viability as a Peak Oil Mitigation Strategy', Philosophical Transactions. Series A: Mathematical, Physical, and Engineering Science 372:1–36.

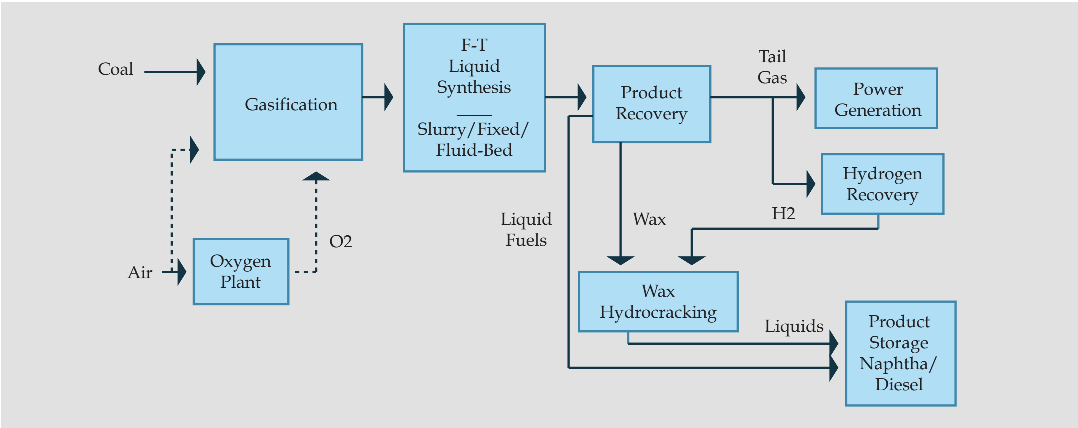
[45] Hydro-cracking refers to a catalytic chemical process, during which H2 is reacted with heavy petroleum products to produce lighter and commercially usable hydrocarbons. See US DOE (2009). Gasification. Washington, US.

***Figure 16:** Simplified direct coal liquefaction (DCL) Process*[46]




DCL is commonly regarded as more efficient for production of liquid fuels, as it requires only partial breakdown of the coal. However, ICL fuels are cleaner, as they are essentially free from nitrogen, sulphur and aromatics, and thus emit fewer contaminants when combusted[47]. As well as a reduced environmental impact, ICL has greater variability and flexibility in outcome products, and stronger supporting infrastructure and past knowledge – and has been put forward as the more likely option for CTL development[48]. Moreover, if hydrogen fuel cells gain importance and utilisation in the future, ICL processes can produce hydrogen, rather than hydrocarbons, creating another potential future application[49].

***Figure 17:** Simplified fischer-tropsch synthesis scheme for indirect coal liquefaction (ICL)*[50]

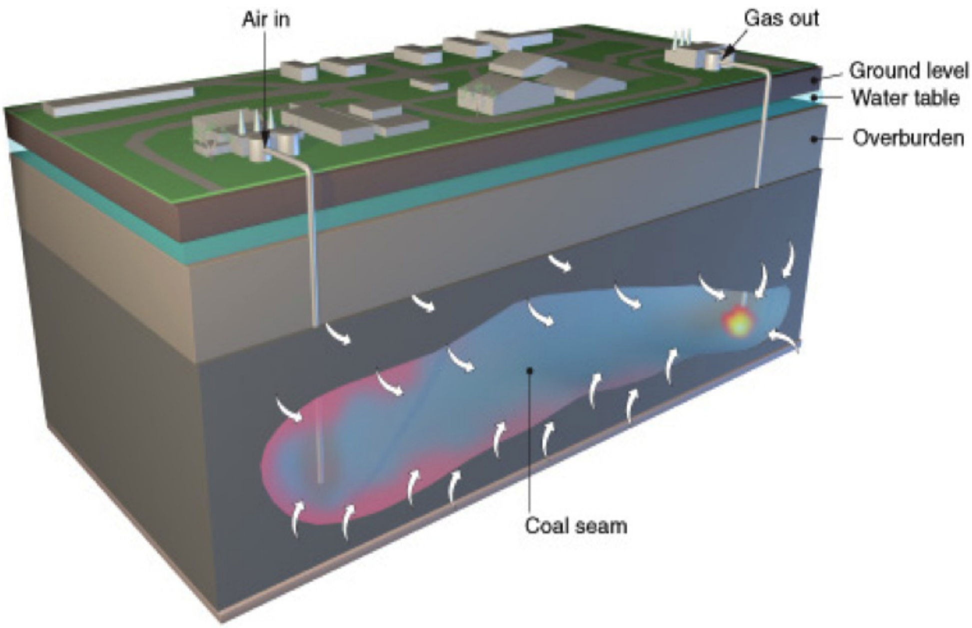



*Underground Coal Gasification (UCG)* is a process of converting coal that is unworked, and still in the ground, into a gas that can be utilised in power generation, industrial heating, or manufacture of synthetic fuels, see Figure 18.

[46] Taken from DoE (2011). Direct Liquefaction. Washington, US.
[47] Höök, M., & Aleklett, K. (2010). 'A Review on Coal-to-liquid Fuels and its Coal Consumption', International Journal of Energy Research 34:848–864.
[48] Höök et al. (2014). Op. Cit.
[49] Höök, M., & Aleklett, K. (2010). Op. Cit
[50] Taken from DoE (2011). Op. Cit.

The UCG process requires drilling two wells into the coal seam, which are then heated to a high temperature with oxidants injected through one well[51]. Water is also needed and may be pumped from the surface or may come from the surrounding rock. The coal face is ignited and, at high temperatures (1,500 kelvin) and high pressures, this combustion generates carbon monoxide, carbon dioxide, and hydrogen. Oxidants react with the coal to create syngas, which is then drawn out through the second well.

***Figure 18:** Simplified version of general UCG process*[52]




CTL/CTG are more technically advanced than UCG, and compete directly with each other. However, there are several problems associated with these technologies. First, very low thermal efficiencies are associated with hydrocarbon liquefaction – in the range of 45-55%. Given that substantial volumes of coal are required to generate fuels in any useful amount, these technologies are only viable in areas with abundant coal reserves, limiting large-scale production to six nations globally (Australia, China, India, South Korea, South Africa, United States) and creating infrastructure issues. Second, coal must be carefully quality controlled for low sulphur to prevent denaturing of expensive catalysts[53]. Third, CTL/CTG plant is very costly to build, and construction takes four to five years[54]. Moreover, since a long plant life is crucial to guaranteeing a return for investors, local coal reserves must be sufficient to ensure this is possible[55].

Although UCG has certain advantages over CTL/CTG in terms of lower plant costs, less surface emission of sulphur and nitrous oxides, and potential synergies with CCS post-extraction period, this technology also has several disadvantages. One key concern is associated with utilising new low-quality coal reserves that yield low quality gas with too much hydrogen.

[51] Anderson, R. (2014). 'Coal gasification: The clean energy of the future?' BBC News. London, UK.
[52] Taken from DoE (2014). Op. Cit.
[53] Xu, J., Yang, Y., & Li, Y. (2015). 'Recent Development in Converting Coal to Clean Fuels in China', Fuel 152: 122-130.
[54] Höök, M. et al. (2014). Op. Cit.
[55] Ibid.

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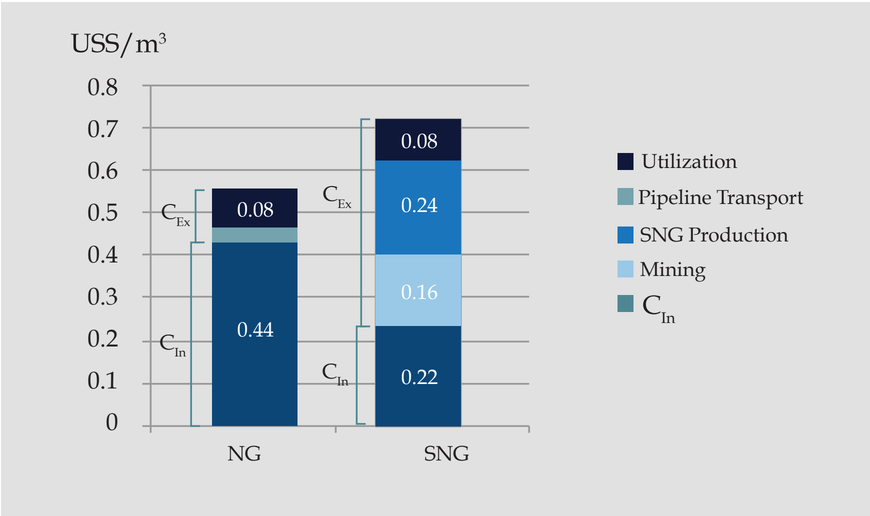
***Figure 19:** Life cycle cost comparison*




A comparative life cycle cost analysis[56] of conventional natural gas and synthetic gas shows that the environmental and societal costs of SNG production are much higher than that of natural gas. The majority of these costs derive from the SNG production stage and coal mining. Although natural gas costs (0.44 USD/m³) are twice as high as those of synthetic gas (0.22 USD/m³), analysis suggests that the life cycle cost of synthetic gas and conventional natural gas is 0.71 USD/m³ and 0.55 USD/m³, respectively (see Figure 19).

# 2.2 Development

During the Second World War, the German military produced 90% of their jet fuel, and 50% of their diesel, through CTL[57]. After the war, the technological lead enjoyed by Germany was assumed by South Africa, which decided to rely on coal conversion projects in response to its fuel shortage as a result of apartheid-era isolation[58]. Development has predominantly been by the oil and gas company Sasol, and the country has a daily capacity of 160,000 bbl[59] and meets 30% of South Africa's fuel demand using CTL[60].

In the United States, investments in CTG were made during the 1970s and 1980s, as a result of the global oil shocks. The 'normalisation' of oil prices in the 1990s reduced interest in CTG and decreased investment. Only one US-based company, Dakota Gas, had significant experience with CTG processes during this period[61]. At the time, natural gas prices were volatile and on the rise. The recent large-scale commercialisation of shale gas resources has pushed down the natural gas prices in the US. As a result, producing synthetic natural gas (SNG)[62] from CTG has become economically less attractive due to competition from shale gas[63].

[56] Li, S. Ji, X., Zhang, X., et al. (2014). 'Coal to SNG: Technical Progress, Modelling and System Optimization through Exergy Analysis', Applied Energy 136: 98–109.

[57] Höök, M. et al. (2014). Op. Cit.

[58] Becker, P. (1981). 'The Role of Synthetic Fuel In World War II Germany - Implications for Today?' Air University Review, 32:45-53.

[59] Perineau, S. (2013). 'Coal Conversion to Higher Value Hydrocarbons: A Tangible Acceleration' Cornerstone Magazine. World Coal Association. Hoboken, US.

[60] Höök, M., & Aleklett, K. (2010). Op. Cit.

[61] Perineau, S. (2013). Op. Cit.

[62] Synthetic natural gas (SNG) is a syngas derived from coal conversion based on the methanation process. See DoE (2011). Op. Cit.

[63] Institute for Energy Research (IER) (2014). China to Build 50 Coal Gasification Facilities. Washington, US.

In China, increasing demand for cleaner energy products like natural gas is the chief driving force behind development of coal conversion processes[64]. According to Chinese state-owned power companies, these plants are considered 'new energy' that would satisfy China's natural gas shortage problem[65]. Apart from energy security concerns, the Chinese government has 'declared war'[66] on air pollution in major city centres. Part of the response is to reduce coal use in cities and instead transport gas from coal conversion projects planned to be built in sparsely populated regions of north-western China, where there are large coal deposits[67]. However, building new coal-processing plants will generate additional water stress for already arid regions in north-western China and contribute to China's net carbon emissions[68].

Section 7 will discuss commercial uses of CTG/CTL/UCG technologies, capital expenditures and ownership trends globally, as well as other technical, economic and environmental factors that impact the value of coal-based energy processing companies.

[64] Xu, J. et al. (2015). Op. Cit.

[65] Wong, E. (2014). 'China's Energy Plans Will Worsen Climate Change, Greenpeace Says', New York Times. Beijing, China.

[66] Blanchard, B., & Stanway, D. (2014). 'China to declare war on pollution, premier says' Reuters. Beijing, China.

[67] IER (2014). Op. Cit.

[68] Ibid.

# 3 Briefing: Role of CCS

## 3.1 Feasibility Update

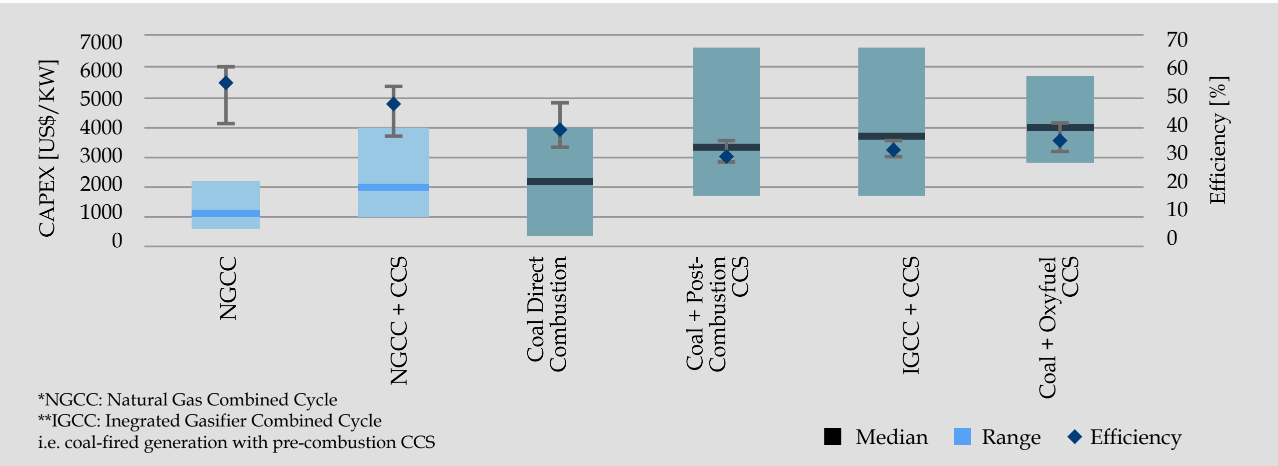
Carbon capture and storage (CCS) is a combination of three separate processes: carbon capture, transport, and storage. Carbon capture technologies are described in Table 14. Of the 15 power generation CCS projects proposed to 2025, seven use post-combustion capture, six use pre-combustion capture, and two use oxy-fuel capture[69].

***Table 14:*** *Carbon capture technologies*

| Technology | Description |
|---|---|
| Post-combustion | Post-combustion carbon capture involves the separation of low-concentration $CO_2$ from other combustion gases, predominantly $N_2$. Chemical or physical solvents are used to absorb $CO_2$. |
| Pre-combustion | Fuels are gasified and steam shifted to create medium concentration $CO_2$ and $H_2$. Physical solvents are used to absorb $CO_2$ prior to combustion. |
| Oxy-fuel | Cryogenic distillation is used to separate $O_2$ from $N_2$ in combustion air prior to combustion. Combustion with oxygen only gives high-concentration $CO_2$ combustion gases. |
| Other Industrial | Certain industrial processes (e.g. ammonia production, natural gas processing) release $CO_2$ as a by-product at various levels of concentration. |

Figure 20 shows the incremental capital expenditure and efficiency penalty for $CO_2$ capture and compressing equipment in typical coal- and gas-fired power stations, excluding other transport and storage equipment. The addition of CCS reduces the efficiency of an average coal-fired power station by 4 to 9%, oxy-fuel capture having the least efficiency losses[70]. For post-combustion capture, compressor power comprises 25% to 40% of overall plant efficiency losses, with the remainder of the losses attributable to the capture process itself[71].

***Figure 20:*** *Conventional generation CCS options*[72]




[69] Global CCS Institute (2015). Large Scale CCS Projects. Docklands, Australia. https://www.globalccsinstitute.com/projects/large-scale-ccs-projects.

[70] Bruckner, T., Fulton, L., Hertwich, E., et al. (2014a). 'Annex III: Technology-specific Cost and Performance Parameters', in IPCC, Fifth Assessment Report. Geneva, Switzerland.

[71] IEA Greenhouse Gas R & D Programme (2005). Retrofit of CO2 Capture to Natural Gas Combined-Cycle Power Plants. Cheltenham, UK.

[72] Data from Bruckner, T. et al. (2014a). Op. Cit.

Transport of $CO_2$ typically involves the compression and pumping of liquid $CO_2$ from the capture plant to the storage area. Saline aquifers, depleted oil and gas fields, and unmineable coal seams are suitable for geological $CO_2$ storage. See Section 5.2.1 for a map of global storage-suitable reservoirs. Enhanced Oil Recovery (EOR) is the process of injecting $CO_2$ into a producing oil or gas field to enhance output, a well-understood practice in the oil and gas industry[73]. The IEA estimates the cost of transporting and storing $CO_2$ may vary from US$1/t up to $100/t, with examples of <US$5/t for onshore storage in the US, to >US$25/t in offshore saline aquifers in Europe[74]. The IPCC uses a central estimate of US$10/t$CO_2$[75].

CCS implementation is hindered by its high capital costs and plant efficiency penalty. Both increase the levelised cost of electricity (LCOE) of a CCS-equipped power station relative to an equivalent unabated power station. The Global CCS Institute recently estimated a carbon abatement cost for coal with CCS of US$48 to $109/t and US$74 to $114/t for gas with CCS, including transport and storage, for a typical project in the US[76].

## 3.2 Scenario Inclusion

CCS is included as a mitigation and negative emissions technology in several future energy and climate scenarios. Projected CCS deployment of select 2°C warming scenarios are shown in Table 15 below.

***Table 15:** Projections of CCS deployment by 2040 of select 2°C warming scenarios*

| Scenario | Projected Deployment |
|---|---|
| IEA WEO: 450S | 5 Gt$CO_2$/yr, 60% in power |
| IEA ETP: 2DS | 4 Gt$CO_2$/yr, 57% in power |
| IPCC AR5: Cost-efficient 430-530 ppm | 5.5 to 12.1 Gt$CO_2$/yr (imputed) |

The IPCC synthesises technology uptake modelling subject to climate and economic constraints. A 450 scenario without CCS increases the mitigation costs by 138%, requires substantial afforestration and land-use change, and requires more mitigation early in the century. A 450 scenario with CCS makes substantial use of BECCS by mid-century to offset slower mitigation in other sectors[77].

In the IEA NPS, less than 5% of global coal-fired power stations are equipped with CCS by 2040 as the technology has not had the chance to proceed down cost curves. Between the CPS and the NPS, CCS only adds 2% additional carbon abatement, and only 1% before 2025. In the IEA's 450S, 75% of coal-fired power stations are equipped with CCS in 2040, although the total capacity of operating stations is substantially less.

[73] See IEA (2015). Storing CO2 Through Enhanced Oil Recovery. Paris, France.
[74] IEA (2015). Energy Technology Perspectives (ETP) 2015. Paris, France.
[75] Bruckner, T., Bashmakov, I., Mulugetta, Y, et al. (2014b). '7: Energy Systems', in IPCC, Fifth Assessment Report. Geneva, Switzerland.
[76] Global CCS Institute (2015). The costs of CCS and other low-carbon technologies in the United States – 2015 Update. Docklands, Australia.
[77] Field, C., Barrows, V., Mastrandrea, M., et al. (2014). 'Summary for Policy Makers', in IPCC, Fifth Assessment Report. Geneva, Switzerland.

In 2012, the IEA ETP estimated that 8 GtCO2/yr would need to be stored by CCS by 2050 to ensure a 2DS. The Carbon Tracker Initiative (CTI) used this target to estimate that 2DS greenhouse gas budgets might be extended by 12-14% with this level of CCS investment[78]. Oxford Smith School extended this methodology to bioenergy-enhanced CCS (BECCS) and other Negative Emissions Technologies (NETs), finding these technologies could further extended greenhouse gas budgets by 11-13%[79]. Both the CTI CCS and NETs carbon budget impacts are highly uncertain and imply extreme levels of technology adoption that are very unlikely.

## 3.3 Deployment Update

In October 2014, the first commercial power stations equipped with CCS began operation in Saskatchewan, Canada. Two additional CCS operations began in 2015, and the next power station equipped with CCS is expected to come online in the United States in 2016. To date, there are 15 operational CCS projects, 11 of which are used for enhanced oil recovery (EOR), and only seven of which include the monitoring of stored carbon[80]. An additional 30 projects are in planning till 2025, half of which are associated with power stations[81].

## 3.4 CCS in the Coal Value Chain

### *3.4.1 Thermal Coal Mining*

Because CCS is best applied to stationary point sources of emissions, few opportunities are available to mitigate emissions of coal mining operations with CCS.

### *3.4.2 Coal-Fired Power Utilities*

Coal-fired power stations have potential for both retrofit and the application of CCS to new power stations. In retrofit applications, post-combustion capture is likely the most appropriate and is currently the furthest developed[82]. For new builds, integrated gasification with pre-combustion capture, and oxy-fuel capture are more efficient[83].

In 2012, the OECD examined the global fleet of power stations retrofitable with CCS[84]. This study combines their methodology with geological suitability and policy outlooks from the Global CCS Institute, see Section 5.2.1 for details.

### *3.4.3 CPT*

Emerging opportunities for CCS are available in CPTs. CPTs often involve an interim gasification step – ideal for capture similar to pre-combustion capture. Overall, CCS technologies can also help the reduction of emissions by up to 11% if employed in coal-processing plants[85].

[78] CTI (2013) Unburnable Carbon 2013: Wasted Capital and Stranded Assets. London, UK.

[79] Caldecott, B., Lomax, G., & Workman, M. (2014). Stranded Carbon Assets and Negative Emissions Technologies. Smith School of Enterprise and the Environment, University of Oxford. Oxford, UK.

[80] IEA (2015). ETP 2015. Op. Cit.

[81] Global CCS Database (2015). Op. Cit.

[82] IEA GHG (2011). Retrofitting CO2 Capture to Existing Power Plants. Op. Cit.

[83] Bruckner, T. et al. (2014a). Op. Cit.

[84] Finkenrath, M., Smith, J., & Volk, D. (2012). CCS Retrofit, IEA. Paris, France.

[85] Perineau, S. (2013). Op. Cit.

There are potential synergies between UCG and CCS, as $CO_2$ can be stored in the coal cavity after extraction and gasification[86]. Although a combination of UCG and CCS has been proposed as a 'green solution' for capturing $CO_2$ underground, maximum achievable carbon dioxide storage in coal voids left after in situ coal gasification is estimated as being only 14%[87]. Moreover, methods of heating and extraction during UCG generate significant thermal stresses in the coal voids, which could lead to roof collapse and leakage of stored carbon dioxide[88]. See Section 7 for details.

# 3.5 Policy and Legal Developments

Leading examples for CCS policy support include the EU's Enabling Directive on CCS (2009/31/EC), and the CCS legislation of Alberta, Canada and Victoria, Australia. Among other things, these regulations describe the conditions and extent of liability transfer after storage is found to be stable.

In September 2015, the Global CCS Institute surveyed the development of legal and regulatory frameworks for approving and managing CCS projects worldwide. They find that Australia, Canada, Denmark, the UK, and the US all have well developed legal and regulatory frameworks under which CCS projects may be developed[89].

# 3.6 Emerging Issues

## 3.6.1 Long-term Storage Suitability and Leakage

Even in high-deployment scenarios, the physical availability of geological storage is unlikely to be an issue for the deployment of CCS. However, the availability of geological storage that is both economically viable is likely to be. Concerns over potential leakage and the long-term stability of stored carbon may also prevent the political acceptance of CCS, presenting further barriers to the uptake of the technology.

The potential leakage of $CO_2$ from storage reservoirs presents a source of major uncertainty for the uptake of CCS. Issues include safety from $CO_2$ asphyxiation, leading to environmental or human catastrophe; the migration of $CO_2$ within storage reservoirs, leading to unforeseen leakages; seismic impacts on stored carbon; and the slow leakage of stored carbon eroding the climate benefit of storage. Even if technical and economic challenges can be overcome, local resistance to long-term storage may prevent the successful deployment of the technology.

## 3.6.2 Liability

Liabilities around the long-term storage of $CO_2$ are an emerging concern for CCS implementation. Issues include economic damages for escaped $CO_2$, interactions between regulation and liability, extended claim limitation periods due to the geological timescale of $CO_2$ storage, inactionable injunctions against continuing emissions leakage, financial security against emissions pricing for escaped $CO_2$, jurisdictional issues in administrative responsibilities of CCS projects, and the extent to which liability for a CCS project may be transferred (e.g. from a company to the state at the conclusion of a project)[90]. New CCS legislation and existing legislation applied in a CCS context are both yet to be tested. New interpretations and case law specific to CCS will clarify legal liabilities, but while these are in development, liability will remain a risk for CCS developers and operators.

[86] Anderson, R. (2014). Op. Cit.

[87] Schiffrin, D. (2015). 'The Feasibility of in-situ Geological Sequestration of Supercritical Carbon Dioxide Coupled to Underground Coal Gasification', Energy and Environmental Science 8: 2330-2340.

[88] Ibid.

[89] Global CCS Institute (2015). CCS Legal and Regulatory Indicator. Docklands, Australia.

[90] Havercroft, I., & Macrory, R., (2014). Legal Liability and Carbon Capture and Storage, Global CCS Institute. Docklands, Australia.

### 3.6.3 *Perception*

Cumulative emissions are responsible for the warming of the climate and the IPCC AR5 determined that some emissions pathways will require negative emissions to constrain cumulative emissions to safe levels. In spite of this, the IPCC calls the future availability of carbon dioxide removal technologies 'uncertain'. On CCS specifically, the IPCC notes that experts have only moderate agreement and insufficient evidence to evaluate whether CCS can limit the lifetime emissions of fossil fuel plants; whether BECCS can effectively deliver net negative emissions; and if sequestered carbon can be securely stored long-term[91].

The World Energy Council reports on the perceptions of 1,045 global energy leaders in the private and public sectors. Since 2010, energy leaders have reported a declining awareness of the impact of CCS, while uncertainty remains high[92]. Mixed opinions and insufficient evidence are barriers to the wide adoption of CCS as a key technology for mitigating climate change.

## 3.7 Opinion

Several additional factors may prevent the scale adoption of CCS as a mitigation technology. First, CCS is not currently developing at the pace necessary to meet the 2°C scenarios of the IEA and the IPCC. Second, other mitigation substitutes are becoming cost-competitive much more quickly than CCS. Third, a technology pathway which necessarily includes enhanced oil recovery is subject to additional economic and reputational risks.

By 2040, in the IEA's 450S, CCS is deployed to store 4000 Mt$CO_2$ per year (Mtpa). The 15 currently operating projects are anticipated to store 28.4 Mtpa. The 30 additional projects planned to operate before 2025 will bring the total storage to 80 Mtpa, an annual growth rate of 11%. To reach 4000 Mtpa by 2040 will require a 48% growth rate from the 2025 planned fleet, or 22% growth from the operating fleet this year. This growth rate is unrealistic given the current state of deployment and technical progress.

The IEA foresees substantial deployment of CCS under the 450S only if policy supports CCS to become more affordable. As a mitigation technology for power generation, CCS will need to compete with falling prices of wind and solar power, and widespread efforts to improve grid flexibility. McKinsey estimates that by 2030, the abatement cost of solar and high-penetration wind power will be €18.0 and €21.0 per t$CO_2$ respectively, while CCS coal retrofits, new builds, and gas new builds will be €41.3, €42.9, and €66.6 per t$CO_2$ respectively[93]. Bloomberg New Energy Finance (BNEF) estimates that the global average LCOE for onshore wind power is US$83/MWh, $122 for crystalline solar PV, and $174 for offshore wind[94], while the Global CCS Institute estimates the US levelised cost of electricity (LCOE) for coal with CCS is US$115/MWh to $160, and $82 to $93 for CCS-equipped gas-fired power[95]. For markets and policymakers seeking abatement options in the context of finite public funds, CCS may remain a low priority for support.

[91] Field, C. et al. (2014). Op. Cit.
[92] World Energy Council (2015). 2015 World Energy Issues Monitor. London, UK.
[93] McKinsey & Company (2010). Impact of the Financial Crisis on Carbon Economics. New York, US.
[94] Zindler, E. (2015). 'Wind and solar boost cost-competitiveness versus fossil fuels', Bloomberg New Energy Finance (BNEF). London, UK and New York, US.
[95] CTI (2015). Op. Cit.

The IEA suggests that the technology development pathway for power generation with CCS begins with collocating the power station with EOR projects to enable commercial viability[96]. The IEA admits that the public are already 'sceptical of end-of-pipe solutions apparently promoted by the same industries they hold responsible for the problem'[97]. When co-located with EOR the stored carbon is used to extract additional hydrocarbons. Critics would argue any purported climate change merit of these projects is greenwashing – a reputational risk for the companies involved. Moreover, dependence on EOR also exposes power stations with CCS to oil price commodity risks. If the price of oil falls, then the profitability of EOR falls, and the profitability of the power station is reduced.

In conclusion, CCS is unlikely to be significant in mitigating power sector emissions. Deployment of CCS has already been too slow to match IEA and IPCC scenarios. CCS compares unfavourably with other power sector mitigation options, especially considering that CCS also reduces plant efficiency, exacerbating existing merit-order challenges for conventional generators. CCS should remain an attractive option for industrial and process emitters that have few other mitigation options, and may be significant as a long-term option for delivering negative emissions with BECCS.

[96] IEA (2013). Technology Roadmap – Carbon Capture and Storage. Paris, France.
[97] Ibid.

# 4 Policy Summaries

Detailed policy summaries have been prepared for the ten countries where most of the economic activity in the thermal coal value chain occurs: Australia, China, Germany, Indonesia, India, Japan, Poland, South Africa, the United States, and the United Kingdom. Between them these countries produce 86%, and consume 84%, of the world's thermal coal[98].

In this section, an analysis of policy relevant to coal-fired utilities, thermal coal miners, and CPT companies has been conducted. For each country, climate change and energy policy is examined, the state of environmental regulations is summarised, any CPT developments are discussed, and emerging issues are identified.

## 4.1 Australia

### *4.1.1 Climate Change and Energy Policy*

Australia is the twelfth largest economy in the world and the world's second largest coal exporter. In 2014, Australia exported five times more coal than it consumed domestically.

With growing interest in climate change through the 2000s, the Clean Energy Act 2011 was passed by Julia Gillard's Labour government in February 2011. The Act established a carbon tax on facilities directly emitting over 25kt$CO_2$e per year. The tariff would begin at A$23/t in FY2012-13 and rise to A$24.15/t in FY 2013-14[99]. The carbon tax became an election issue in the run up to the 2013 election. The new Liberal government under Tony Abbott repealed the carbon tax in July 2014 with the Clean Energy Legislation (Carbon Tax Repeal) Act 2014[100].

The new government instead issued a Direct Action Plan to achieve a 5% reduction of emission levels below 2000 levels by 2020. Central to the plan is an A$2.55bn Emissions Reduction Fund which targets efficiency upgrades, land use change, and methane capture to deliver low marginal-cost emissions reductions. The Emissions Reduction Fund includes a safeguarding mechanism to ensure economy-wide emissions fall to meet the target. The safeguarding mechanism constrains facilities emitting over 100kt$CO_2$e to a baseline level of emissions, capturing over half of the country's emissions[101].

The Renewable Energy (Electricity) Act 2000 mandates demand for Large-scale Generation Certificates (LGCs) and Small-scale Technology Certificates (STCs). Electricity retailers must surrender a mandated amount of LGCs and STCs to the Clean Energy Regulator. LGCs are created with every MWh of large-scale renewable electricity generation. STCs are created on the installation of small-scale domestic and commercial renewable energy and efficiency technology. Taken together, it is expected that 23.5% of Australia's electricity will come from renewable sources by the year 2020[102].

Since 2009, black and brown coal-fired power generation has fallen at an average of 4.6% and 3.9% a year respectively. Wind power has grown at an average of 24.5% while gas-fired and hydro generation over the same period have been constant. Rooftop photovoltaic solar generation provided 2% of Australia's electricity in 2014, and is expected to grow 24% per year for the next three years.

[98] IEA (2015). Coal MTMR. Op. Cit.

[99] Australian Government (2011). Australia Clean Energy Act 2011. Canberra, Australia.

[100] Australian Government (2014a). Clean Energy Legislation (Carbon Tax Repeal) Act 2014. Canberra, Australia.

[101] Australian Government (2014b). Emissions reduction fund: Overview. Canberra, Australia.

[102] Hunt, G. & Macfarlane, I. (2015). 'Certainty and growth for renewable energy', Media Release. Canberra, Australia.

Growth in renewable generation and falling electricity demand have caused a decline in coal-fired generation, especially black coal. In 2014, renewable sources provided 15.1% of Australia's electricity[103].

Short-term and spot markets for natural gas have existed in the state of Victoria since 1999, but only since 2010 and 2011 in Sydney, Adelaide, and Brisbane. In 2014, average spot prices for natural gas were approximately A$4/GJ (US$5.92/MMBTU), and were A$2.5/GJ (US$3.70/MMBTU) in Brisbane. Liquefied natural gas became Australia's third largest export in 2014, with major export terminals approaching completion. Future gas prices are expected to rise and be linked with international LNG prices in the future[104].

### 4.1.2 *Environmental Regulations*

Australia has robust permitting and environmental protection legislation[105]. Environmental assessment is part of the site permitting process and includes provisions for environmental impact statements; land, water, and air contamination; threatened species; noise and waste management; materials transport; and remediation standards and insurance. Permitting and enforcement are typically conducted by state and territory authorities, but recent legislation has made certain environmental issues federal concerns.

In Australia, mineral rights are wholly owned by the Australian States and Territories. The governments of those states and territories may grant companies extraction and disposal rights subject to royalties for the state and territory governments and taxes at multiple levels of governance. In all states, companies are subject to special regulations for mining activities and environmental protection. Companies must obtain tenements for exploration, production, and retention of minerals as well as environmental authorities for environmentally relevant activities, subject to state level mining and environmental protection departments.

The Environmental Protection and Biodiversity Conservation (EPBC) Act 1999 brought certain environmental and heritage risks under federal jurisdiction due to their national significance. World Heritage Sites, offshore marine areas, and threatened species are protected under the EPBC Act. In 2013, the EPBC Act was amended to reprioritise water resources as a matter of national environmental significance and to add water triggers to the coverage of the EPBC Act specifically for coal seam gas projects and large coal mining projects[106].

State-level water protection legislation establishes the process for licensing and regulating water resources. The Water Act 2007 established the Murray-Darling Basin Authority, to manage the water resources of the basin on behalf of the five states and territories it supplies. The pollution of water resources is prohibited by state environmental protection legislation. For offshore resources and coal seam gas and large coal mining projects, federal legislation prohibits the pollution of water resources.

Conventional air pollutants are managed by jurisdictional environmental protection departments according to National Environmental Protection Measures for air quality and air toxins[107]. No pollution abatement technologies are currently required for Australian power stations[108]. The Australian Academy of Technological Sciences and Engineering has estimated that the unabated emission of $PM_{10}$, $SO_2$, and NOx cost an additional A$2.6bn in health care a year[109].

[103] AER (2014) State of the Energy Market 2014. Melbourne, Austrlia.

[104] Ibid.

[105] For a summary, see Clifford Chance LLP (2013). Q & A on Environmental Law in Australia. London, UK.

[106] The Australian Government (2013). EPBC Amendment Bill 2013. Canberra, Australia.

[107] Standing Council on Water and Environment (2014). National Environment Protections Measures. Canberra, Australia. http://www.scew.gov.au/nepms.

[108] CSIRO (2012) Environmental Impact of Amine-based CO2 Post- combustion Capture (PCC) Process, Australian National Low Emissions Coal Research and Development Project. Canberra, Australia.

[109] The Australian Academy of Technological Science and Engineering (2009). The hidden costs of electricity. Melbourne, Australia.

### 4.1.3 CPT Developments

Despite being the world's largest coal exporter, Australia imports 40% of its oil and oil products[110]. Monash Energy CTL Project, jointly supported by Anglo Coal and Shell, the Arckaringa CTL Power Project, proposed by Altona Energy, and Chinchilla UCG trial by Linc Energy,[111] are the chief demonstration CPT projects in Australia. The Monash Energy project is based on a long-term plan for converting brown coal resources to cleaner liquids[112]. Although the Arckaringa project was originally proposed as a CTL project, a new feasibility study shows that decreasing power demand in the South Australian grid has made funding of the project difficult[113]. A new Coal to Methanol (CTM) Plant is proposed alongside the CTL project to overcome funding restrictions and to produce commercially valuable methanol.

Operating the first commercially successful pilot UCG plant in Chinchilla, Linc Energy originally was founded in 1998 as a joint venture company with CS Energy, a government-owned company in Queensland to develop UCG for power generation[114]. After developing the UCG process and before commercialisation, CS Energy sold its shares in the plant[115]. In 2013, Linc Energy ceased its operations in Chinchilla, citing regulatory uncertainty in Queensland, which favoured the rival CSG sector over UCG[116], and high costs[117] of working in Australia. The company is also facing liabilities up to A$32.5m for environmental harm caused at this UCG plant[118]. On the other hand, Altona Energy PLC regained full ownership of the Arckaringa CTL Project after ending its joint venture partnership with CNOOC New Energy in in 2014, and later entered into another partnership with Sino-Aus Energy Group and Wintask Group Ltd, which would provide a maximum of A$33 million in the project[119].

### 4.1.4 Emerging issues

*Changing attitudes to climate change*

In the 2013 federal election, Tony Abbott's Liberals defeated Kevin Rudd's Labour Party. Repealing Australia's carbon tax was central to the campaign, a promise Abbott delivered in July 2014. Abbott has since been replaced as Prime Minister by Malcolm Turnbull after an internal party leadership vote in September 2015. Turnbull is recognised for having a progressive stance on climate change, but commentators have been sceptical as to whether the Australian government will adopt any policy changes under his leadership[120]. The next Australian federal election will be held on or before January 14, 2017.

*Coal Seam Gas Opposition*

Coal seam gas continues to attract opposition in parts of Australia, both from protestors[121] and legislators[122].

[110] Fraser, A. (2010). 'Underground coal gasification the next big thing in energy mix', The Australian Business Review. Brisbane, Austrlia.

[111] Ibid.

[112] MacDonald-Smith, A. (2008). 'Shell, Anglo to delay a $5 billion clean fuels project', Bloomberg.

[113] Altona Energy plc (2013). 'Australia: Altona Energy announces results of Arckaringa coal to methanol technical feasibility study', Energy-pedia News. St. Albans, UK.

[114] Fraser, A. (2010). Op. Cit.; Garcia, E. (2015). 'Underground coal gasification plant poisons community', greenleft weekly. Broadway, Australia.

[115] Garcia, E. (2015). Op. Cit.

[116] Validaki, V. (2013). 'Linc Energy dumps coal gasification project', Australian Mining.

[117] Garvey, P. (2013). 'Linc Energy calls it quits on UCG project', The Australian Business Review.

[118] Milman, O. and Evershed, N. (2015). 'Mining company being sued over gas leaks gave money to LNP and Labor', The Guardian.

[119] Unsted, S. (2015). 'Altona Energy agreement on Arckaringa amendment', Alliance News.

[120] e.g. Butler, M., (2015). 'Malcolm Turnbull's Faustian pact on climate change is heartbreaking' The Guardian.

[121] e.g. TM (2015). 'Stop coal seam gas banners', ABC.

[122] e.g. Gerathy, S. (2015). 'CSG bill: Shooters join NSW Government to kill off proposal', ABC.

*Export Sensitivity*
With a commodities-based export economy, Australian miners carry significant exposure to both commodity prices and policy and disaster risks all around the world. Examples include China's coal import tax, a bargaining chip imposed in October 2014 during free trade negotiations, and the Fukushima Daiichi nuclear accident. The former had severe impacts on Glencore PLC[123] and BHP Billiton PLC , and the latter caused a 35% drop overnight in the share price of Paladin Energy PLC, an Australian uranium producer[124]. Japan's change in energy policy post-Fukushima, however, proved to be a boon for Australian coal producers who provided 63% of Japan's enlarged post-Fukushima coal imports in 2014[125].

*The Utility Death Spiral*
A large country with dispersed populations, plentiful sun, and falling electricity demand spells the perfect storm for Australian utilities – see Box 2 The 'Utility Death Spiral'. In June 2015, the Australian Senate completed an inquiry into the performance and management of electricity network companies[126]. They address the problem of the utility death spiral directly and also highlight the moral hazard of delegating infrastructure responsibility to the network service providers[127]. The authors call on the regulator to take steps to prevent inefficiencies of the network operators and on governments to anticipate and respond to the utility death spiral in Australia.

**Box 2:** *The 'Utility Death Spiral'*

The 'Utility Death Spiral' describes the disruption to conventional power utility companies in Europe, North America, and elsewhere[128]. The 'spiral' is the virtuous cycle of distributed energy resources (e.g. rooftop solar PV) eroding the distribution network business model of the central utility, which in turn raises retail electricity prices making distributed energy resources even more competitive. A wider description also includes:

- Falling electricity demand caused by efficiency and retreat of electricity-intensive industries
- Intermittent renewables generate at peak load times when prices might be highest
- Low marginal cost centralised generation, especially renewables, receive grid priority, decreasing market prices and stranding conventional generation

Utilities exposed to the utility death spiral and related market forces face losses of profitability, lower credit ratings, and falling share prices. Specific observations on the utility death spiral are made in the appropriate countries' policy summaries.

# 4.2 China

## *4.2.1 Climate Change and Energy Policy*

China is the world's second largest economy, and the largest producer and importer of coal. In November 2014, the Presidents of both China and the United States made a historic joint

[123] Paton, J. (2014). 'China Coal Tariffs Add to Pressure on Producers in Australia', Bloomberg.
[124] Pool, T. (2013). Uranium supply, demand & prices, International Nuclear Inc. Vienna, Austria.
[125] IEA (2015). Coal MTMR. Op. Cit.
[126] The Australian Senate (2015). Performance and management of electricity network companies, Environment and Communications References Committee. Canberra, Australia.
[127] In this case, the network service providers 'gold plated' their infrastructure investments, knowing that they would be better compensated for a larger asset base. The assets underperformed, due also in part to the utility death spiral, but the Australian taxpayer bore the costs – the moral hazard in question.
[128] CTI (2015). Coal: Caught in the EU Utility Death Spiral. London, UK.

announcement of cooperation to meaningfully address climate change[129]. China submitted its intended Nationally Determined Contribution (INDC) ahead of COP21 to the UN on June 30, 2015[130]. The INDC follows on substantial clean energy progress made by China under its 12th Five-Year Plan (FYP) (2011-15), its National Climate Change Plan, and its Air Pollution Prevention and Control (APPC) Law[131].

By 2014, non-fossil fuel primary energy supply had reached 11.2%. Solar and wind power capacity reached 28 and 95GW respectively, exceeding the initial outlooks of the 12th FYP. Between 2011 and 2015, growth in new-build coal-fired power stations fell from 9% to under 5%[132]. Since 2008, utilisation rates for thermal power stations has fallen from 60% to 54%[133]. Projected growth of renewables is shown in Table 16. Seven cap-and-trade pilot projects have also begun in Chinese cities, with a nationwide emissions trading scheme expected for 2017[134]. A wide range of mitigation and adaptation activities are underway in China[135].

***Table 16:*** *China renewables targets 2017 from APPC*

| | 2014 Installed Capacity [GW][136] | 2017 Target Capacity [GW] | CAGR |
|---|---|---|---|
| Hydro | 301 | 330 | 4.5% |
| Wind | 95 | 150 | 25.6% |
| Solar | 28 | 70 | 58.1% |

By the end of 2014, 19.9 GW of nuclear power had been installed in China, likely falling below the levels of investment necessary to achieve 50GW by 2017 as called for in the APPC. The installation of renewables has proceeded faster than necessary to achieve the 12th FYP – the growth projections to meet the APPC target are conservative.

Natural gas is being supported as an energy form which can displace carbon-intensive and air-polluting intensive coal. The EIA estimates that China has over 31 trillion cubic meters of technically recoverable shale gas – more than any other country[137]. In 2011 and 2012, China auctioned exploration rights for shale gas with mixed success, reducing shale gas subsidies in April 2015[138]. China is currently constructing four LNG regasification facilities and import contracts are expected to provide the mainstay of Chinese gas needs[139]. At the beginning of 2014, coal-to-gas projects producing 83 bcm per year of gas were approved. Reuters estimates China's gas demand in 2014 was 184 bcm[140].

Gas prices are set by the Chinese central government. The slowing of the Chinese economy to a 'new normal' has diminished recent gas demand, reduced LNG imports. The central government is expected to cut natural gas prices in the near future[141].

[129] The White House (2015). 'U.S.-China Joint Presidential Statement on Climate Change', Office of the Press Secretary. Washington, US.
[130] People's Republic of China (PRC) (2015). Enhanced actions on climate change: China's INDC, NDRC. Beijing, China.
[131] PRC (2013). Law on Air Pollution Prevention and Control, Clean Air Alliance of China. Beijing, China.
[132] Cornot-Gandolphe, S. (2014). China's Coal Market: Can Beijing tame King Coal? Oxford Institute for Energy Studies, University of Oxford. Oxford, UK.
[133] Myllyvirta, L. (2015). 'New coal plants in China – a (carbon) bubble waiting to burst', Greenpeace Energy Desk. London, UK.
[134] Hornby, L. (2015). 'Doubt cast over start of China emissions trading scheme', The Financial Times.
[135] See NDRC (2015). China's Policies and Actions on Climate Change. Beijing, China.
[136] National Energy Board (2015). National Electric Power Industry Statistics. Beijing, China.
[137] US Energy Information Agency (EIA) (2015). Technically recoverable shale oil and gas resources: China. Washington, US.
[138] Guo, A. (2015) 'China cuts subsidies for shale gas developers thoruhg 2020', Bloomberg.
[139] Global LNG Ltd (2015). World's LNG Liquefaction Plants and Regasification Terminals. London, UK.
[140] Hua, J. & Rose, A. (2015). 'China's sputtering economy crimps gas demand, cuts spot LNG buys', Reuters. Beijing, China.
[141] Tham, E. (2015). 'China plans up to 30 pct cut in natural gas prices', Reuters. Shanghai, China.

### 4.2.2 *Environmental Regulations*

Historical reliance on coal for domestic and industrial energy supply has caused crisis-levels of conventional air pollution in China. For a period between 2008 and 2014, China Real Time found that air pollution levels in Beijing exceeded unhealthy levels for sensitive individuals at least 50% of the time (by Chinese standards)[142]. Chinese Premier Li Keqiang 'declared war' on pollution in 2014, and Chinese policy has followed.

Chinese policy actions like the 12 FYP and the APPC address conventional air pollution levels and carbon pollution simultaneously. Beyond the decarbonisation measures above, the APPC banned the import of high-ash and high-sulphur content from January 2015 and expanded coal washing to 70% by 2017. In the regions of Beijing-Tianjin-Heibei, Yangtze River Delta, and Pearl River Delta, coal consumption is capped and expected to decline, all heavy industries and coal-fired power stations must be fitted with flue-gas desulphurisation, and urban and suburban zones will be banned from consuming coal from 2020 onwards.

Responsibility for environmental protection in China is complex. The Environment and Resources Protection Commission (ERPC), Ministry of Land and Resources (MLR), and Ministry of Environmental Protection (MEP) all have national coverage and provincial and sub-provincial offices. These offices are not directly subordinate to national level authorities, and establish their own jurisdiction, monitoring, and enforcement conventions in each area [143]. In April 2014, a new law was passed which establishes more stringent rules for environmental enforcement, but does little to resolve power and coordination problems in the vertical and horizontal relationship of Chinese environmental enforcement organisations [144].

China faces severe water scarcity and quality challenges. In 2010 the State Council issued a policy intention to establish 'three red lines': standards for water use efficiency, minimum water quality, and total aggregate use[145]. After efficiency targets in consecutive FYPs, and the world's largest river diversion project[146], Chinese urban water prices were substantially reformed in 2014 – for execution by the end of 2015. In January 2014, the Ministry of Water Resources (MWR) issued a guidance for water reform which indicated that water pricing would move towards a market mechanism[147]. A month earlier, the MWR announced a plan which would not allow the development of large coal bases to threaten water resource availability[148].

### 4.2.3 *CPT Developments*

China plans to build 50 CTG plants in less populated northwestern parts of the country – 80% of new CTG plants will be in provinces or regions of Xinjang, western Inner Mongolia, Ningxia and Gangsu[149]. Shrinking profits in the coal sector and demand for clean energy products have been major force in China's coal conversion projects[150]. In 2013, the country was assessed to have a natural gas shortage[151] of 22 billion $m^3$, however, it is coal-rich[152].

[142] Wayne, M. & Chen, T. (2015). 'China's bad air days, finally counted', The Wallstreet Journal. Beijing, China.
[143] Zhang, B. & Cao, C. (2015). 'Policy: Four gaps in China's new environmental law', Nature 517:433-434.
[144] PRC (2014). People's Republic of China Environmental Protection Law. Beijing, China.
[145] Moore, S. (2013). 'Issue Brief: Water Resource Issues, Policy and Politics in China', The Brookings Institute.
[146] Aibing, G. (2015). Op. Cit.
[147] Ministry of Water Resources (MWR) (2014). 'Ministry of Water Resources on deepening the reform of water conservation', China Water Resource News.
[148] Yongjing, W. (2014). 'MWR of the General Office on efforts to develop water resources planning', MWR. Beijing, China.
[149] IER (2014). Op. Cit.
[150] Liu, C. (2015). 'Chinese companies plunge into coaltoliquids business, despite water and CO2 Problems', ClimateWire. Yulin, China; Xu, J. et al. (2015). Op. Cit.
[151] Li, H., Yang, S., Zhang, J., et al. (2016). 'Coal-based Synthetic Natural Gas (SNG) for Municipal Heating in China', Journal of Cleaner Production 112:1350-1359.
[152] Bai, J. & Aizhu, C. (2011). 'China Shenhua coal-to-liquids project profitable –exec', Reuters. Tianjin, China.

Since 2010, a number of CTL and CTG demonstration projects have been implemented, and many are due to be expanded. Moreover, a Chinese firm, Shenhua Group, is collaborating with the highly experienced South African firm Sasol on a CTL project[153]. Over the past 20 years, international and local gasifier vendors have been competing to licence their technology for use in China – the biggest international companies include Shell, Siemens GSP, General Electric Energy, and Lurgi. China is expected to reach a capacity of 310,000 bbl/day of CTL and CTG by 2016[154].

In China, leading power generation companies, such as Datang, China Guodian Corporation and China Power Investment, and other major state-owned oil and gas companies – China National Petroleum Corporation (CNPC), Sinopec and China National Offshore Oil Corporation (CNOOC) – have shown great interest in the coal conversion sector[155]. Most of funding for these projects comes from subsidies given by local governments and loans from the Chinese Development Bank, which offers RMB50 billion for four to five coal conversion projects until 2018[156]. However, regulatory uncertainties surrounding CTG/CTL projects in China have affected investment in the coal conversion sector; in particular the Chinese government's concerns about overcapacity and the environmental impact of a loosely regulated sector have slowed down the approval of these projects[157]. Moreover, their economic profitability has shrunk due to falling returns in the power business, and high technical and other operational costs.

### 4.2.4 Emerging Issues

*Domestic Coal Production Tax and Moratorium*

Small-scale coal mining operations grew rapidly in the 1980s with a lasting legacy of local pollution and enforcement challenges. Chinese policymakers have been attempting to reduce small-scale mine operations, shutting 1,725 such mines in 2014, and preferring to consolidate coal production in large-scale remote 'coal bases'[158]. In January 2015, a nationwide value-added tax on coal production was introduced. Local governments enforced a rate of 2% to 8% to reduce reliance on land sales for government revenue[159].

At the end of 2015, China issued a moratorium on approvals for new coal mines. From 2016 to 2018, no new coal mines will be approved. It also plans to close another 1,000 mines in 2016[160].

*Conventional Air Pollutants*

China continues to take a strong stance on the mitigation of conventional air pollutants, mitigating health and environmental impacts. By 2012, 680 GW of the country's 826 GW of coal-fired power had been fitted with flue gas desulphurisation technology[161]. Imports of high ash and high sulphur coal were banned in 2015[162]. China may seek additional options for decreasing conventional air pollutants, which will impact both end-users of coal in China and their global suppliers.

[153] Ibid.
[154] Perineau (2013). Op. Cit.
[155] The Economist (2014). "Coal gasification in China: Unconverted", The Economist.
[156] Cornot-Gandolphe, S. (2014). Op. Cit.
[157] The Economist (2014). Op. Cit.
[158] Stanway, D. (2014). 'China to close nearly 2000 small coal mines', Reuters. Beijing, China.
[159] Stratfor (2015). 'China Imposes a new Coal Production Tax', Stratfor Global Intelligence.
[160] Bloomberg News (2015). 'China to halt new coal mine approvals amid pollution fight', Bloomberg.
[161] McIlvaine Company (2012). Flue Gas Desulfurization, Denitration Industry for Coal-fired Power Plants in 2012. http://www.mcilvainecompany.com/Decision_Tree/new%20chinese%20fgd.htm
[162] Wong, F. (2014). 'China to ban imports of high ash, high sulfur coal from 2015', Reuters. Shanghai, China.

*Emerging Water Stress*

China's actions to mitigate water stress may have large implications for the coal industry as its massive coal bases are being built in areas of high water stress (see Section 5.2.1). A recent PNAS study finds that water is being exported from these areas both physically and virtually in the embedded water of products made in these areas[163]. China may face difficult policy decisions as water stress impacts coal productivity.

# 4.3 Germany

## 4.3.1 *Climate Change and Energy Policy*

Germany is a founding member of the European Union (EU) and is the fourth-largest economy in the world. Germany imports and produces coal in roughly equal proportions, ranking seventh in the world for total primary energy supply of coal. As a member of the EU, Germany has binding climate targets and is a signatory of the Kyoto Protocol. See Box 3 for climate change and renewable energy policy elements common to all EU member states.

**Box 3:** *European union common measures*

The EU takes coordinated action on certain policy matters like climate change. The EU Emissions Trading Scheme (ETS) was established by EC Directive 2003/87/EC. The EU ETS covers approximately 45% of the EU's emissions, mostly from large stationary sources (e.g. power plants, industry), and commercial aviation. As a cap-and-trade mechanism, EU member states receive decreasing emissions quotas which they allocate or auction to their domestic emitters. The ETS is the main policy tool designed to achieve the EU's target of 20% GHG reductions below 1990 levels by 2020. The EU ETS was also designed to accommodate the flexibility mechanisms of the Kyoto Protocol, which were synchronised with the EU ETS (2004/101/EC).

Now in its third phase of coverage and allocation iterations, the price of an emissions allowance (1 tonne of $CO_2e$) has fallen since 2008 from €20-30/t to less than €10/t in 2015. The fall in prices is generally believed to be caused by an over-allocation of emissions allowances and slow growth[164]. Combined with the increasing difference in spark spread between gas and coal-fired power, the fall in carbon price had the opposite of the desired effect. New gas-fired power stations were stranded at the high end of the merit order and old coal-fired generation assets had their lives extended[165].

The Renewable Energy Roadmap of 2007 set an EU-wide policy target of 20% greenhouse gas (GHG) reductions on 1990 levels by 2020, to have 20% of all primary energy provided by renewables, and to achieve 10% biofuel use. These targets were passed on to member states in the 2009 Renewable Energy Directive (2009/28/EC) and associated Effort Sharing Decision (406/2009/EC). EU member states have different targets under the directive.

In its INDC, the EU has committed to emissions reductions of 40% below 1990 levels by 2030. Member states have enacted the EU directives and their own climate and energy policies, which are discussed in the appropriate sections.

[163] Zhao, X. (2015). Physical and virtual water transfers for regional water stress alleviation in China, Proceedings of the National Academy of Sciences (PNAS) 112: 1031-1035.

[164] Oliver, C. & Clark, P. (2015). 'EU plan to revive lifeless carbon market', The Financial Times. London, UK and Brussels, Belgium.

[165] Caldecott, B. & McDaniels, J. (2014). Financial Dynamics of the Environment: Risks, Impacts, and Barriers to Resilience, Smith School of Enterprise and the Environment, University of Oxford. Oxford, UK.

The AGEB reports that since 2009, wind, biomass, and photovoltaic power have grown at 9%, 10%, and 42% respectively, displacing nuclear and gas-fired power[167]. In 2014, 25.8% of Germany's power came from renewable sources. Coal power consumption has remained relatively constant, providing approximate 43% of the country's power. According to its National Action Plan drawn up in response to the Renewable Energy Directive, Germany expects to exceed its target reduction by 2020, achieving 19.6% of all primary energy from renewable sources, with 38.6% of all electricity generated renewably[168].

The German energy transition, the *Energiewende*, has existed in name since the 1980s, however it became a mainstream state policy in September 2010 with the publication of the government's future energy concept[169], a policy plan which described the transition away from nuclear and coal power with the uptake of renewables, efficiency, and flexibility. Under this plan, nuclear power was called a 'bridging technology' and the lives of Germany's nuclear power fleets were to be extended up to several decades. However, faced with public unrest about nuclear power after the Fukushima accident in Japan, the government announced a moratorium on nuclear power generation. The closure of nuclear power was reprioritised in the *Energiewende* and Germany carbon emissions through the early 2010s remained relatively constant as renewables displaced nuclear power instead of coal[170]. 8.4GW of nuclear power generation were phased out by 2011, and 12.5GW are expected to be phased out between 2015 and 2022[171].

The German electricity market is dominated by the Big Four: RWE, EnBW, E.ON, and Vattenfall. In 2013, RWE and Vattenfall, with the two largest generating fleets in Germany, posted losses of US$3.8bn and $2.3bn respectively, see the 'Utility death spiral' in Box 2. Share prices of the Big Four have fallen accordingly and E.ON has split into two companies. E.ON's nuclear and fossil fuel fleet will go to new subsidiary Uniper, while E.ON's renewable and smart-energy interests will remain under the former brand[172].

In response to the death spiral (see Box 2), utilities have been curtailing base-load capacity investments. Governments and regulators are considering market reforms to ensure sufficient generation capacity is available to prevent shortfalls. In Germany, the government has decided to enact market reforms rather than a capacity market[173]. A capacity reserve however, may act as a 'retirement plan' for German lignite power stations which would have otherwise faced a steep emissions penalty and would have been retired early by principal operators RWE and Vattenfall[174].

### 4.3.2 Environmental Regulations

Germany is a developed country with strong environmental regulations. As an EU member state, Germany's environmental policy is harmonised with that of the greater EU, see Box 4.

**Box 4:** *European Common Environmental Policy*

> The EC's 7th Environmental Action Programme (1386/2013/EU) binds member states to the protection of air, water, soil, health, climate, and biodiversity, with collective goals for the period of 2014 to 2020.

[166] European Commission (2008). 'Annex – Germany' in Environment Policy Review. Brussels, Belgium.

[167] AG Energiebilanzen e.V. (2015). Bruttostromerzeugung in Deutschland ab 1990 nach nergieträgern. Berlin, Germany.

[168] Federal Republic of Germany (2009). National Renewable Energy Action Plan in accordance with Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Berlin, Germany.

[169] BMWi (2010). Energy Concept. Berlin, Germany.

[170] Appunn, K. & Russell, R. (2015). 'Germany utilities and the Energiewende', Clean Energy Wire.

[171] Heinrich Boll Foundation (2015). Energy Transition. http://energytransition.de/ .

[172] Steitz, C. (2014). 'German utility E.ON to split focus on renewables, grids', Reuters. Frankfurt, Germany.

[173] BMWi (2014). An Electricity Market for Germany's Energy Transition. Berlin, Germany.

[174] Argus Media Ltd, (2015). 'Germany shelves climate levy for lignite reserve', Argus Media. London, UK.

The Environmental Impact Assessment Directive (2014/52/EU) requires the developers of any public or private project to complete an assessment of a wide range of potential environmental and human impacts of their project. Member states may refuse development consent on the basis of the submitted environmental impact assessment.

The EU Water Framework Directive (2000/60/EC) requires member states to manage water resources in their countries sustainably. Member states must monitor and manage all water use in their jurisdictions, reducing and remediating pollution, restoring ecosystems, charging polluters equitably for their use of ecosystem services, and ensuring sustainable access to water for individuals and businesses.

The Industrial Emissions Directive (2010/75/EU) requires member states to control pollutant emissions from large industrial sources in an integrated way, simultaneously protecting air, water, and land emissions. The directive contains special provisions for power plants. In a practical sense, all European coal-fired power stations must be fitted with flue gas desulphurisation, or must trade emissions permits or close by 2023[175].

The Environmental Liability Directive (2004/35/EC) establishes liability for organisations whose businesses cause harm to the environment or environmental resources. Organizations are always liable for specified activities which cause grievous environmental harm (e.g. release of heavy metals) and are more generally liable for environmental damage if they are found to be negligent or at fault.

In 2010, EU member states reached a decision (2010/787/EU) to phase out state aid to uncompetitive coal mines. The EU requires that all state aid to coal mining cease by 2018.

The German public and legislators have taken a cautious approach to hydraulic fracking for natural gas, waiting for sufficient evidence to demonstrate its health and environmental safety. Hydraulic fracturing for gas in Germany is effectively banned through to 2018[176].

### *4.3.3 Emerging Issues*

#### *4.3.3.1 Lignite generation in the capacity reserve*

The creation of the capacity reserve has been criticised for its targeted support of Germany lignite assets. Critics argue that the reserve will protect the jobs of lignite miners and the profitability of lignite operators, delaying the transition away from emissions-intensive coal. Some commentators have questioned whether the capacity reserve is an illegal subsidy to the plant operators, or whether the capacity reserve will suppress electricity prices and prevent additional capacity investment.

## 4.4 Indonesia

### *4.4.1 Climate Change and Energy Policy*

Indonesia is the world's largest exporter of coal, mostly to China. Summaries of Indonesia's current and expected electricity consumption are available from the IEA[177] and Indonesia's primary utility[178], the PT PLN.

[175] Sloss, L. (2009). Legislation in the European Union and the impact on existing plants, IEA Clean Coal Center. London, UK.
[176] Copley, C. (2015). 'Germany sets very high bar for fracking ', Reuters. Berlin, Germany.
[177] The Differ Group (2012). The Indonesian electricity system - a brief overview. Oslo, Norway.
[178] Sakya, I. (2012). Electricity Power Development in Indonesia, PT PLN. Jakarta, Indonesia.

Indonesia's power generation is expected to grow 9% through to 2019, leading economic growth of 6%. By the end of 2011 Indonesia had achieved an electrification rate of 74%, with 85% of the power coming from the state-run company PLN. Renewable and non-renewable off-grid power also provides electricity to approximately 2% of the population. Growth in renewable power generation through 2020 for southeast Asia is shown in Table 17.

***Table 17:** Renewable power growth in Southeast Asia to 2020*[179]

| Source | CAGR |
|---|---|
| Hydro | 1.1% |
| Geothermal | 5.1% |
| Bioenergy | 12% |
| Wind/Solar | 29% |

Among southeast Asian countries, Indonesia has notable geothermal and hydro power resources, and marginal wind resources. Renewable energy is expected to grow from 11% of all grid-connected power generation in 2011 to 19% in 2020. Coal power generation in the same period is expected to grow from 90 TWh to 233 TWh, driven by economic growth and displacing diesel power.

Over half of the investment in new generation assets in Indonesia by 2020 is expected to be provided by independent power producers. The PLN has a regulated monopoly on the transmission and distribution of electricity, with the right-of-first-refusal on the sale of electricity as well. The PLN is obligated to purchase power on feed-in-tariffs which differ according to technology and region, the maximum of which is US$0.30 for solar PV[180]. While the Indonesian government has been reducing subsidies for liquid fuels, the operating budget of the PLN receives direct support from the Ministry of Finance, amounting to a subsidy of 40% of the value of a kWh.

While coal power capacity is expected to grow in Indonesia, PLN has prioritised high-efficiency boilers for its planned generating capacity increases. 2GW of supercritical coal-fired generating capacity were expected for completion before 2015, and 11GW of ultra-supercritical coal-fired generating capacity are expected before 2020[181]. PLN's fleet currently includes 18GW of subcritical coal-fired generating capacity, one third of which burns lignite, the other two sub-bituminous coal.

The IEA has drawn attention to the growing reluctance of international financial institutions to finance coal-fired power stations (e.g. the World Bank, the US Treasury[182]). Independent power producers are expected to provide over half of the generation additions to 2020, but Indonesia may have difficulty attracting foreign investment to finance these additions. The shortfall may be made up by investment from China.

The IEA estimates that under a variety of pricing scenarios, combined cycle gas turbines in southeast Asia are unlikely to be competitive with supercritical coal-fired power.

[179] IEA (2015). Southeast Asia Energy Outlook 2015. Paris, France.
[180] Halstead, M., Mikunda, T., & Cameron, L. (2014). Policy Brief: Indonesian Feed-in-Tariffs, MitigationMomentum. Amsterdam, Netherlands.
[181] Sakya, I. (2013). Current Status and Future Development of Coal Thermal Power Plant in Indonesia, PT PLN. Tokyo, Japan.
[182] US Department of the Treasury (2013). 'U.S. Takes A Significant Step Toward A Clean Energy Future', Press Center. Washington, US.

### 4.4.2 Environmental Regulations

Businesses wanting to conduct activities which will impact the environment in Indonesia must conduct an environmental impact assessment (ADMAL) and an environmental management and monitoring plan (UKL-UPL) to receive an environmental licence from the Ministry of Environment[183]. In order to receive a licence, funds to guarantee environmental remediation must be paid to the ministry. The Ministry of Environment and subsidiary regional and local authorities are poorly coordinated and lack the resources to perform their current functions. The ministry relies on companies to self-report their compliance, and even under self-reporting, less than half of the companies comply with air, water, and land pollution regulations[184].

Businesses wanting to mine coal or minerals may obtain a (special) mining business permit (IUP(K)) for either exploration or operation from the Ministry of Energy and Mineral Resources. From 2012 to 2015 the coal and mining industry have been subject to a series of reforms, see a summary by Ashurst and Oentoeng Suria & Partners[185]. Mining companies have been given legal limits to foreign ownership and progressive divestment requirements through operational life. An export ban has been imposed on raw materials, requiring in-country processing and upgrading to stimulate Indonesian development. For coal this restriction may manifest itself in calorific upgrading but the details are as yet uncertain. Finally, a cap on total coal exports has been imposed.

Indonesia is well endowed with renewable water resources, having the fifth most renewable fresh water per capita in the world[186]. However highly populated areas of Java face water shortages in the dry seasons. Water scarcity is most acute on the island of Java, where 60% of Indonesia's population consumes 50% of all irrigation water. By 2020, the islands of Java, Bali, and Nusa Tenggara will all have dry season deficits.

Water planning is administered by the Ministry of Public Works. Industrial water excluding agriculture accounted for 24.6km$^3$ in 2005, approximately 5% of all of Indonesia's water use[187]. In February 2015, Indonesia's Constitutional Court overturned legislation which gave private interests powerful access rights to water resources[188].

## 4.5 India

### 4.5.1 Climate Change and Energy Policy

India is a large producer, importer, and consumer of coal. The Ministry of Power summarises the state of energy development in India[189]. In 2015, 24% of India's population did not have basic access to electricity[190], and those that did were subject to capacity shortfalls. India has aggressive plans for renewable energy deployment but currently plans for coal-fired power to support much of its ongoing growth. India is targeting a large increase in coal electricity generation[191], but is hindered by high transmission and distribution losses (20% to 30%), power theft, and coal shortages.

[183] World Services Group (2012). New Regulation on Environmental Licenses in Indonesia. http://www.worldservicesgroup.com/publications.asp?action=article&artid=4501.

[184] Li, W. & Michalak, K. (2008). Environmental Compliance and Enforcement in Indonesia, Asian Environmental Compliance and Enforcement Network. Bangkok, Thailand.

[185] Prior, S. & Riffdann, R. (2014). Indonesian Mining Law Update, Ashurst LLP and Oentoeng Suria & Partners LLP. Singapore and Jakarta, Indonesia.

[186] Hadipuro, W. (2010). 'Indonesia's Water Supply Regulatory Framework: Between Commercialisation and Public Service?', Water Alternatives, 3:475-491.

[187] Knoema (2015). World Data Atlas, Indonesia – Industrial Water Withdrawal, http://knoema.com/atlas/Indonesia/topics/Water/Water-Withdrawal/Industrial-water-withdrawal.

[188] Sundaryani, F. (2015). 'Court bans monopoly on water resources', Jakarta Post. Jakarta, Indonesia.

[189] Ministry of Power (2015). Power Sector – At a glance, http://powermin.nic.in/power-sector-glance-all-india. New Delhi, India.

[190] Australian Government (2015). Op. Cit.

[191] Das, K. (2015). 'India aims for big coal output boost next fiscal year', Reuters. New Delhi, India.

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In June 2008, India's government released the first National Action Plan on Climate Change. The plan detailed eight 'missions' which would form the core of India's response to climate change, ranging from renewable energy to the built environment[192]. The Jawaharlal Nehru National Solar Mission was launched in January 2010 to deploy solar power across India. The mission supports long-term policy, domestic production, large-scale installations, and research and development to achieve 20GW of installed capacity by 2022 and grid parity in the same year[193]. In the 2015-16 Union budget, the 2022 target for solar power was increased to 100GW as well at 60GW of wind power and 10GW of other renewables[194]. The Climate Policy Initiative[195] estimates that onshore wind power has already reached grid parity with Indian coal-fired power, and solar power will reach grid parity by 2019.

India currently has 173GW of coal-fired and 24GW of gas-fired power capacity[196]. It still has an overall deficit of power generation, although that deficit has fallen to less than 5% since 2013. India currently has 36GW of renewable power capacity, of which 24GW are wind-generated and 4GW by solar. In their INDC, India projects that 40% of its power will be derived from non-fossil sources by 2040, and commits to shrinking emissions intensity per unit of GDP by 33% to 35% by 2030[197].

The IEA projects that coal-fired power will be critical for India's endeavours to provide electricity for its population and meet growing demand[198]. In 2015, 113GW of coal-fired generation capacity were in construction or planned. Approximately half of all capacity additions before 2017 are expected to employ supercritical combustion, after which it becomes mandatory. Supercritical combustion requires high-calorific value, low-ash coal, while Indian reserves are mostly low-quality, high-ash. India would have to rely on imports to provide this coal despite ambitious domestic production programmes targeting self-sufficiency[199].

Despite a strong outlook at the beginning of the decade, India's total primary energy demand for natural gas has grown slowly, from 8% in 2008 to 8.7% in 2012[200]. The country faces an ongoing deficit of natural gas, with domestic production too low and LNG import prices too high for end-users. Four LNG regasification terminals are currently on-stream, with another four in construction or planning[201], but gas use will remain limited by domestic distribution infrastructure. Market prices and recently-revised state production prices are too high to allow gas-fired power to compete with coal-fired power.

### *4.5.2 Environmental Regulations*

The Environmental Protection Act 1986 gives the government of India broad scope to protect the environment and acts as an umbrella for issue-specific legislation on water, air, forests, wildlife, and biodiversity protection. The Ministry of Environment, Forest and Climate Change issues environmental clearances based on Environmental Impact Assessments conducted according to regulations issued under the Environmental Protection Act. Like other emerging economies, India has challenges enforcing its environmental protections, caused by a lack of resources, inappropriate legal structures, and corrupt reporting[202].

[192] PEW Center (2008). National Action Plan on Climate Change, Government of India. Arlington, US.

[193] Ministry of New and Renewable Energy (2014). JNN Solar Mission. http://www.mnre.gov.in/solar-mission/jnnsm/introduction-2/.

[194] Nampoothiri, M. (2015). 'Union Budget 2015 - Highlights for the Indian Solar Sector', Intel Solar India.

[195] Shrimali, G., Srinivasan, S., Goel, S., et al. (2015). Reaching India's Renewable Energy Targets Cost-Effectively, CPI and Bharti Insistute of Public Policy. Mohali, India.

[196] Ministry of Power (2015). Power Sector at a Glance ALL INDIA. http://powermin.nic.in/power-sector-glance-all-india

[197] Government of India (2015). India's Intended Nationally Determined Contribution. New Delhi.

[198] IEA (2015). WEO 2015. Op. Cit.

[199] Australian Government (2015). Op. Cit.

[200] EY (2014). Natural gas pricing in India. New Delhi, India.

[201] Global LNG Ltd (2015). Op. Cit.

[202] OECD (2006). Environmental Compliance and Enforcement in India: Rapid Assessment. Hanoi, Vietnam.

Water resources in India are governed by a patchwork of legislation and regulations, some issued by the Ministry of Water Resources, River Development & Ganga Rejuvenation, and others by state and local governments[203]. Industries in India draw water from both ground and surface sources, but these two sources have different legal interpretations, further exacerbating resource mismanagement[204 205]. 89% of all water use is for irrigation purposes; only 4% of water is used by industry[206]. Indian coal will need to be washed to upgrade it to the quality required for supercritical combustion, adding significantly to the water consumption of the fuel[207].

In April 2015, the Ministry of Environment, Forestry, and Climate Change proposed new regulations under the Environment Protection Act. These require cooling technology upgrades and water intake limits, and proposes $SO_2$, $NO_x$, and Hg limits in India for the first time[208].

### *4.5.3 CPT Developments*

Several less-developed projects are being considered[209]. A 2015 study showed that the country's commercial energy requirement will increase four to five times by 2032, electricity generation requirements would increase six to seven times, and oil demand would increase three to six times from current levels. UCG was put forward as a potential solution to projected growth in energy demand, as it would allegedly allow inaccessible and uneconomical coal reserves to be utilised. India has almost 300,000 billion tonnes of geological reserves of coal – but over 120,000 billion tonnes of these are deeper than 300 metres. It has been argued that UGC has the potential to bring these reserves into service[210]. Coal India Limited is proposing UCG plants for Katha (Jharkhand) and Thesgora (Madya Pradesh) area[211]. Additional UCG pilot projects in West Bengal and Rajasthan have been initiated by the Oil and Natural Gas Corporation Ltd (ONGC) and the Gas Authority of Indian Ltd.[212]

## 4.6 Japan

### *4.6.1 Climate Change and Energy Policy*

Japan is the world's third-largest economy and relies almost exclusively on imported fuel. Japan has been the world's largest importer of LNG since the 1990s[213], and is second only to China in coal imports, with no domestic production.

On the March 11th, 2011, Tohoku earthquake and tsunami occurred off the Eastern coast of Japan severely damaging the reactors of Fukushima Daiichi Nuclear Power Plant. The tsunami destroyed back-up generators for cooling equipment, and nuclear meltdowns occurred in the worst nuclear disaster since Chernobyl in 1986. In response, the government suspended 26GW of Japan's 49GW of nuclear reactors, a decision which has had a profound impact on the development of Japan's energy mix[214].

[203] Cullet, P. (2007). Water Law in India, International Environmental Law Research Center. Geneva, Switzerland.

[204] Preveen, S., Sen, R., & Ghosh, M. (2012). India's Deepening Water Crisis? Columbia Water Center, Columbia University. New York, US.

[205] Aguilar, D. (2011). Groundwater Reform in India: An Equity and Sustainability Dilemma, Texas International Law Journal 46:623-653.

[206] KPMG (2010). Water sector in India: Overview and focus areas for the future. Delhi, India.

[207] IEA (2015). WEO 2015. Op. Cit.

[208] Ministry of Environment, Forestry, and Climate Change (2015). Environment (Protection) Ammendment Rules, 2015. New Delhi, India.

[209] Perineau (2013). Op. Cit.

[210] Khadse, A. (2015) 'Resources and Economic Analyses of Underground Coal Gasification in India', Fuel 142: 121–128.

[211] Future Market Insights (FMI) (2015). Underground Coal Gasification Market: Asia-Pacific Industry Analysis and Opportunity Assessment 2014-2020. Pune, India.

[212] Khadse, A., Qayyumi, M., Mahajani, S., et al. (2007). 'Underground Coal Gasification: A New Clean Coal Utilization Technique for India', Energy 32: 2061-2071.

[213] International Gas Union (2014). World LNG Report – 2014 Edition. Vevey, Switzerland.

[214] Berraho, D. (2012). Options for the Japanese electricity mix by 2050, MSc Thesis, KTH School of Industrial Engineering and Management. Stockholm, Sweden.

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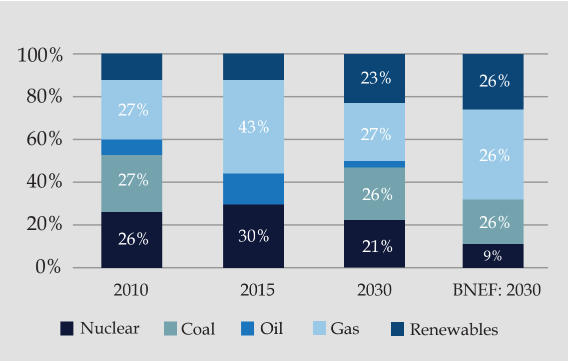
***Figure 21:** Japanese generating mix*[215]




Japanese utilities turned to fossil fuels to make up for the generation shortfall. The transition caused a jump in the Japanese retail price of electricity – a 25% and 40% increase over 2010 for residential and industrial prices respectively[216]. In response to the nuclear accident, LNG imports grew 24% between 2010 and 2012. Asian LNG prices rose over 50%, falling only recently with the drop in oil price[217].

In 2012, Japan introduced a generous feed-in-tariff scheme which, combined with high retail prices, led to a rapid expansion of PV capacity, reaching over 24GW of solar capacity by mid-2015, up from 5GW before the FIT scheme started[218]. The subsidy was reduced gradually and in 2014 the government indicated that it would begin to re-open nuclear power stations[219]. Japan's solar growth finally slowed in Q2 2015, however it will remain one of the largest PV markets in the world[220]. Japan's current generating mix and the government's proposed future generating mix are shown in Figure 21. BNEF projects nuclear generation will not recover to the extent the government predicts, rather that the shortfall will be provided by gas[221].

In its INDC, Japan has committed to reducing greenhouse gas emissions by 25.4% below 2005 levels by 2030[222]. Japan's GHG emissions in 2013 were 1408 $MtCO_2e$, up from 1304 $MtCO_2e$ in 2010 largely due to a re-carbonisation of energy in the aftermath of the Fukushima Daiichi disaster[223]. Japan also has two regional cap-and-trade systems, in Tokyo and Saitama[224], and a carbon tax on liquid fuels, LPG, LNG, and coal[225].

### *4.6.2 Environmental Regulations*

Japan has a robust framework of environmental law, regulations, and permitting[226]. The Basic Environmental Law of 1993 established Japan in a modern era of environmental management, building on earlier laws for pollution control and nature conservation. The Environmental Impact Assessment Law requires large projects including power stations to conduct an extensive environmental impact assessment prior to construction consent.

The Water Pollution Control Law protects all Japanese freshwater resources, regulating industrial effluents either by concentration or volume. The Air Pollution Control Law established controls on conventional air pollutants including $SO_2$, $NO_x$, and PM. Japan has taken strong measures to control

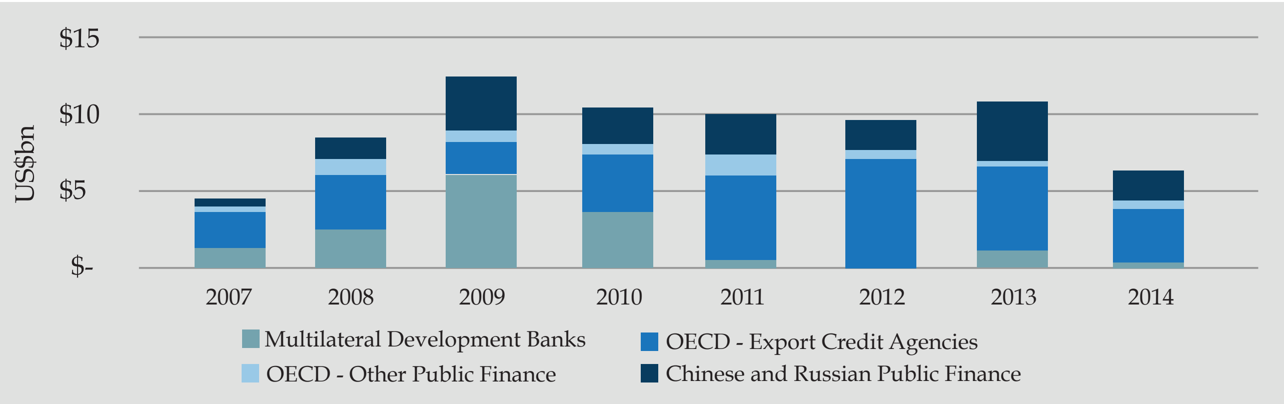
[215] Iwata, M. & Hoenig, H. (2015). 'Japan Struggles to Find Balanced Energy Strategy', Wall Street Journal. Tokyo, Japan.
[216] Jiji Press (2015) 'Nuclear power plant restarts part of wider plan to meet 2030 'best energy mix', The Japan Times.
[217] Bradley, S. & Zaretskaya, V. (2015). 'Natural gas prices in Asia mainly linked to crude oil, but use of spot indexes increases', EIA Today in Energy. Washington, US.
[218] Tsukimori, O. (2015). 'Solar power supplies 10 percent of Japan peak summer power: Asahi', Reuters. Tokyo, Japan.
[219] Topham, J. & Sheldrick A. (2014). 'Future grows darker for solar energy growth in Japan', Reuters. Tokyo, Japan.
[220] Watanabi, C. (2015). 'Solar Shipments in Japan Drop First Time Since 2012 Incentives', Bloomberg.
[221] Izadi-Najafabadi, A. (2015). 'Japan's likely 2030 energy mix: more gas and solar', BNEF.
[222] Government of Japan (2015). Submission of Japan's INDC. Tokyo, Japan.
[223] Ministry of the Environment (2015). National Greenhouse Gas Inventory Report of Japan, Greenhouse Gas Inventory Office of Japan. Tokyo, Japan.
[224] The World Bank (2013). 'Tokyo's Emissions Trading System', Directions in Urban Development, June.
[225] IEA (2015). WEO 2015. Op. Cit.
[226] For a summary see Ozawa, H. & Umeda, S. (2015). 'Environmental law and practice in Japan: overview', Thomson Reuters. Tokyo, Japan.

conventional air pollutants since the 1970s[227]. With few indigenous mineral resources, remediation and extraction policies are a low priority in Japan.

### 4.6.3 Emerging Issues

*OECD Agrees to end export credit to coal-fired power*
In November 2015, OECD countries agreed to substantially restrict export credit finance for coal-fired power stations. Several international development banks, including the World Bank, the European Investment Bank, and the European Bank for Reconstruction and Development have already committed to restricting financing for low-efficiency, high-carbon power stations, typically power stations with emissions in excess of 500g/kWh., The Natural Resources Defence Council (NRDC) reports that export credit agencies of OECD countries have largely filled this gap[228], see Figure 22. The November agreement imposes a similar criteria on OECD export credit agencies.

***Figure 22:*** *International public finance of coal*[229]




Japan has provided more public coal investment than any other OECD nation. Japan, Korea, and Australia were the loudest voices of opposition to the US-led initiative to restrict public foreign coal financing[230].

## 4.7 Poland

### 4.7.1 Climate Change and Energy Policy

Poland is eighth in the world in production of coal and is a minor coal exporter. In its total primary energy, Poland is substantially dependent on oil and gas imports, 85% of which come from Russia. Electricity generation was liberalised in the 1990s with natural gas following in the 2010s, but competition has been difficult to establish[231]. Energy security remains one of Poland's top priorities, so it has remained dedicated to its indigenous coal energy resources. Greenpeace estimates that Poland spends €1.43bn/yr subsidising coal-fired power[232].

Poland has emissions and renewable energy obligations as a member of the EU, see Box 3. Under the Renewable Energy Directive, Poland must meet 15% of its energy needs with renewable sources by 2020[233]. In 2012, Poland met 11% of its energy needs with renewable sources. Renewable energy

[227] Maxwell, M. et al. (1978). 'Sulphur Oxides Control Technology in Japan', Interagency Task Force Report. Washington, US.

[228] Bast, E, Godinot, S., Kretzmann, S., et al. (2015). Under the Rug. Natural Resources Defense Counil (NRDC), Oil Change International, and World Wide Fund for Nature.

[229] Reproduced from NRDC (2015). Under the Rug. Op. Cit.

[230] Sink, J. & Nussbaum, A. (2015). 'In coal setback, rich nations agree to end export credits', Bloomberg.

[231] European Commission (2014). EU Energy Markets in 2014. Brussels, Belgium.

[232] Ogniewska, A. (2012). Subsidising the Past, Greenpeace. Warsaw, Poland.

[233] Ministry of Economy (2009). Energy Policy of Poland until 2030. Warsaw, Poland.

provided 10.7% of Poland's electricity, approximately half of which was biomass-fired power generation[234]. Almost 90% of all electricity in Poland is still provided by coal power. Poland plans to introduce nuclear (10%) and gas (10%) power and expand renewables (17%) by 2030 to increase its energy security and reduce carbon emissions[235]. The Emerging Markets Information Service (EMIS) estimates that renewable generation may provide 17% of Poland's electricity by 2020[236].

Poland faces a substantial infrastructure challenge. Over 40% of Poland's thermal generating plants are over 30 years old. LNG regasification and interconnectors will allow more competition in Polish energy markets. The LNG regasification plant under construction at Swinoujscie is expected to begin commercial imports in 2016[237]. A 1000MW interconnector with Lithuania is expected to be complete by the end of 2015[238]. The first of two nuclear power stations are expected to be operating by 2023[239].

The coal mining industry in Poland continues to face upheaval. Polish coal mining only began privatisation in 2009 when it joined the EU[240]. Poland's mines are not profitable and the wages and pensions of the miners are heavily subsidised by the government[241]. Despite Polish coal demand, competition with low-price imports is causing Polish production to fall.

Between 2011 and 2015, 70 wells were drilled in Poland for shale gas. Polish protestors took a strong stance against companies drilling and fracking despite enthusiasm from politicians about the prospect of energy supplies secure from Russia. Geological conditions and environmental approvals proved much more difficult than in the US and the falling price of oil hurt project outlooks. In June 2015 ConocoPhillips, the last IOC exploring for shale gas in Poland, announced it would be ceasing operations in Poland and no commercial production of shale gas has occurred[242].

### 4.7.2 Environmental Regulations

Poland is an EU member state and is required to harmonise its national legislation with directives from the EU, see Box 4. As a post-communist state heavily dependent on coal, Poland has been resistant to climate and other environmental policies which may be detrimental to its economy[243].

In 2012, Poland issued a Transitional National Plan which avoided imposing environmental penalties on its coal-fired power stations that should have begun in 2016. Poland now has until 2020 to comply with the EU Industrial Emissions Directive (2010/75/EU)[244].

### 4.7.3 Emerging Issues

*Water pricing*

There is speculation that the Ministry of the Environment will introduce an industrial water price. This would affect the profitability of Polish power stations which would need to pay for their water use.

[234] Ministerstwo Gospodarki (2012). Interim Report on progress in the promotion and use of energy from renewable sources in Poland in 2011–2012. Warsaw, Poland.

[235] The Economist, (2014). 'A different Energiewende', The Economist.

[236] EMIS (2014). Energy Sector Poland. London, UK.

[237] Strzelecki, M. (2015). 'Poland Opens LNG Terminal, Pledges to End Russian Dependence', Bloomberg.

[238] LitPol Link (2015). Progress of Work. http://www.litpol-link.com/about-the-project/progress-of-works/.

[239] Ministry of economy (2012). Diversification of energy sources in Poland: Nuclear energy option. Warsaw, Poland.

[240] The Economist (2015). 'Striking contrast', The Economist. Warsaw, Poland.

[241] Vorutnikov, V. (2014). 'Polish Coal Industry Faces Tough', CoalAge.

[242] Barteczko, A. (2015). 'Conoco the last global oil firm to quit Polish shale gas', Reuters. Warsaw, Poland.

[243] For a summary see Jankielewicz , K. (2015). 'Environmental law and practice in Poland: Overview', Thomson Reuters. London, UK.

[244] Easton, A, (2012). 'Poland defers emissions restrictions to 2020 from 2016', Platts. Warsaw, Poland.

*Political significance of coal mining subsidies*

The Polish government is attempting to restructure the Polish coal mining industry so it can continue to subsidise the sector, evading EU state aid rules (see Box 4). Polish coal mining unions continue to hold substantial political clout in the country despite Polish mines being economically uncompetitive[245]. The winner of the October 2015 election was the conservative Law and Justice Party, which campaigned on a Eurosceptic platform and support for the Polish coal industry[246].

# 4.8 South Africa

## 4.8.1 Climate Change and Energy Policy

South Africa is the world's sixth largest consumer of coal and the sixth largest exporter. 25% of South Africa's coal production is exported, 40% is used to produce electricity, and 25% for coal processing technologies. Electricity production in South Africa is dominated by the main public utility Eskom, which produces 95% of South Africa's power, 45% of all African power, and exports to Botswana, Lesotho, Mozambique, Namibia, Swaziland, Zambia and Zimbabwe[247]. While 85% of South Africans have grid access[248], Eskom's first new generation capacity in two decades just became active in 2015, and South Africa's population and industries remain subject to frequent rolling blackouts[249].

Since 2011, South Africa has committed to a 'peak, plateau, and decline' emissions curve, with emissions peaking between 398 and 614 MtCO2e between 2020 and 2025 and plateauing for up to ten years[250]. South Africa maintains this commitment in their INDC, despite their mitigation efforts falling short of a 'fair' allocation according to various studies[251].

In 2011, the South African government published an Integrated Resource Plan, which lays out policy objectives and activities for the long term, subject to regular review. Having had its first review in 2013, renewables are projected to take a more significant role in South Africa's capacity additions[252]. Following a short-lived feed-in-tariff system, the Department of Energy announced a new Renewable Energy Independent Power Procurement Program (REIPPP). Between 2011 and 2013, 64 projects were awarded for 3.9 GW generating capacity, mostly in wind (2.0 GW), solar PV (1.5 GW), and concentrated solar power (0.4 GW)[253]. Major utility Eskom is currently building 4.8GW of new coal capacity and returning-to-service another 3.7GW[254].

With few other indigenous power resources besides coal, South Africa made early use of coal processing technologies, especially to advance energy security interests during the apartheid era. Sasol, a large South African coal processing technology company uses coal and the Fischer-Tropsch process to produce liquid fuels and other chemicals from coal gasification[255]. Sasol's facility at Secunda can produce 150 bbl/day from coal and gas feedstocks, 21.7% of South Africa's total

[245] Oliver, C. & Foy, H. (2015). 'Poland to push EU on coal mine subsidies', Financial Times. Warsaw, Poland.
[246] Schveda, K. (2015). 'Poland lurches to the right: What does it mean for the climate?', Greenpeace Energy Desk. London, UK.
[247] Eskom (2015). Company Information. http://www.eskom.co.za/OurCompany/CompanyInformation/Pages/Company_Information.aspx.
[248] The World Bank (2015). Access to electricity - % of population. http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS
[249] Wexler, A. (2015). 'Power Outages Mar South Africa's Economic Expansion', Wall Street Journal. Brakpan, South Africa.
[250] Government of South Africa (2015). National Climate Change Response. Pretoria, South Africa.
[251] Government of South Africa (2015). South Africa's INDC. Pretoria, South Africa.
[252] South Africa Department of Energy (DOE) (2013). Integrated Resource Plan for Electricity, Update Report. Pretoria, South Africa.
[253] Eberhard, A., Kolker, J., & Leigland, J. (2014). South Africa's Renewable Energy IPP Procurement Program: Success Factors and Lessons, World Bank Group. Washington, US.
[254] Gross, C. (2012). Electricity Generation Options considered by Eskom, Eskom.
[255] South Africa Coal Roadmap (SACRM) (2011). Overview of the South Africa Coal Value Chain, Fossil Fuel Foundation. Sandton, South Africa.

production[256]. South Africa also has a large infrastructure of upgrade refineries which supply domestic demand from imported crude oil.

### 4.8.2 Environmental Regulations

South Africa has made significant progress in developing environmental protection laws and regulations, especially regarding biodiversity. Challenges remain for South Africa to embed principles of environmental stewardship across its wider government – both in the other services which regulate energy, mining, and infrastructure, and to disseminate responsibility appropriately to provincial and local authorities[257].

The country's current fleet of generating stations are not fitted with conventional air pollution control measures. In order to comply with the government's minimum emissions standards, these plants will need to be fitted with emissions control technology before 2020[258].

South Africa carries a large exposure to the physical risks of climate change. Increases in temperature and decreases in precipitation are expected to be particularly severe in southern Africa. Climate change will exacerbate existing human health and resource challenges which will delay or disrupt development and poverty alleviation[259].

### 4.8.3 CPT Developments

In South Africa, continued Sasol CTL operations are due to a number of factors: i) availability of cheap low-grade coal, ii) large capital investments in the sector, and iii) adequate economies of scale for producing feedstock for high value chemicals[260]. In 2013, Sasol revealed its new growth plans under 'Project 2050', where four new coal mining projects – Thubelisha, Impumelelo, Shondoni and Tweedraai— will be replacing old mining sites and expected to secure the required coal reserves till mid-century[261]. Sasol has also been actively pursuing international cooperation and investment opportunities across a range of countries, including Australia, Canada, China, India, Nigeria, Mozambique, Qatar, and Uzbekistan, where there are substantial deposits of low grade coal and potential for large-scale development[262].

Johannesburg-based South African company Sasol Ltd is an integrated energy and chemicals company, whose major shareholders include Allan Gray Investment Council, Coronation Fund Managers, Investec Asset Management, the South African Government Employees Pension Fund, and the Industrial Development Corporation of South Africa Limited (IDC)[263]. In recent years, Sasol has withdrawn from several joint-partnerships in China due to regulatory delays. Sasol was planning to invest US$10 billion on CTL plant together with Shenhua Ningxia Coal Industry, however the company cancelled the project after Chinese government failed to respond to an application in 2011[264]. A CTL joint venture between Sasol and Tata Group costing US$20bn and expected to produce 160,000 barrels of oil equivalent per day was proposed for the eastern state of Odisha in India[265]. In 2014, however, the project was cancelled by the Indian government due to delays[266].

[256] South Africa DOE (2013). Op. Cit.

[257] OECD (2013). OECD Environmental Performance Review – South Africa 2013. OECD Publishing.

[258] Stephen, C., Godana, P., Moganelwa, A. et al. (2014). Implementation of de-SOx technologies in an Eskom context & the Medupi FGD plant retorfit project, Eskom Holdins SOC

[259] Niang, I., Ruppel, O., Abdrabo, M., et al. (2014). 'WGII, Chapter 22: Africa', in IPCC, Fifth Assessment Report. Geneva, Switzerland.

[260] IEA Clean Coal Center (2009). Review of worldwide coal to liquids R, D, & D activities and the need for further initiatives within Europe. London, UK.

[261] Creamer, M. (2013). 'Sasol Mining's coal-to-liquids horizon extending to 2050', Mining Weekly.

[262] IEA Clean Coal Center (2009). Op. Cit.; Sasol Ltd (2015). Overview, http://www.sasol.com/about-sasol/company-profile/overview.

[263] Sasol Ltd (2015). Historical milestones. http://www.sasol.com/about-sasol/company-profile/historical-milestones.

[264] Marais, J. (2011). 'Sasol quits China coal-to-liquids plant as approval stalled', Bloomberg.

[265] Singh, R. (2013). 'Coal-to-Oil $20 billion projects said to stall: corporate India', Bloomberg.

[266] Business Standard Reporter (2014). 'Government cancels coal blocks of 8 companies', Business Standard. New Delhi, India.

### 4.8.4 Emerging Issues

*Proposed Carbon Tax*

The South African Government has proposed a carbon tax which will become active in 2017. The tax is planned to be US$8.50/t$CO_2$e and would increase 10% per year until 2019. The draft carbon tax bill was open for public comment until December 15, 2015[267].

*South African Mining Tax Reform*

In 2012, the government issued a report entitled 'State Intervention in the Minerals Sector' which proposed a number of tax reforms that would increase the state's benefits from mining activities[268]. The Davis Tax Committee is a committee of experts consulted for the alignment of South African tax proposals with overarching growth and development goals. Although the committee broadly recommended the status quo be maintained for mining taxes[269], this is likely to be an issue that will be revisited.

*Discard and Duff Coal*

As a result of coal beneficiation, it is estimated that South Africa discards 60Mt of degraded discard or 'duff' coal per year. An official survey in 2001 by the Department of Minerals and Energy estimated that over 1000Mt of discard coal exists in uncontrolled stockpiles around the country[270]. This coal presents immediate environment-related risks from spontaneous combustion and groundwater leaching, and long-term risks as a source of substantial carbon emissions. Remediation of these stockpiles may involve combusting the discard as fuel in modern boilers[271].

## 4.9 United Kingdom

### 4.9.1 Climate Change and Energy Policy

The United Kingdom is the world's fifth largest economy and the seventh largest importer of coal. In 2014, 24% of the UK's coal was produced domestically. Coal provided 36% of the UK's electricity in 2013, dropping to 30% in 2014[272] and 28% in the first three quarters of 2015[273].

The UK has a number of targets for energy- and economy-wide decarbonisation, set domestically and linked to EU targets (see Box 3). The UK's pioneering Climate Change Act 2008 established a legally-binding target of limiting emissions to 80% below 1990 levels by 2050. The Act established five-year carbon budgets to achieve interim progress. The fourth carbon budget targets a 35% reduction below 1990 levels by 2020[274]. The fifth carbon budget was published November 2015 and calls for a 57% cut in emissions by 2030[275].

[267] Deprtment of National Treasury (2015). 'Publication of the Draft Carbon Tax Bill for public comment', media statement. Pretoria, South Africa.

[268] PMG Asset Management (2013). Mining Taxation, the South African Context. Birmginham, UK.

[269] Ajam, T., Padia, N., et al. (2012). First interim report on mining, The Davis Tax Committee.

[270] Department of Minerals and Energy (2001). National inventory discard and duff coal. Pretoria, South Africa.

[271] Belaid, M., Falcon, R., Vainikka, P. et al. (2013). 'Potential and Technical basis for Utilising Coal Beneficiation Discards in Power Generation by Applying Circulating Fluidised Bed Boilers', ICEES, 2:260-265.

[272] DECC (2015). Digest of UK Energy Statistics (DUKES) 2015. London, UK.

[273] DECC (2015). Energy Trends December 2015. London, UK.

[274] The Committee on Climate Change (2015). Carbon budgets and targets. https://www.theccc.org.uk/tackling-climate-change/reducing-carbon-emissions/carbon-budgets-and-targets

[275] The Committee on Climate Change (2015). The fifth carbon budget – The next step towards a low-carbon economy, https://www.theccc.org.uk/publication/the-fifth-carbon-budget-the-next-step-towards-a-low-carbon-economy/

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Under the Renewable Energy Directive, the UK must achieve 15% of its total primary energy from renewable sources by 2020[276]. The UK has responded with policy support for the expansion of onshore and offshore wind and bioenergy, and domestic policy to achieve 116TWh of generation from renewable sources by 2020. In 2014, the UK generated approximately 65TWh of electricity from renewable sources and another 35GW of renewable electricity generation was given consent, with an additional 18GW in planning[277]. In spite of this, the UK remains at risk of missing its target, due to slow adoption of renewable heating and transport fuels.

In 2012 the UK began a process of electricity market reform (EMR)[278]. EMR established a number of policy directions for the UK in addressing the energy trilemma, including a carbon floor price, an emissions performance standard, a capacity market, and a contracts-for-difference (CfD) feed-in-tariff system.

The Big Six utilities in the UK have yet to feel the utility death spiral to the same extent as their German peers (or parent companies, as in the case of E.ON and npower (RWE))[279]. Distributed energy resources have yet to erode power loads to the same extent. However must-run renewables and increasing carbon prices further supressed coal asset utilisation rates, which dropped 7.8 percentage points in 2014 to 51.2%[280].

### 4.9.2 Environmental Regulations

The UK is an EU member state, with substantial environmental policy harmonised with broader EU environmental policy (see Box 4).

The last UK deep coal mine was closed on December 18, 2015[281]. UK coal mines have struggled for market share against low price imports. At the end of 2014, there were still 26 coal surface mines, producing 7.9Mt of coal per year in approximately equal portions in England, Wales, and Scotland. Of nine extension applications filed in 2014, only three were approved[282].

In early 2015, the parliaments of Scotland and Wales both passed moratoriums on hydraulic fracturing. Across the UK, challenges with infrastructure, environmental oversight and mineral rights, and local opposition have made shale gas exploration very difficult[283].

### 4.9.3 Emerging Issues

*UCG moratorium in Scotland*

In October 2015, the Scottish government passed a moratorium on UCG in Scotland. The ban is separate to an existing ban on hydraulic fracturing but both will require consultative processes and further health and environment impact studies before they can be lifted. Most affected is Cluff Natural Resources which had planned to use UCG to produce gas from the coalbeds beneath the Firth of Forth[284].

*Changes to the Climate Change Levy Exemption*

Changes to the Climate Change Levy were announced in July 2015. From August 2015, renewable energy suppliers would no longer be eligible for exemption from the climate change levy – a levy placed on all energy supplies with separate rates for electricity, gas, and solid and liquid fuels.

[276] DECC (2009). National Renewable Energy Action Plan for the United Kingdom. London, UK.

[277] Constable, J. & Moroney, L. (2014). An Analysis of Data from DECC's Renewable Energy Planning Database Overview, Renewable Energy Foundation. London, UK.

[278] UK DECC (2012). Electricity Market Reform: Policy Overview. London, UK.

[279] Friends of the Earth (2014). The big six on the run. London, UK.

[280] Costello, M. & Jamison, S. (2015). 'Is the utility death spiral inevitable for energy companies?', UtilityWeek.

[281] Macalister, T. (2015). 'Kellingley colliery closure: 'shabby end' for a once mighty industry', The Guardian.

[282] Planning Officers' Society (2014). Surface coal mining statistics 2014. Nottingham, UK.

[283] Stevens, P. (2013). Shale Gas in the United Kingdom, Chatham House. London, UK.

[284] Dickie, M. (2015). 'Scotland widens fracking moratorium', The Financial Times. Edinburgh, UK.

*Coal phase out by 2025*

On November 18, 2015, Amber Rudd, Secretary of State for Energy and Climate Change, delivered a major speech in which she articulated the government's priorities in addressing the energy trilemma. Among other things, she indicated that gas would be preferred to coal in the design of the capacity market; total phase-out of coal would be targeted for 2025; and auctions for additional offshore wind contracts would be subject to cost reduction targets[285].

*Bank of England Prudential Regulation Authority Climate Change Adaptation Report*

In April 2014, the Prudential Regulatory Authority (PRA) of the Bank of England accepted an invitation from the Department of Environment, Food and Rural Affairs (DEFRA) to examine the impact of climate change on the UK insurance sector. In late September 2015 the PRA published its draft response and found that the UK insurance sector is exposed to three forms of risk worthy of further consideration.[286]

- Physical risks: The direct risks from extreme weather and a changing climate, and also secondary indirect risks resulting from such events, such as supply chain disruptions and resource scarcity.
- Transition risks: The financial risks inherent in the transition to a low-carbon economy, such as the repricing of carbon-intensive assets under various changes to policy or substitute technologies.

Liability risks: Risks arising from the compensation of damages which may have occurred as a result of a failure to appropriately respond to climate change.

- See Box 5 for more details.

The UK is a leader in global finance and insurance. Changing perceptions of climate change risks within finance have impacts well beyond the UK's borders.

### Box 5: *Emerging climate change liabilities*

The PRA report found that company directors and fiduciaries (e.g. pension fund trustees) could be at risk from litigation as a result of the following actions (or inactions)[287],[288]:

- *Contributing to climate change*: companies that have contributed to climate change may be liable for the economic damages caused by climate change. Developments in the climate science underpinning attribution and the apportioning of responsibility mean that such cases may become possible.
- *Failing to manage climate risk*: company directors and fiduciaries may be held liable for not adequately managing or responding to climate risks.
- *Failing to disclose risks to shareholders and markets*: listed companies are required to disclose information, including on material risks, to capital markets. Companies that have failed to disclose material climate risks could have cases brought against them by investors and regulators.

[285] UK Government (2015). Amber Rudd's speech on a new direction for energy policy. https://www.gov.uk/government/speeches/amber-rudds-speech-on-a-new-direction-for-uk-energy-policy.

[286] Bank of England (2015). The impact of climate change on the UK insurance sector, Prudential Regulatory Authority (PRA). London, UK.

[287] Bank of England (2015). Op. Cit.

[288] See also Barker, S. (2013). Directors' duties in the anthropocene, UNPRI.

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# 4.10 United States

## *4.10.1 Climate Change and Energy Policy*

The United States is second in the world in coal production and consumption, and is also a major net exporter. A coordinated response to climate change has been slow to develop in the United States, and instead a patchwork of federal, state, and municipal policy has developed to address both greenhouse gas emissions and to incentivise renewable energy.

Policy support for renewable energy is provided by a mixture of state and federal regulatory policies, fiscal incentives, and grants and public investment[289]. Twenty-nine states have a Renewables Portfolio Standards (RPS) or similar, which require investor-owned utilities (IOUs) to generate or purchase a certain amount of their electricity from renewable sources. The legislation often also includes multipliers and/or targets for certain renewable sources, targets for distributed generation, provisions for utility size, and caps on overall spending[290]. An additional eight states also have voluntary Renewables Portfolio Goals.

In August 2015, the federal government released the Clean Power Plan, to be enacted by the Environment Protection Agency under the Clean Air Act[291]. The plan is the most substantial effort ever undertaken by the United States federal government to address climate change. Under the plan, states are given emission intensity and state-wide emissions targets, and states must meet one of the targets in whichever way it chooses. The EPA suggests three building blocks for a state-level policy, including improving the efficiency of coal-fired power stations, and replacing power stations with natural gas-fired power stations and renewables. The EPA has provided states with an example emissions-trading model, which it will enforce if the states fail to provide their own plans[292]. In aggregate the Clean Power Plan will reduce emissions by 32% below 2005 levels by 2030.

The Clean Power Plan follows earlier regional cap-and-trade initiatives in the United States: the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI). The RGGI is a cap-and-trade plan of nine north-east US States operating since 2008. Under the RGGI, fossil fuel power stations must surrender emissions certificates to cover the extent of their emissions. The states auction the certificates and allocate the proceeds towards energy efficiency and renewable energy incentives[293]. The WCI began with wide support but by the time of its adoption membership had declined to California and the Canadian provinces of Québec and Ontario. The WCI envisions multi-sector participation and currently covers electricity utilities and large industrial emitters. California held its first auction of allowances in January 2012[294].

The growth of unconventional oil and gas substantially lowered gas prices in the US and oil prices around the world. US utilities are rapidly diverting capital into gas-fired power stations rather than coal. Table 18 shows a number of growth projections to 2020, all of which were made before the final announcement of the Clean Power Plan.

[289] REN21 (2015). Renewables 2015 Global Status Report. Paris, France.

[290] Durkay, J. (2015). State renewable portfolio standards and goals, National Conference of State Legislature. http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx#az.

[291] US EPA (2015). Overview of the Clean Power Plan, in The Clean Power Plan. Washington, US.

[292] US EPA (2015). Proposed Federal Plan and Proposed Model Rules, in The Clean Power Plan. Washington, US.

[293] Regional Greenhouse Gas Initiative (2015). Programme Overview. http://www.rggi.org/design/overview.

[294] California Air Resources Board (2011). Overview of ARB Emissions Trading Program. Sacramento, US.

***Table 18:** US electricity source CAGR projections to 2020*[295,296]

| Generation Growth to 2020 | EIA: Reference Case | EIA: High Oil and Gas Resource | BNEF Medium-Term Outlook |
|---|---|---|---|
| Coal | 0.9% | -1.6% | -2.2% |
| Gas | -1.0% | 3.0% | 2.9% |
| Renewables | 3.6% | 3.6% | 7.3% |

Before the shale gas revolution, the US was poised to become a large LNG importer. Thirteen planned regasification terminals have been cancelled, while four liquefaction plants are now in construction with another 15 in planning or proposal stages[297]. The Brookings Institute warns that with a low oil price, falling demand, and strong Asian competition, none of the proposed US liquefaction plants will reach completion[298]. Some of the terminals are being converted to export or bi-directional terminals, allowing US shale gas to access higher priced markets in Europe and Asia[299,300].

### 4.10.2 Environmental Regulations

The United States Environmental Protection Agency (EPA) was created in the 1970s, consolidating many previous federal environmental agencies into one organisation. The EPA is responsible for the protection of human health and the environment and is empowered to write regulations and enforce compliance across the US.

The Clean Air Act (1963) empowers the EPA to make and enforce regulations to control air pollution. The act has been used effectively to manage ozone depleting substances and motor vehicle emissions, among other things. In the 1990s, over concerns of acid rain, the EPA began regulation of SO2 emissions from large power stations, implementing a cap-and-trade emissions trading scheme. In 2014, the IEA reported that 69% of US coal-fired power stations met their conventional air pollution targets using abatement technology, 10% were planned to retire, and 20% were undecided whether to retrofit to ensure compliance or plan retirement[301].

The Clean Water Act (1977) empowers the EPA to make regulations which manage and mitigate pollution of US water resources. It empowers the EPA to grant or withhold permits for a number of environmentally invasive activities. In August 2014, the EPA issued regulations regarding cooling water intake for manufacturing and power generation industries. The regulations establish a wide range of criteria to protect local environments against heat, chemical, and resource stress from cooling water effluent[302].

US states have different requirements for remediation bonding. The US coal industry is regulated by the Surface Mine Control and Reclamation Act (SMCRA), however states may enact their own regulations provided they meet or exceed the stringency of the SMCRA. The SMCRA expressly allows self-bonding by coal companies, but some states may disallow this practice in their own jurisdictions. Self-bonded coal miners are becoming liabilities for US states who may be obligated to remediate environmental damage if the company goes bankrupt, see discussion below[303].

[295] EIA (2015). Annual outlook with projections to 2040. Washington, US.
[296] Annex, M. (2015). Medium-term outlook for US power, BNEF White Paper.
[297] Global LNG Ltd (2015). Op. Cit.
[298] Boersma, T., Ebinger, C., & Greenly, H. (2015). An assessment of US natural gas exports, The Brookings Institute. Washington, US.
[299] Armistead, T. (2015). 'LNG Ready for Export', Energybiz, Jan/Feb 2012.
[300] Richards, B. (2012). 'The Future of LNG', Oil and Gas Financial Journal.
[301] EIA (2014). Electricity – Detailed State Data. http://www.eia.gov/electricity/data/state/.
[302] US EPA (2015). 'National Pollutant Discharge Elimination System—Final Regulations for Cooling Water Intake Structures at Existing Facilities', Federal Register 158:48300-48439.
[303] Miller, G. (2005). Financial Assurance for Mine Closure and Reclamation, International Council on Mining and Metals. Ottawa, Canada.

### *4.10.3 CPT Developments*

In the US, although there is no CTL production unit in operation, a significant number of projects in Wyoming, Illinois, Arkansas, Indiana, Kentucky, Mississippi, Missouri, Ohio and West Virginia are being considered.[304] In 2010, 12 CTL projects were proposed or under development, which would increase production from nothing to 250,000 barrels per day in 2035.[305] The projected cost of these projects range from US$2 billion to $7billion, which is being financed by major oil companies, such as Shell, and other large companies like Rentech (the Natchez Project in Mississippi), Baard (CTL project in Ohio), and DKRW (CTL facility in Wyoming)[306].

In the US, the Great Plains Synfuels Plant in North Dakota was funded by government subsidies and bankruptcy procedures, which covered the capital cost of the project[307]. In fact, a partnership of five energy companies behind the project defaulted on a US$1.54 billion loan provided by the US DOE in 1985[308]. Despite the default, DOE continued operating the plant through the ANG Coal Gasification Company (ANG), and then sold the project to two subsidiaries of Basin Electric Power Cooperative in 1989.

### *4.10.4 Emerging Issues*

*RPS repeal*

Despite wide progress in the adoption of RPSs, states have recently been repealing or reducing their commitments to sustainable power generation. Ohio froze its RPS goals in May 2014. In February 2015, West Virginia repealed its RPS outright. In May 2015, Kansas reduced its portfolio standard from mandatory to voluntary. North Carolina is also considering a freeze of its RPS, and the legislation is currently under review by the North Carolinian senate[309].

The decline of coal and the utility death spiral (see Box 2) have given fresh incentives to companies to lobby for the repeal of RPSs. The rapid deployment and growing cost-competitiveness of renewables have also fed arguments that renewables deployment is approaching self-sufficiency. Repeal lobbyists observe that electricity prices are higher in states with active RPSs and argue that it is the high cost of renewables that burdens consumers in these states.

*Emerging Liability concerns*

Peabody Energy Corp and Exxon Mobil Corp Public Disclosure of Risk

In November 2015, the New York State Office of the Attorney General (NYAG) released the result of its investigation into Peabody Energy Corp.'s public disclosure of climate change risk under the Martin Act, which protects shareholders and the public from fraudulent disclosures. The NYAG found[310] that Peabody's annual reporting between 2011 and 2014 had:

i) claimed ignorance of the impact of climate change policy on its business activities when it had in fact conducted analysis of the impact of a carbon tax on some of its business activities
ii) misrepresented the IEA's CPS as the central or only projection of global energy demand and supply, when in fact the IEA NPS is the IEA's central scenario and both the NPS and 450S project weaker outlooks for future coal demand.

[304] IEA Clean Coal Center (2009). Review of worldwide coal to liquids R, D, & D activities and the need for further initiatives within Europe. London, UK.
[305] David Gardiner & Associates LLC (2010). Investor risks from development of oil shale and coal-to-liquids, CERES. Washington, US.
[306] Ibid.
[307] Yang, C. & Jackson, R. (2013). 'China's Synthetic Natural Gas Revolution', Nature Climate Change 3: 852–854.
[308] United States General Accounting Office (GAO) (1989). Synthetic Fuels: An Overview of DOE's Ownership and Divestiture of the Great Plains Project. Washington, US.
[309] Dyson, D. & Glendening, J. (2015). 'States are unplugging their renewable energy mandates', Wall Street Journal.
[310] New York Attorney General (2015). 'A.G. Scheiderman Secures Unprecedented Agreement with Peabody Energy ', Press Release. New York, US.

Peabody and the NYAG reached a settlement via an 'assurance of discontinuance' for Peabody's 2015 filing[311]. Peabody's settlement reflects a failure to disclose climate change risk exposure, see Box 5. In November 2015, the NYAG issued a similar subpoena to Exxon Mobil Corp[312]. Exxon is alleged to have misrepresented climate change risks to its shareholders and the public.

*Changing ability to self-bond for remediation liability*

The Surface Mining Control and Reclamation Act 1974 requires coal mining companies to post bonds to guarantee their ability to reclaim disrupted land at the conclusion of mining activities. Companies meeting certain financial criteria have been able to self-guarantee their ability to reclaim disrupted land[313]. With years of consecutive losses and falling share prices, state regulators are beginning to investigate US coal miners that self-guarantee their remediation liability[314].

In May 2015, the Wyoming Department of Environmental Quality told Alpha Natural Resources Inc that they no longer qualify for self-bonding[315]. The department is also investigating Arch Coal and Peabody Energy. Controversy surrounds the practice of the miners to self-bond by affiliate or subsidiary companies and the book vs. market value of shareholder equity on the company's balance sheet[316]. Alpha Natural Resources filed for bankruptcy in August 2015 with liabilities 2.5 times greater than its asset base[317].

*Shareholder Responsibility to Bear Regulatory Costs*

Evidence from the past suggests that shareholders that own generation capacity in competitive markets will be expected to bear the costs of regulatory changes on coal-fired power stations. For those power stations in rate-of-return regulated markets, it is also likely that shareholders will have to bear at least some costs of regulatory changes; however, both literature and precedent suggest that there may be an argument for passing some costs of stranded assets to taxpayers.

Federal Energy Regulatory Commission (FERC) Order 888 introduced competition into power generation in the US electricity industry. Electric utilities and shareholders argued that they made investments because of specific government policies or because of incentives encouraging such investments. With the introduction of competition, many assets, including power stations, were assumed to become stranded costs (the difference between the net book value of a generating plant limited to government-specified returns under rate-of-return regulation and the market value of that plant if it were required to sell its output in a competitive market) as competition drove electricity rates down and lower cost power stations entered the market[318]. This was acknowledged in 1994 by the FERC, which agreed that stranded costs should be compensated if they were verifiable and directly related to the government's introduction of competition[319].

311 Peabody Energy Corp. (2015). Assurance of Discontinuance. New York, US.

312 Rosenberg, M. (2015). 'NY attorney general wields powerful weapon in Exxon climate case', Reuters. New York, US.

313 Miller, G. (2005). Op. Cit.

314 Bonogofsky, A. Jahshan, A., Yu, H., et al. (2015). Undermined Promise II. National Wildlife Federation, NRDC, WORC.

315 Jarzemsky, M. (2015). 'Alpha Natural Resources Creditors Ready for Possible Restructuring Talks', Wall Street Journal.

316 Williams-Derry, C. (2015). 'How coal "self-bonding" puts the public at risk', Sightline Institute.

317 Paterson, L. (2015). 'In Coal Country, No Cash in Hand for Billions in Cleanup', Inside Energy.

318 Joskow, P. (2000). 'Deregulation and Regulatory Reform in the U.S. Electric Power Sector', in Deregulation of Network Industries: What's Next?, The Brookings Institute. Washington, US.

319 Martín, A. (2000). Stranded Costs: An Overview, Center for Monetary and Financial Studies. Madrid, Spain.

Since Order 888, deregulation has taken place in seven of ten regional US markets[320]. Taxpayers paid full compensation to firms for the introduction of competition into power generation; however, compensation was limited to stranded assets that were the direct result of state or federal government policies[321].

Nevertheless, there are strong arguments against taxpayers compensating shareholders, so shareholders should expect to bear at least some costs of clearly anticipatable regulatory changes with the potential to strand assets. The delay between the global recognition of the need to reduce GHG emissions (taking the 1992 UN Conference on Environment and Development as a starting point), and the potential realisation of this goal will have provided investors ample time for 'the realisation of value from previous investments and the opportunity to alter new investments'.[322]

[320] Woo, C. et al. (2003). 'Stranded Cost Recovery in Electricity Market Reforms in the US', Energy 28:1–14.
[321] Brennan, T. & Boyd, J. (1996). Stranded Costs, Takings, and the Law and Economics of Implicit Contracts, Resources for the Future. Washington, US.
[322] Burtraw, D. & Palmer, K. (2008). 'Compensation Rules for Climate Policy in the Electricity Sector', Journal of Policy Analysis and Management 27:819–847.

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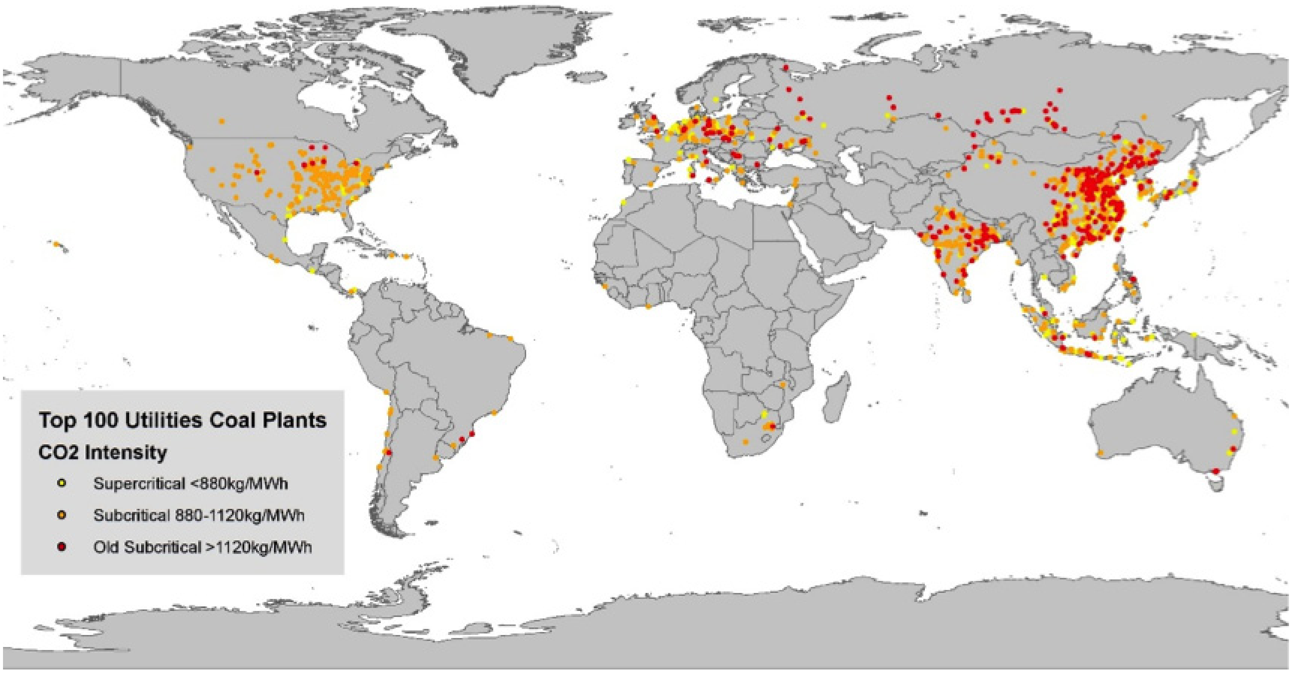
# 5 Coal-Fired Power Utilities

Coal-fired power utilities are examined for their exposure to environment-related risks. We examine the capital expenditure plans, ownership structures, and debt obligations of coal-fired power utilities. We then develop and test a number of hypotheses pertaining to the environment-related risk exposure of these companies. With these hypotheses, we develop an opinion on how environment-related risks could alter companies' capital plans and debt position. Figure 23 shows the location of the power stations of the world's top 100 coal-fired power utilities. The top 100 coal-fired power utilities 42% of the world's coal-fired generating stations, and 73% of all coal-fired generating capacity.

***Figure 23:** Coal-fired power stations of the top 100 coal-fired power utilities*




## 5.1 Market Analysis

This section surveys available data and estimates of company capital planning, ownership, and bond issuances.

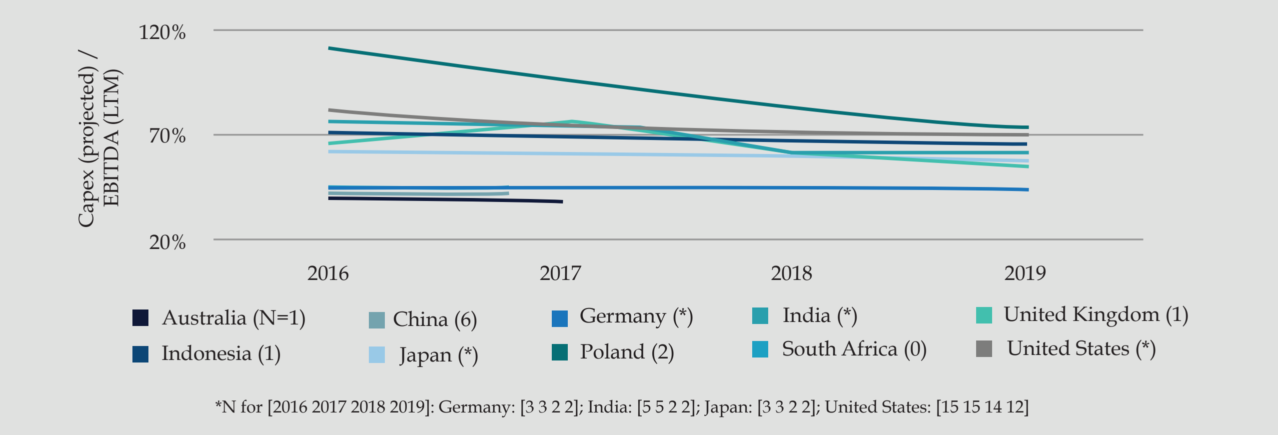
### *5.1.1 Capital Projects Pipeline*

The capital plans of companies help determine future exposure to environment-related risks. For utilities, these capital plans are especially significant given the decades-long life and payback time of generation assets. Box 6 identifies how environment-related uncertainties should be accommodated in capital planning.

Figure 24 shows aggregate capex projections by region (as a percentage of EBITDA) for the top 100 coal-fired power utilities (where data was available[323]). German and Australian utilities are planning the least capex as a ratio of their EBITDA, while the United States leads the grouping and Polish companies are clear outliers in their near-term capex spending relative to EBITDA.

[323] Data was available for 49 of the 100 companies from Standard & Poor's Capital IQ, November 2015.

***Figure 24:** Aggregate capex projections normalised by EBITDA (last 12 months)*[324]




***Box 6:** Uncertainty in capital planning*

As company directors maximise shareholder value, they must accommodate a wide range of risks and uncertainties over a project lifecycle. These include:

- Near-term cost overruns, e.g. during construction
- Risks to operating profitability, including changing commodity prices, labour and fuel/material costs, and maintenance frequency
- End-of-life remediation costs
- Total useful economic life

Allessandri et al argue[325] that conventional risk management techniques like discounted-cash-flow analysis are unsuited to projects with long timeframes and high uncertainty. They argue instead that decision-makers should incorporate qualitative techniques like scenario planning into decisions made under high levels of uncertainty. Courtney et al similarly argue[326] that traditional approaches to planning under uncertainty can be 'downright dangerous'.

EY's Business Pulse[327] lists the top four impacts on power and utility companies as compliance and regulation, commodity price volatility, political intervention in markets, and uncertainty in climate change policy. These factors are typically 'uncertain' – the probability distribution of their occurrence or impact is unknown.

Table 59 in Appendix A shows the total coal-fired generation and fleet-wide capacity for the top 100 coal-fired power utilities. Operating plant capacity is disaggregated by fuel source and capacity in construction or planning is shown by fuel source as a percentage of total operating capacity.

Figure 25 shows global and regional projected coal-fired power generating capacity, operating, in construction, and planned from datasets compiled by the Oxford Smith School. Generating capacity from this new dataset is compared with scenarios from the IEA WEO 2015. Because of differences in database coverage, IEA projections have also been scaled to 2013 data, shown in the dashed series denoted by "*". Plant life is assumed to be 40 years on average.

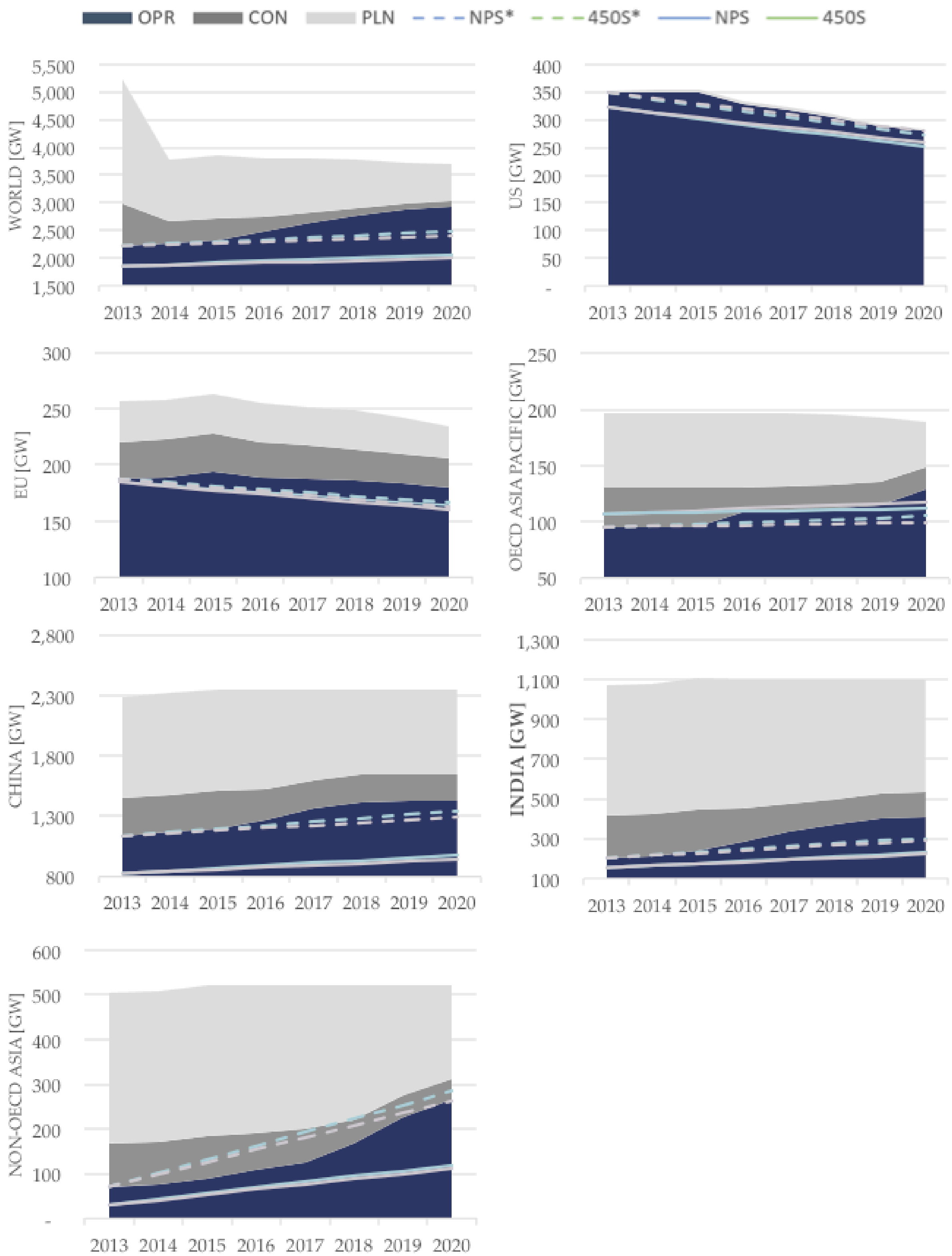
[324] Data taken from Standard & Poor's Capital IQ, November 2015.

[325] Alessandri, T., Ford, D., Lander, D., et al. (2004). 'Managing risk and uncertainty in complex capital projects', The Quarterly Review of Economics and Finance, 44:751-767.

[326] Courtney, H. et al. (1997). 'Strategy Under Uncertainty', Harvard Business Review.

[327] EY (2013) Power and utilities report, Business Pulse.

***Figure 25:*** *Projection of operational, in construction, and planned coal-fired power stations, all companies, from composite database with comparison to IEA projections*



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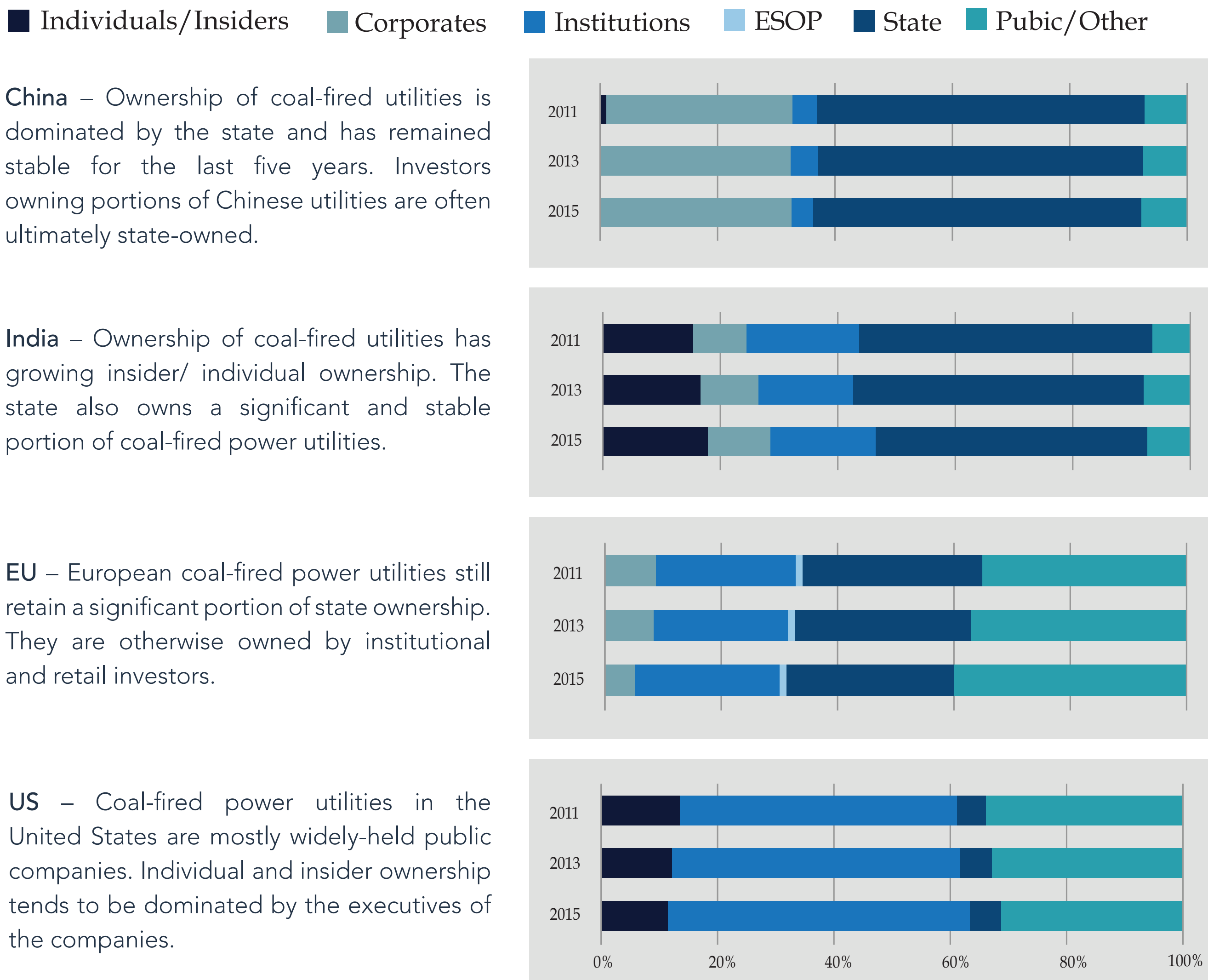
### *5.1.2 Ownership Trends*

The ownership of coal-fired power utilities is shown for selected regions in Figure 26. Widely-held public companies are likely to have different decision-making processes than entirely state-owned companies.

***Figure 26:*** *Coal-fired power utility ownership changes by region*[328]




China – Ownership of coal-fired utilities is dominated by the state and has remained stable for the last five years. Investors owning portions of Chinese utilities are often ultimately state-owned.

India – Ownership of coal-fired utilities has growing insider/ individual ownership. The state also owns a significant and stable portion of coal-fired power utilities.

EU – European coal-fired power utilities still retain a significant portion of state ownership. They are otherwise owned by institutional and retail investors.

US – Coal-fired power utilities in the United States are mostly widely-held public companies. Individual and insider ownership tends to be dominated by the executives of the companies.

Table 60 in Appendix A shows ownership information for the 100 top coal-fired power utilities. For each company, the location of the head office, the ultimate corporate parent, corporate parent's ownership type, and the aggregate market value (in billion USDs) of the various holders' positions is shown.

The distribution of ultimate corporate parents varies at regional level. Both China and India represent the two regions with the largest proportion of privately owned corporate parents; 79% and 63% respectively. The US and Europe are predominantly publicly owned. For US utilities, 69.6% are ultimately owned by public companies, and 4.3% are owned by public investment firms. For the EU, 80% of companies are ultimately owned by public companies. Regarding state ownership, US governments own 13% of US utilities, while 6.3% of Indian utilities are state owned.

[328] Data from Standard & Poor's Capital IQ, November 2015.

Table 19 summarises the ultimate corporate parent ownership structure. Data is extracted from Table 60. Results include percentages. Numbers in parentheses represent the number of observations.

***Table 19:** Distribution of ownership for coal-fired power utilities, by region*

| | Government | Private Company | Private Investment Firm | Public Company | Public Investment Firm |
|---|---|---|---|---|---|
| (A) Total | 5.0%<br>(5) | 45.0%<br>(45) | 1.0%<br>(1) | 48.0%<br>(48) | 1.0%<br>(1) |
| (B) China | 0.0%<br>(0) | 79.2%<br>(19) | 4.2%<br>(1) | 16.7%<br>(4) | 0.0%<br>(0) |
| (C) US | 13.0%<br>(3) | 13.0%<br>(3) | 0.0%<br>(0) | 69.6%<br>(16) | 4.3%<br>(1) |
| (D) India | 6.3%<br>(1) | 62.5%<br>(10) | 0.0%<br>(0) | 31.3%<br>(5) | 0.0%<br>(0) |
| (E) EU | 0.0%<br>(0) | 20.0%<br>(3) | 0.0%<br>(0) | 80.0%<br>(12) | 0.0%<br>(0) |
| (F) Other | 4.5%<br>(1) | 45.5%<br>(10) | 0.0%<br>(0) | 50.0%<br>(11) | 0.0%<br>(0) |

### 5.1.3 Bond Issuances

Exposure to high levels of debt increases risk for both debt and equity holders of coal-fired power utilities as the priority of either is further diluted in the event of the company's insolvency. Table 61 in Appendix A shows bond issuances of the top 100 coal-fired power utilities.

To build a general picture of the future direction for bond issuances in the coal-fired power utility industry, fixed-income securities are examined through ratio analysis. A number of financial ratios are examined, including those related to profitability, capital expenditure, liquidity, leverage, debt coverage, and the ability for utilities to service existing debt. The analyses are conducted between 1995 and 2014 to represent the last 20 years of data.[329] The dataset for 2015 was limited, thus was omitted. Some financial data were unavailable for private coal-fired utilities. Thus, the analysis only includes securities which could be publicly traded. Table 62 in Appendix A reports the median values for the financial ratios across time, while Figure 27 presents the median ratios with 25th and 75th percentiles to illustrate the distribution of observed ratios.

[329] Data were taken from Thomson Reuters Datastream, November 2015; and Standard & Poor's Capital IQ, November 2015.

### **Box 7:** *Environment-related risks and rating downgrades of coal-fired utility companies*

Ratings analyses were obtained from Standard & Poor's Rating Services (S&P) for coal-fired generating companies that suffered a rating action due to climate or environmental factors between September 2013 and September 2015 S&P analyses the business and financial risk exposure of companies.

For business risks, S&P examines factors like the company's regulatory environment, diversification, market outlook, market share, and exposure to 'environmental compliance'. Where companies operate in a strong regulatory environments (e.g. regulated retail power markets), have a diversified customer base and/or a dominant market share, and manage their exposure to or compliance with 'environmental regulation' they are found to be less at risk. Changes in market outlooks are also included in company business risks, though they are not attributed to any underlying environment-related risk.

For financial risk, S&P examines a company's cash position, including their capital spending; mergers, acquisitions, and sales; leverage; and liquidity. S&P evaluates financial risk using a few key metrics, including the ratios of funds-from-operations (FFO) to debt and debt to EBITDA, and liquidity ratios. Environment-related risks are included in financial risk as well, either directly or indirectly. Southern Co.'s impending spending on environmental compliance, for example, was seen as a risk to its financial profile. Indirectly, Duke Energy's sale of 6GW of coal- and gas-fired generating assets to Dynergy in 2014, which may have been motivated by environment-related risks, resulted in an improvement in credit rating. Finally, S&P has observed where changing market conditions can hurt a company's FFO. The available ratings are shown in Table 20.

**Table 20:** *Credit ratings for coal-fired power utilities*[330]

| Company | Business Risk | Financial Risk | Rating | Date |
|---|---|---|---|---|
| Alliant Energy Corp | Excellent | Significant | A-/Stable/A-2 | 2014/11/10 |
| American Electric Power Co. Inc | Strong | Significant | BBB/Stable/A-2 | 2014/05/02 |
| CEZ a.s. | Strong | Significant | A-/Stable/-- | 2014/12/07 |
| DTE Energy | Excellent | Significant | BBB+/Positive/A-2 | 2014/10/14 |
| Duke Energy | Excellent | Significant | BBB+/Positive/A-2 | 2014/11/05 |
| Dynegy Inc. | Weak | Highly Leveraged | B/Stable/NR | 2014/03/31 |
| Formosa Plastics Corp | Satisfactory | Intermediate | BBB+/Stable/-- | 2014/12/04 |
| Great Plains Energy Inc | Excellent | Significant | BBB+/Stable/A-2 | 2015/03/28 |
| NRG Energy Inc | Fair | Aggressive | BB-/Stable/NR | 2014/09/16 |
| RWE AG | Strong | Significant | BBB+/Stable/A-2 | 2014/09/22 |
| Southern Co | Excellent | Significant | A/Negative/A-1 | 2014/10/31 |
| The AES Corp | - | - | BB-/Stable/-- | 2014/07/17 |
| Vattenfall AB | Strong | Significant | A-/Stable/A-2 | 2014/10/09 |

[330] From Standard & Poor's RatingsDirect Reports, various.

In October 2015, S&P reported on how environment and climate (E&C) risks have entered global corporate ratings since November 2013[331]. In those two years, S&P overserved 299 instances when E&C factors were significant in ratings analysis. In 56 of the cases, the E&C factor resulted in a ratings action, 80% of which were negative in direction. The sectors most exposed to ratings action were oil refining and marketing, regulated utilities, unregulated power and gas, and oil and gas exploration and production.

S&P incorporates E&C risks into their ratings in several ways. S&P assesses the management and governance response of companies to emerging ESG risks. E&C risks are included within ESG risks and in 117 of 299 of the review period results, the management response to emerging E&C risks was material to the analysis of the companies in question (both positive and negative). In one case the mismanagement of an environmental compliance requirement led to a credit downgrade (Volkswagen AG).

S&P also considers the impact of extreme weather on companies' real economy assets, supply chains, and markets. As climate change increases the likelihood of extreme weather, companies face potential shut downs, lost work hours, damaged equipment, disrupted supply chains, and volatile markets. Companies with diverse geographies and low chances of extreme weather are insulated from these risks.

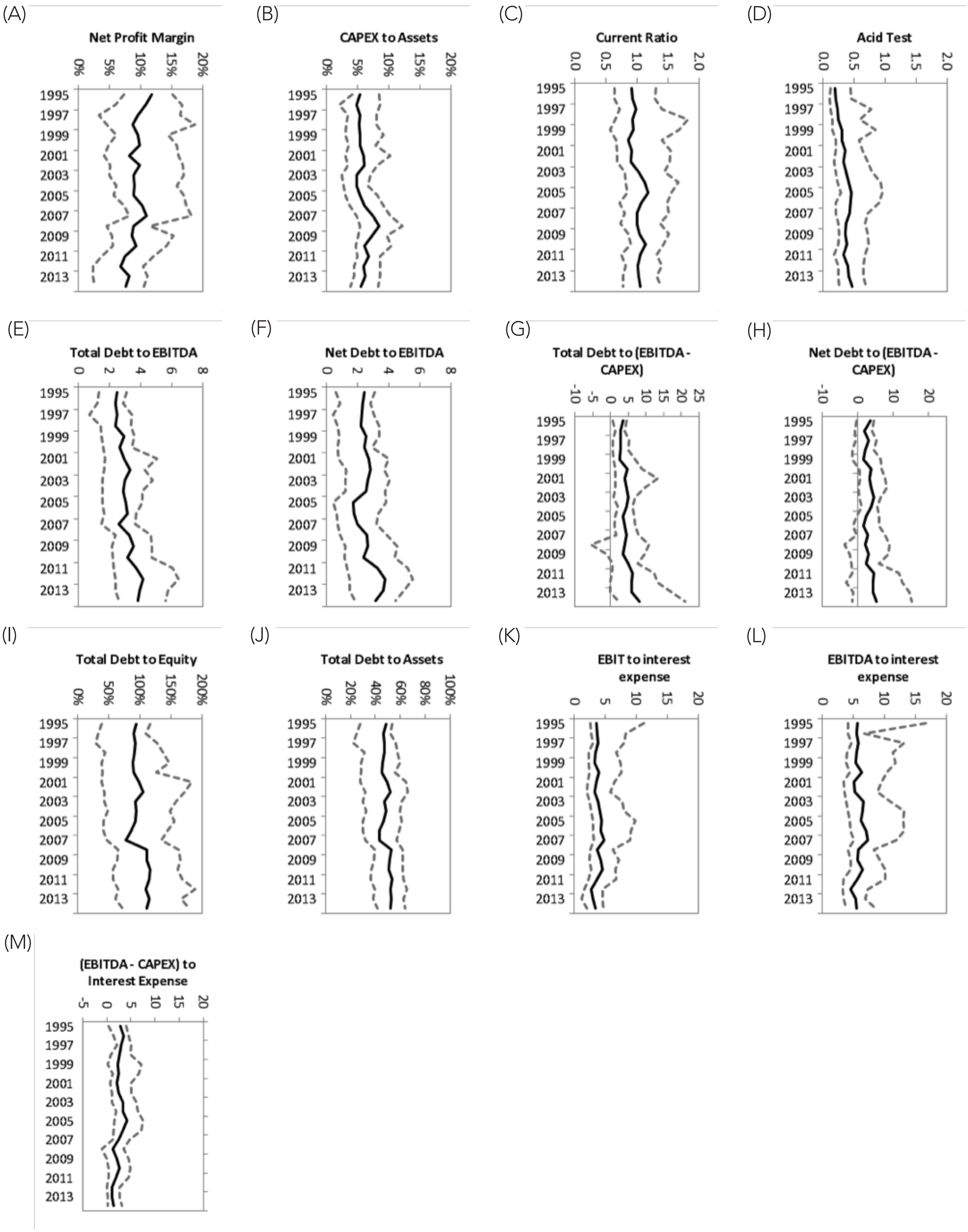
Three examples illustrate how S&P uses E&C factors to evaluate company risk. Volkswagen AG was downrated to A- from A for failure of environmental compliance leading to a substantial penalty and indicative of underlying mismanagement. Tenneco Inc was upgraded to BB+ from BB for their positioning in clean-air products, which are likely to be in higher demand in the future. Energy XXI was downgraded to B- from B because its business activities are primarily in the US Gulf Coast, where climate change is likely to result in more extreme weather.

For the utility sector specifically, S&P plays close attention to how government policy and regulations may expose companies to new risks. In liberalized power markets, government policies have substantial potential to disrupt incumbent positions with new entrants, new technologies, and distributed generation. The majority of business risks identified are risks to profits and growth, and risk of substitution. Even how company management maintains cash flow while responding to new regulatory requirements can inform the risk outlook for the company.

S&P expects the ratings actions due to E&C risks to continue to rise in the near future as extreme weather increases risk to weather-exposed companies, and governments introduce more stringent policies to address climate change.

[331] Standard & Poor's RatingDirect (2015). How Environmental And Climate Risks Factor Into Global Corporate Ratings.

***Figure 27:*** *Ratio analysis for all coal-fired power utilities, with median, 25th, and 75th percentiles*



The first two ratios examined report general profitability and capital expenditure in the coal-fired power utility industry, both of which are relevant to the industries' ability to service its debt commitments. Chart (A) of Figure 27 presents the profit margins for coal-fired power utilities. Margins were greatest in 1995, at 11.8%, and the pre-global financial crisis (GFC) between 2006 and 2007, at 11.0%. The latter is unsurprising considering the peak in global coal prices pre-GFC. After these dates, profit margins generally trended below 10%; 2012 was the worst performing year due to a drop in global coal prices: profit margins were 6.8%. Overall, the results suggest a slow decline in profitability through time.

Capital expenditure represents the funds required to acquire, maintain, or upgrade existing physical assets. Chart (B) shows that capital expenditure relative to total assets has been relatively constant through time. Capital expenditure fluctuates between 4.8% and 8.5% of total assets. The higher capital expenditures were typically observed following the GFC. This could be the result of various corporate actions: first, investment in infrastructure; second, compliance with environmental mandates; or third, greater spending on projects to boost bottom-line profits. The latter is only applicable in regions where profit margins are regulated relative to expenses.

The current ratio and acid test are used as a proxy for liquidity in the industry. The former ratio measures the ability to service current liabilities using current assets, while the latter measures the ability to service current liabilities using cash, near-cash equivalents, or short-term investments. Charts (C) and (D) show both liquidity ratios have increased through time. From 2003 onwards, the current ratio exceeded unity, indicating that the industry would be able to pay all short-term liabilities using its current assets. The acid test ratio has also increased, from 0.19 (1995) to 0.48 (2014). The change indicates an increase in the holdings of cash, near-cash equivalents, or short-term investments or decrease in current liabilities.

Two financial leverage ratios are examined: the debt/equity ratio in Chart (I) and the debt/assets ratio in Chart (J). Both ratios have increased over time, suggesting the industry is financing its growth with debt and/or may be retiring equity. Whereas total shareholder equity previously outweighed total debt, this relationship has reversed in recent years. Similarly, Chart (J) shows that debt now typically represents more than half of total assets. While leveraging can be beneficial, servicing debt can become increasingly difficult with decreasing profit margins. Overall, the industry is increasing its financial leverage, which can translate to greater financial risk, interest expenses, and volatile earnings.

Coverage ratios measure the industry's ability to meet its financial obligations. Three ratios are considered: 1) EBIT/interest, 2) EBITDA/interest, and 3) (EBITDA-CAPEX)/interest. The EBIT/interest ratio in Chart (K) shows that the operating income of the industry is typically between 2.73 and 4.92 times greater than interest expense. As the utility industry is capital-intensive, Chart (L) considers EBITDA which accounts for large depreciation and amortisation on assets. Consequently, the EBITDA/interest ratios range from 4.65 to 7.37 times interest expense. Both ratios are relatively constant through time. Chart (M) considers the impact of capital expenditures on the industry's ability to cover interest expenses. When deducting annual CAPEX, the industry only just generates enough cash to meet interest payments. The ratios range from 1.16 to 4.20 times interest expense. The GFC decreased the (EBITDA-CAPEX)/interest to a mere 1.23x. In 2012-13, the ratio was as low as 1.16 times interest expense. In 2014, the EBITDA-CAPEX had a small rebound to 1.42 times interest expense. Overall, the ratios suggest that the coal-fired power utility industry can cover its interest expenses but some utilities have little cash remaining after capital expenditures. Figure 27 indicates that the ratio becomes negative for some utilities, indicating that interest expenses exceed cash flows.

The final four ratios represent the industry's ability to retire incurred debt. The ratios can be broadly interpreted as the amount of time needed to pay off all debt, ignoring interest, tax, depreciation and amortisation. The ratios are divided into two groups: group 1 considers the numerators: 'total debt' and 'net debt', where the latter subtracts cash and near-cash equivalents for total debt; group 2 considers the denominators: EBITDA and (EBITDA-CAPEX), where the latter controls for capital expenditures.

Considering Charts (E) and (F), both ratios indicate the compounding effects of increasing debt and decreasing profitability. Overall, the industry's ability to retire its debt is declining. In 2014, Chart (E) shows that it would take 3.85 years to pay off total debt using current operating income; Chart (F) shows 3.20 years excluding when utilising near-cash equivalents. When deducting CAPEX, these ratios dramatically increase. In 2014, Chart (G) indicates that the industry will take approximately 8.34 years to pay off its total debt at current levels of profitability and capital expenditure. Over the same period, Chart (H) reports 5.41 years after utilising near-cash equivalents. In conclusion, all four ratios indicate that the industry is taking on increasing amount of debt, which will take longer to retire. Accordingly, we examine the maturity schedule of the industry.

Figure 28 illustrates the maturity schedule for the coal-fired power utility industry. Data were available for 78 of the 100 coal-fired power utility companies. The schedule is divided into total amount outstanding (USD) in Plot (A) and the maturity dates of various contracts in Plot (B). Both graphs are delineated by major region: China, US, Europe, and 'other regions'[332].

Plot (A) of Figure 28 shows that the majority of the total debt amount is due between 2016 and 2025, and Chinese and the US-based utilities are among the largest debt-issuers. US-based utilities have borrowed heavily until 2045. Notably, both Plots (A) and (B) illustrate a small amount of borrowing until 2095-2100. Plot (B) shows that the US-based utilities issued considerably more contracts in comparison to other regions. In combination, it suggests that the average contract size for the US is smaller than other regions, but more numerous.

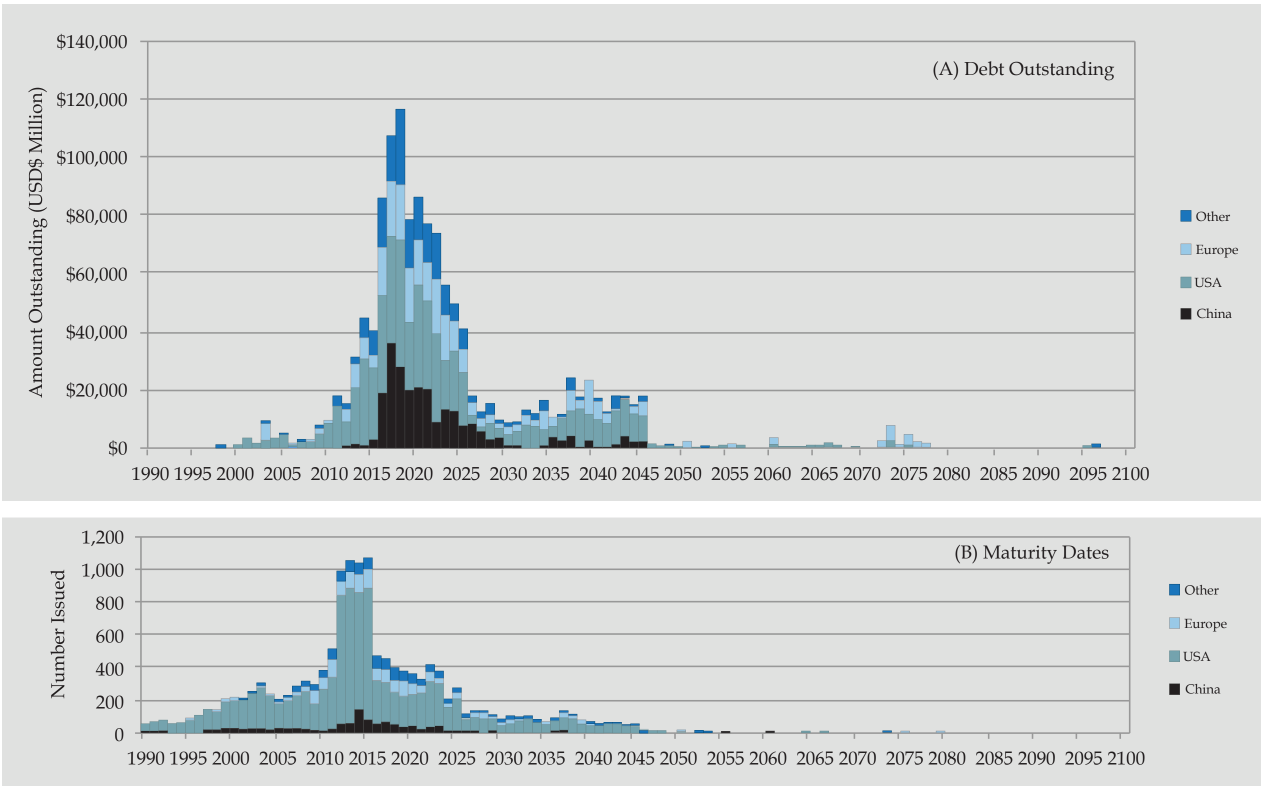
Table 21 examines perpetual debt across the regions. US- and European-based utilities have issued the largest number of perpetual contracts. Similar to the results above, the US utilities has issued a larger number of contracts, but of smaller value. The total amount of European utilities' perpetual debt is more than double that of other regions. Of European utilities' total perpetual debt, France, Germany, and Italy have issued US$20,964m, $1,229m, and $500m, respectively.

***Table 21:*** *Coal-fired power utilities' perpetual debt*

| | China | US | Europe | Other |
|---|---|---|---|---|
| Amount outstanding (US$m) | $6,104 | $9,081 | $22,693 | $3,985 |
| Number issued | 30 | 1,281 | 973 | 16 |

[332] Note, for the 'other' amount outstanding series, we omit $455 billion of debt for Tenaga Nasional Berhad (Malaysia) in 2021. The data point significantly skewed the series. After investigation, S&P Capital IQ confirmed that the amount of debt outstanding is indeed valid and correct.

***Figure 28:** Maturity schedules for the utility industry's debt: amount outstanding (A) and maturity dates (B)*




# 5.2 Investment Risk Hypotheses

In this section, we take a view on what the environment-related risks facing coal-fired power stations could be and how they could affect asset values. We call these Local Risk Hypotheses (LRHs) or National Risk Hypotheses (NRHs) based on whether the risk factor in question affects all assets in a particular country in a similar way or not. For example, water stress has variable impacts within a country and so is an LRH, whereas a country-wide carbon price is an NRH. The hypotheses are coded for easier reference. For example, LRH-U1 refers to carbon intensity of coal-fired power stations and NRH-U1 refers to the overall demand outlook for electricity.

Hypotheses for different environment-related risks have been developed through an informal process. We produced an initial long list of possible LRHs and NRHs. This list was reduced to the more manageable number of LRHs and NRHs contained in this report. We excluded potential LRHs and NRHs based on two criteria. First, we received feedback from investors and other researchers in meetings, roundtables, and through correspondence, on the soundness, relevance, and practicality of each hypothesis. Second, we assessed the data needs and analytical effort required to link the hypotheses with relevant, up-to-date, and where possible, non-proprietary, datasets.

The current list of hypotheses and the datasets used to measure asset exposure to them are in draft form. Other datasets may have better correlations and serve as more accurate proxies for the issues we examine. Important factors may not be represented in our current hypotheses. We are aware of these potential shortcomings and in subsequent research intend to expand the number of hypotheses we have, as well as improve the approaches we have used to analyse them.

The summary table that shows the exposure of the top 100 coal-fired utilities to each NRH and LRH can be found in Section 5.3.

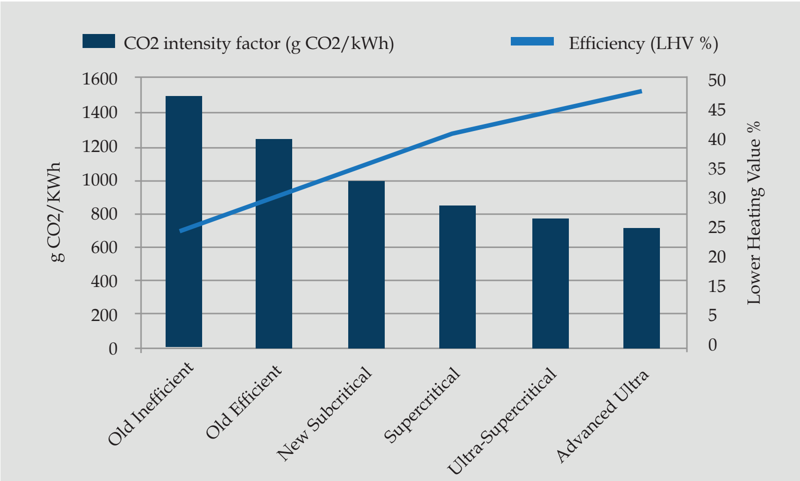
### 5.2.1 Local Risk Hypotheses

*LRH-U1: Carbon Intensity*

The hypothesis is that the more carbon intensive a coal-fired power station, the more likely it is to be negatively impacted by climate policy, whether carbon pricing, emissions performance standards, or other similar measures.

More carbon-intensive power stations are more exposed to transitional risk from climate change mitigation policy. Carbon intensity is directly dependent on power station efficiency, see Figure 29.

***Figure 29:*** *Emissions intensity and efficiencies of coal-fired power stations*[333]




The carbon intensity of power stations can vary widely based on the efficiency of the boiler technology used. Power stations with lower thermal efficiencies are more vulnerable to carbon policies because such policies will more heavily impact inefficient power stations relative to other power stations[334]. This is highly relevant to coal-fired power generation because it is the most emissions-intensive form of centralised generation[335]. Inefficient coal-fired power stations, such as subcritical coal-fired power stations (SCPSs), are the most vulnerable to such policies.

To identify these risks, the emissions intensity of each power station globally is identified in kg.$CO_2$/MWh using CoalSwarm's Global Coal Plant Tracker database and the Carbon Monitoring for Action (CARMA) database. For the top 100 coal-fired power utilities, $CO_2$ intensities for 12% of all power plants and 22% of coal-fired power stations was not available. $CO_2$ intensity for these missing data points was estimated from coefficients derived from a log-log regression of matched data, using fuel type, MW capacity, age, and a country or regional dummy[336] as regressors. This functional form was chosen as it allows for proportional rather than absolute coefficient values, thereby corresponding more closely with the way in which our regressors should affect $CO_2$ intensity in practice.

[333] Taken from IEA (2013). ETP 2013. Op. Cit.

[334] Caldecott, B. & Mitchell, J. (2014). 'Premature retirement of sub-critical coal assets: the potential role of compensation and the implications for international climate policy.' Seton Hall Journal of Diplomacy and International Relations, no. fall/winter.

[335] Moomaw, W., Burgherr, P., Heath, G. et al. (2011). 'Annex II: Methodology' in IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

[336] Regional dummies are employed where there are fewer than 30 observations of plants in a given country.

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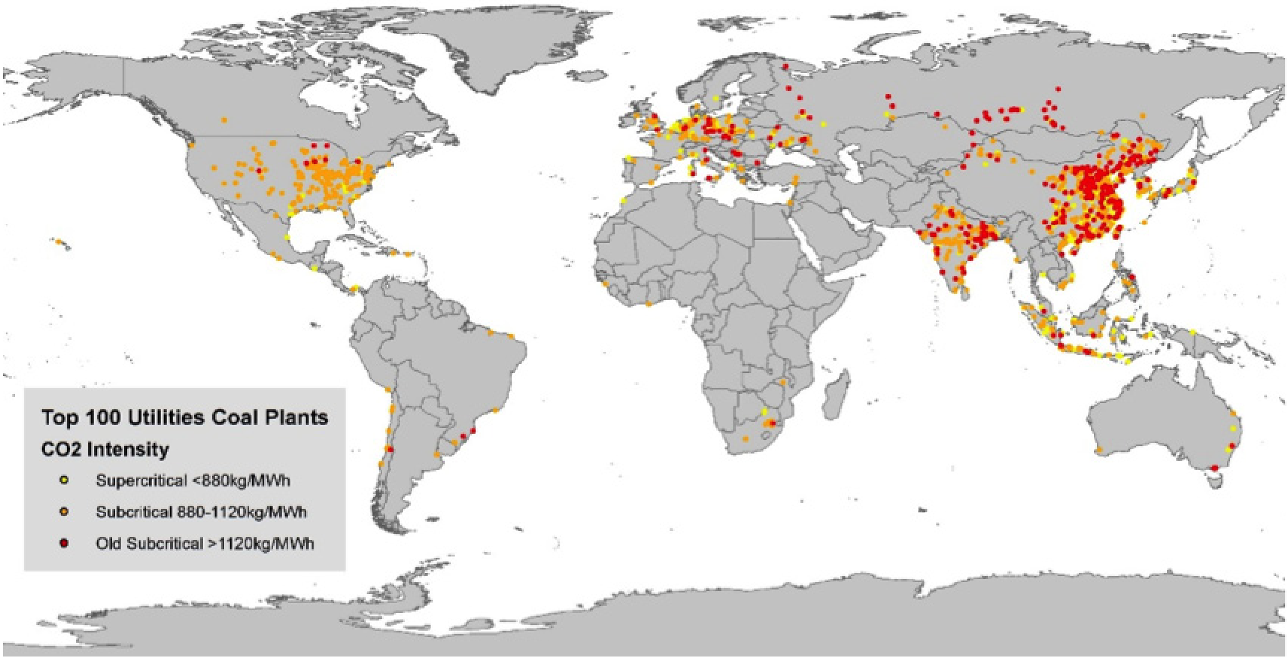
Annual generation data (in MWh) was unavailable for 27% of all top-100 power stations (all fuel sources) and 26% of top-100 coal-fired power stations. This data and plant utilisation rates (in MWh/MW) for missing data points were similarly estimated from coefficients derived from a log-log regression. The regressors employed were fuel type, plant age, and country or region[337]. Similar to $CO_2$ intensity, this functional form was chosen as it should correspond more closely with the way in which our regressors are likely to affect MWh of generation in practice.

Power stations were then aggregated by utility and weighted by MW and MWh to determine the carbon intensity of the coal-fired power stations owned by the top 100 global utilities. Figure 30 shows coal-fired power station emissions intensities around the world.

***Figure 30:*** *Coal-fired power station emissions intensities*




*LRH-U2: Plant Age*

The higher age of power stations creates risks for owners in two ways. First, ageing power stations are more vulnerable to regulations that might force their closure. It is financially and politically simpler to regulate the closure of ageing power stations. Power stations typically have a technical life of 40 years and recover their capital costs after 35 years[338]. Once power stations have recovered capital costs and have exceeded their technical lives, the financial need to compensate is greatly reduced or eliminated[339]. Second, utilities with significant ageing generation portfolios have a higher risk of being required to cover site remediation costs after power station closures and outstanding worker liabilities (i.e. pension costs). Finally, older power stations are more susceptible to unplanned shutdowns and maintenance needs, resulting in the costs of repairs and secondary losses or opportunity costs of underperformance on contracted power delivery.

The age of each generating unit within each power station is identified using CoalSwarm, the World Electric Power Plant (WEPP) database, and CARMA. These are then aggregated to the plant level by weighting the MW capacity of each generating unit.

[337] Regional dummies are employed where there are fewer than 30 observations of plants in a given country.
[338] IEA (2014). Energy, Climate Change, and the Environment. Paris, France.
[339] Caldecott, B. & Mitchell, J. (2014). Op. Cit.

For power stations which lack age data (17% in total, 25% for coal), the average age of stations with the same fuel type across the complete dataset is used. Power stations are then further aggregated by utility company to determine the average age of their coal-fired power generation portfolios as well as the percentage of generation capacity exceeding 40 years of age.

*LRH-U3: Local Air Pollution*

The hypothesis is that coal-fired power stations in locations with high population density and serious local air pollution are more at risk of being regulated and required to either install emission abatement technologies or cease operation. Thus, owners of assets in areas of high population density and high local pollution will have a greater risk of bearing the financial impacts of such possibilities.

There is strong evidence to support this hypothesis from China, the EU, and the US. In China, a number of non-GHG emission policies are forcing the closure of coal-fired power generation in the heavily polluted, heavily populated eastern provinces[340].

Power stations without abatement technologies (e.g. flue gas desulphurisation units and electrostatic precipitators) installed are more at risk of being stranded by having to make large capital expenditures to fit emission abatement technologies. This risk is exacerbated by power station age because investments are harder to justify closer to the end of a power station's technical life.

This is illustrated by the effects of the Mercury and Air Toxics Standards in the United States. Implemented under the 1990 Clean Air Act amendments, the MATS limit emissions of mercury, toxic metals, and acidic gases. 70% of coal-fired power stations are compliant with the regulations. While 6% have plans to comply with the regulation, 16% plans to cease operation instead of comply and another 8% is undecided. The EIA attributes this to the capital expenditure necessary to comply as well as competition from renewables and gas[341].

The following approach is taken to identify risks to utilities that may be created by the co-location of coal-fired power stations with high population densities and serious local air pollution.

- All coal-fired power stations are mapped against a geospatial dataset of global $PM_{2.5}$ pollutionand NASA's SEDAC gridded population dataset. $PM_{2.5}$ data is taken from the analysis of Boys, Martin et al. (2015), and consists of annual ground-level $PM_{2.5}$ averages between 2012 and 2014 derived from satellite observation.
- Average $PM_{2.5}$ pollution within a radius of 100km of each power station is identified. The average population density within a 100km radius of each power station is identified. Then, all power stations are ranked on both factors separately.
- Power stations exposed to $PM_{2.5}$ emissions above the World Health Organisation's annual average $PM_{2.5}$ limit (10 μg/m$^3$) are classified as 'at risk'. Those power stations that rank in the top quintile for population density are classified as 'at risk'. In the case that a power station is 'at risk' for both indicators, it is classified as 'seriously at risk'.
- Power stations with pollution abatement technologies installed are identified using the World Electric Power Plant (WEPP) database. If power stations have one or more emission abatement technologies installed, their pollution abatement risk factors are downgraded one level (i.e. 'seriously at risk' to 'at risk' and 'at risk' to 'not at risk')
- Power stations are then aggregated by utility to identify the percentage of capacity that is 'at risk' or 'seriously at risk'.

[340] Caldecott, B., Dericks, G., & Mitchell, J. (2015). Stranded Assets and Subcritical Coal: The Risk to Companies and Investors, Smith School of Enterprise and the Environment, University of Oxford. Oxford, UK.

[341] Johnson, E. (2014). Planned coal-fired power plant retirements continue to increase, U.S. EIA.

In this hypothesis, $PM_{2.5}$ is used as a proxy for the other conventional air pollutants. Mercury has toxic neurological impacts on humans and ecosystems, but $PM_{2.5}$ is responsible for a more significant range of respiratory and cardiac health impacts associated with coal-fired power[342]. $NO_x$ and $SO_x$ form additional PM pollution once suspended in the atmosphere, and so are included in an evaluation of exposure to $PM_{2.5}$ alone. Figure 31, Figure 32, Figure 33, and Figure 34 show global conventional air pollutant concentrations.

***Figure 31:** Global average PM2.5 concentration, 2012-2014*[343]

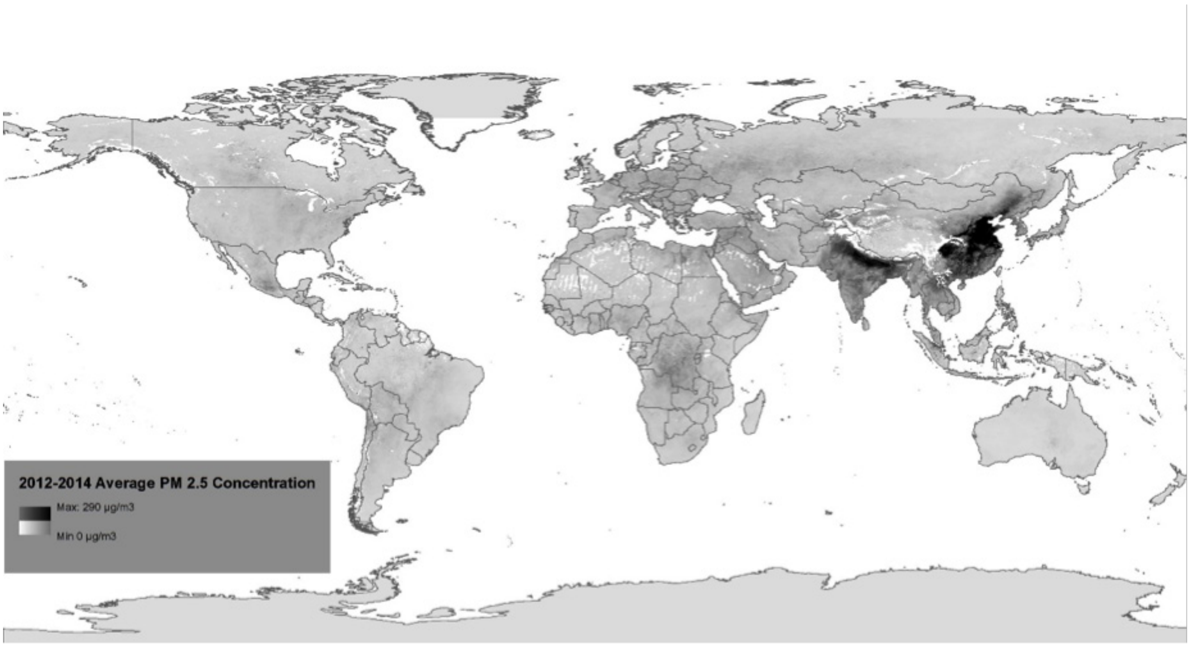
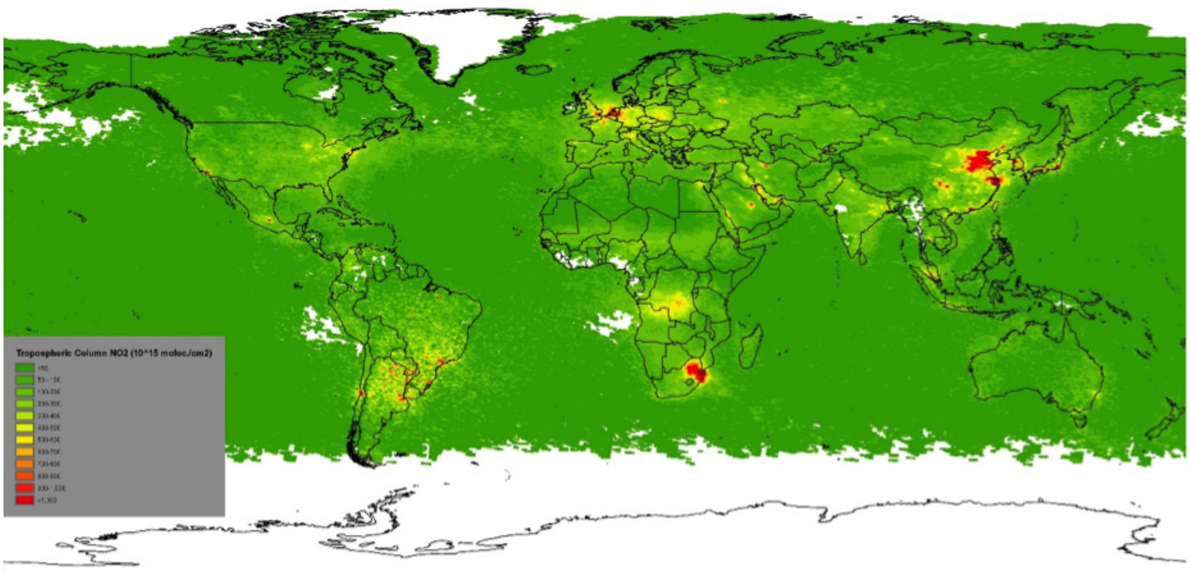



***Figure 32:** Global $NO_2$ concentration, 2015*[344]




[342] Lockwood, A., Welker-Hood, K., Rauch, M., et al. (2009). Coal's Assault on Human Health, Physicians for Social Responsibility. Washington, US.

[343] Boys, B.L., Martin, R.V., van Donkelaar, A., et al. (2014). 'Fifteen-year global time series of satellite-derived fine particulate matter', Environ. Sci. Technol, 48:11109-11118.

[344] Boersma, K., Eskes, H., Dirksen, R., et al. (2011). 'An improved retrieval of tropospheric NO2 columns from the Ozone Monitoring Instrument', Atmos. Meas. Tech., 4:1905-1928.

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***Figure 33:*** *Global $SO_2$ concentration, 2011-2014*[345]

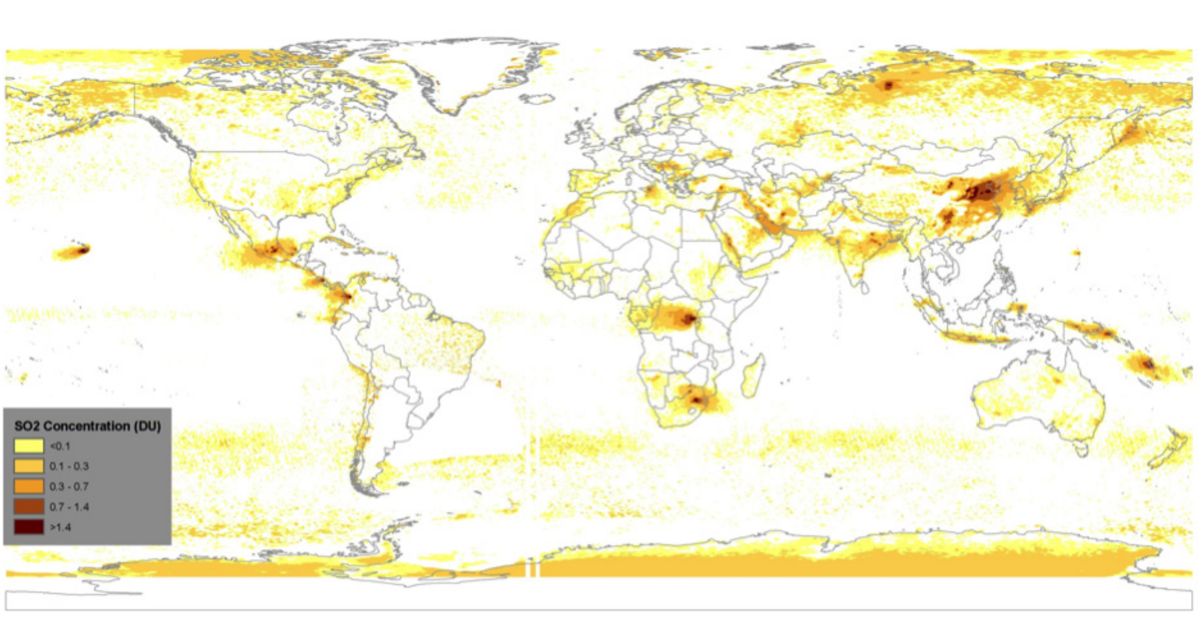
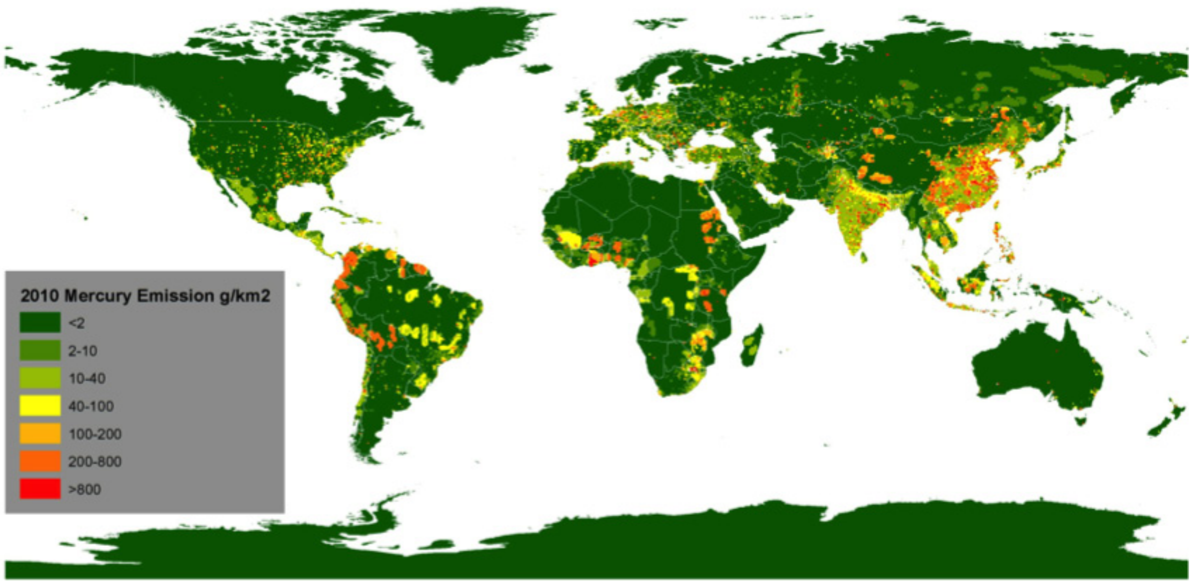



***Figure 34:*** *Global mercury emissions, 2010*[346]




*LRH-U4: Water Stress*

The hypothesis is that power stations located in areas with higher physical baseline water stress or in areas with water conflict or regulatory uncertainty are at higher risk of being forced to reduce or cease operation, of losing licence to operate, or of having profits impaired by water pricing. These risks can be mitigated to an extent by the use of closed-cycle, hybrid, or dry cooling technology.

[345] Krotkov, N. A., McLinden, C. A., Li, C., et al. (2015). 'Aura OMI observations of regional SO2 and NO2 pollution changes from 2005 to 2014', Atmos. Chem. Phys. Discuss., 15:26555-26607.

[346] AMAP/UNEP (2013). 'AMAP/UNEP geospatially distributed mercury emissions dataset 2010v1' in Datasets. http://www.amap.no/mercury-emissions/datasets

These risks can be exacerbated by policy in two ways. First, water-use hierarchies that give residential or agricultural water use precedence over industrial use might worsen impacts of physical scarcity on power generation. Second, areas with high water stress and low industrial water pricing are more vulnerable to policy change.

Coal-fired Rankine-cycle (steam) power stations are second only to nuclear power stations in water use. Cooling is by far the largest use of water in these power stations. The largest factor in determining the water-efficiency of stations is the type of cooling system installed. Secondary factors are the ambient temperature and station efficiency[347].

***Table 22:*** *Water use in electric power generation*[348]

| | | Cooling Technology | | |
|---|---|---|---|---|
| Fuel-Type | Once-Through | Closed-Cycle (Wet) | Hybrid (Wet/Dry) | Dry Cooling |
| Coal | 95,000-171,000 | 2,090-3,040 | 1,045-2,755 | ~0 |
| Gas | 76,000-133,000 | 1,900-2,660 | 950-2,470 | ~0 |
| Oil | 76,000-133,000 | 1,900-2,660 | 950-2,470 | ~0 |
| Nuclear | 133,000-190,000 | 2,850-3,420 | Applicability[1] | Applicability[1] |

Previous research shows that there is strong evidence to suggest that unavailability of water resources is a legitimate concern to the profitability of power stations[349]. In India, coal-water risks have forced nationwide blackouts and water shortages that restrict plants from operating at full capacity and have been shown to quickly erode the profitability of Indian power stations[350]. In China, attempts to abate local air pollution in eastern provinces have pushed coal-fired power generation into western provinces, where there is extreme water scarcity and shortages are expected[351].

The following approach is taken to identify risks to utilities that may be created by physical water stress as well as social or regulatory water risks. The Baseline Water Stress geospatial dataset from WRI's Aqueduct is used to assess physical water stress-related risks. Social and regulatory risks are assessed at the national level in NRH-U9 . Power station cooling technology is taken from the WEPP database and visual inspection of satellite imagery provided via Google Earth during late 2015. It was not possible to identify the cooling technology of 29% of coal plants.

The measure for water stress used in this report is Baseline Water Stress (BWS) from Aqueduct created by the World Resources Institute (WRI). BWS is defined as total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percentage of the total annual available flow within a given watershed. Higher values indicate greater competition for water among users. Extremely high water stress areas are determined by WRI as watersheds with >80% withdrawal to available flow ratios, 80-40% as high water stress, 40-20% as high to medium, 20-10% as medium to low, and <10% as low.[352]

[347] Caldecott, B., Dericks, G., & Mitchell, J. (2015). Op. Cit.

[348] Electric Power Research Institute (EPRI) (2008). Water Use for Electric Power Generation. Palo Alto, US.

[349] EPRI (2008). Op. Cit.

[350] IEA (2012). Op. Cit.

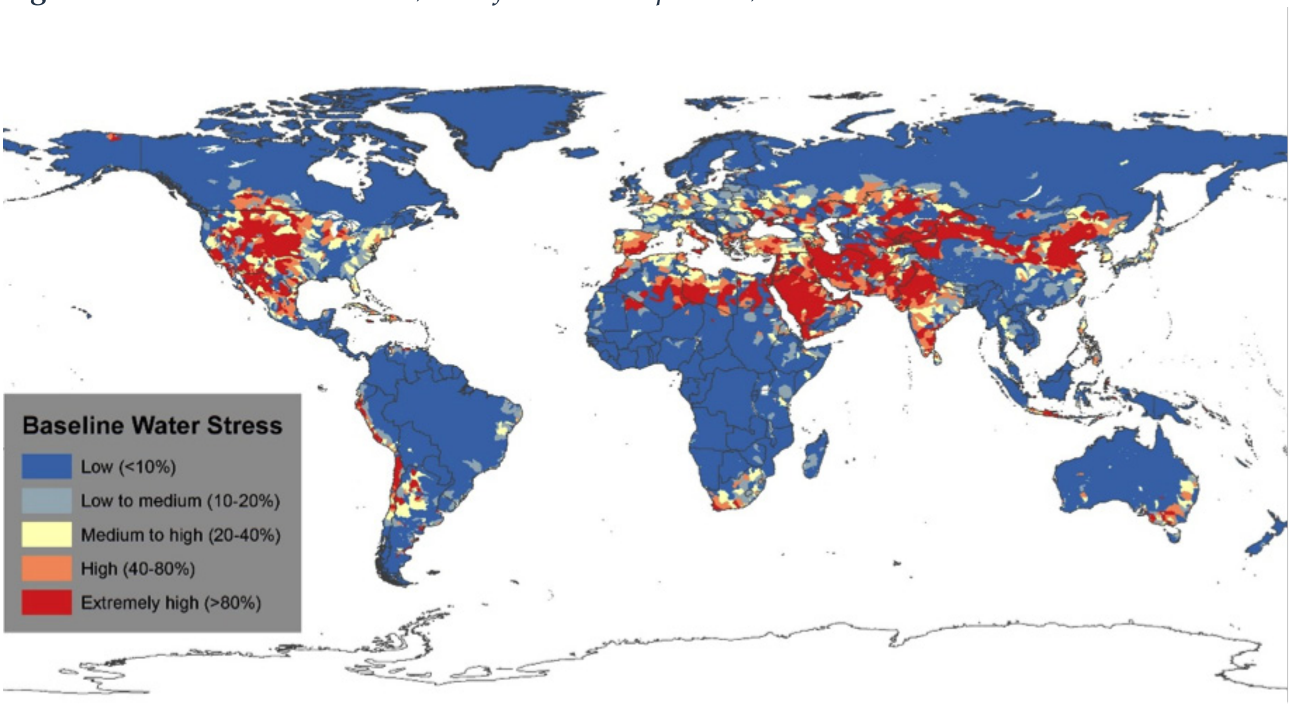
[351] CTI (2014). Op. Cit.

[352] Gassert, F., Landis, M., Luck, M., et al. (2014). Aqueduct global maps 2.1: Constructing decision-relevant global water risk indicators, World Resources Institute. Washington, US.

All coal-fired power stations are mapped against the Aqueduct Baseline Water Stress geospatial dataset. Those power stations that are in watersheds that have 'extremely high water risk'[353] for baseline water stress are identified as 'at risk'. If a power station uses dry cooling technology, it is reclassified as 'not at risk'.

Power stations are then aggregated by utility to identify the percentage of capacity that is 'at risk'. Figure 35 shows global baseline water stress.

***Figure 35:*** *Baseline water stress, data from WRI aqueduct, 2015*

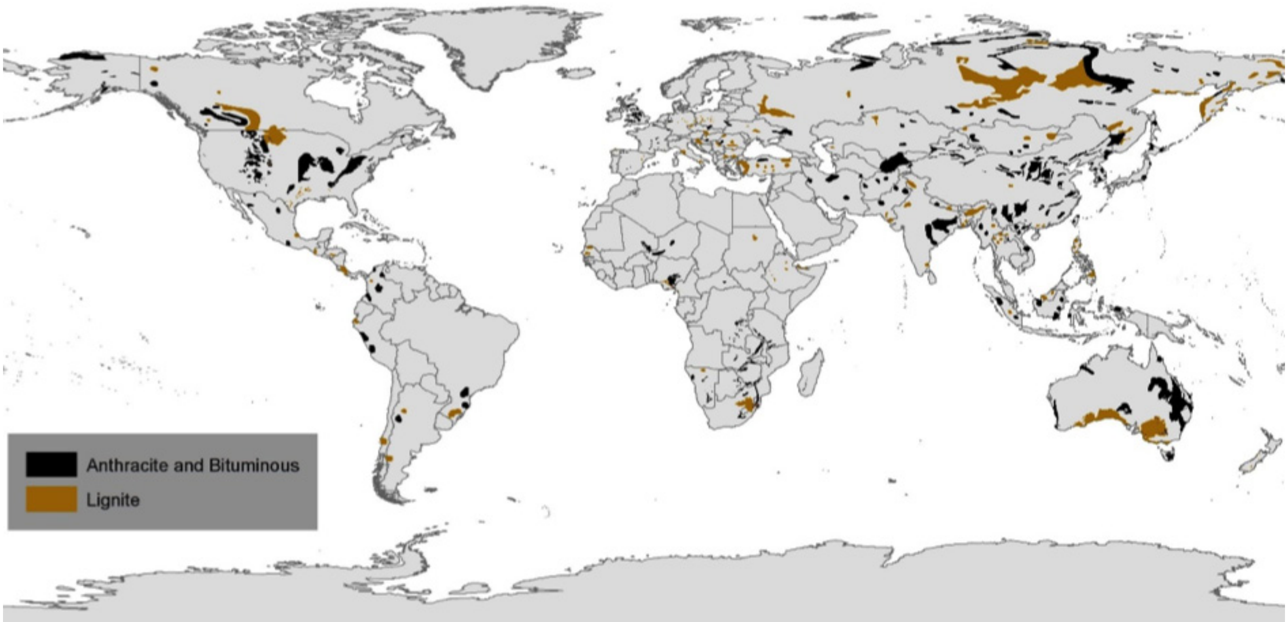



*LRH-U5: Quality of Coal*
The hypothesis is that coal-fired power stations that use lignite are more at risk than those that use other forms of coal. This is because their greater pollution impact makes them more exposed to regulatory risk.

Coal from different deposits varies widely in the quality and type of pollutants it will emit when combusted. With regards to $CO_2$, lignite uniformly emits the most for a given unit of power. Therefore, power stations that burn lignite exclusively are likely to be more vulnerable to carbon regulations. Data on individual power station use of lignite was compiled from CoalSwarm and WEPP. However, for 29% of coal plants the coal type could not be identified from these sources. These remaining power stations were classified as burning lignite if they are co-located with lignite reserves according to Figure 36.

[353] Baseline water stress measures the ratio of total annual water withdrawals to total available annual renewable supply, accounting for upstream consumptive use. Extremely high water risk signifies that >80% of renewable supply is withdrawn.

***Figure 36:*** *World coal deposits by type, data from various sources: compiled by Oxford Smith School.*




*LRH-U6: CCS Retrofitability*

The hypothesis is that coal-fired power stations not suitable for the retrofit of carbon capture and storage (CCS) technology might be at more risk of premature closure. These power stations do not have the option of CCS retrofit in the case of strong GHG mitigation requirements on coal-fired power utilities, enforced either with targeted policy or with carbon pricing. Because CCS plays a large part in in the IPCC and IEA's 2°C scenarios (IPCC AR5 2DS) as well as the IEA's 2°C scenarios[354] (IEA ETP, IEA WEO 450S), it is necessary to evaluate the retrofitability of power stations to assess the resilience of utilities' generation portfolio to policies aiming to align power generation emissions with a 2DS.

No dataset exists for CCS retrofitability.[355] Instead, this is defined as a function of power station size, where only boilers larger than 100MW are economic to retrofit;[356,357] age, where only power stations <20 years old are worth making significant investments in;[358,359] efficiency, where more efficient power stations are more suitable for CCS economically; location, where power stations are within 40km of geologically suitable areas are economically suitable;[360] and policy, where nations with a favourable levels of interest and favourable policy frameworks.[361]

The following approach is taken to identify the percentage of utilities' coal-fired power generation portfolios that may be suitable for CCS retrofits. CCS policy support is considered separately as a NRH.

[354] Refers specifically to the IPCC AR5 430-480PPM, IEA ETP 2DS, and IEA WEO 450S.

[355] IEA (2012). Op. Cit.

[356] National Energy Technology Laboratory (NETL) (2011). Coal-Fired Power Plants in the United States: Examination of the Costs of Retrofitting with CO2 Capture Technology, DOE. Washington, US.

[357] Although MITei (2009). Retrofitting of Coal-fired Power Plants for CO2 Emission Reductions. suggests that 300MW is the threshold for power stations generally, 100MW is taken as a conservative case.

[358] NETL (2011). Op. Cit.

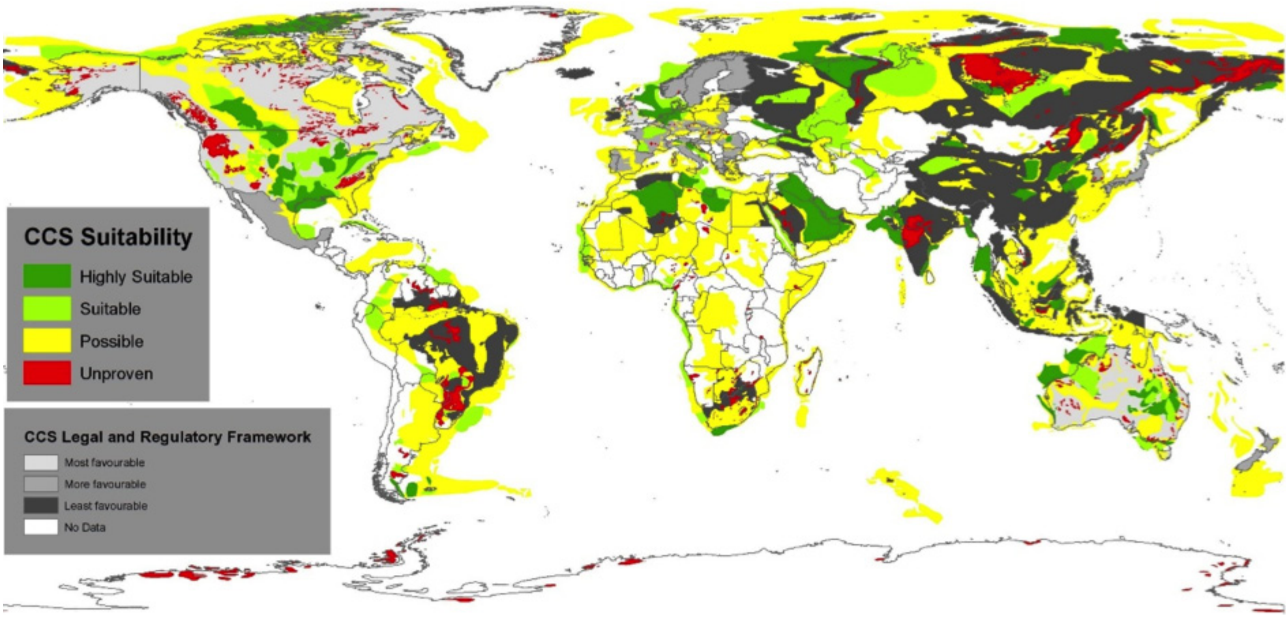
[359] This is the central scenario of the OECD CCS retrofit study.

[360] 40km has been suggested as the distance to assess proximity to geological reservoirs, see NETL (2011).

[361] As defined by Global CCS Institute (2015). CCS Legal and Regulatory Indicator. Op. Cit.

Power stations with generators larger than 100MW, that are younger than 20 years, and emit <1000g $CO_2$/KWh are deemed technically suitable for CCS retrofit, and are then mapped against the Global CCS Suitability geospatial dataset to determine whether they are within 40km of areas highly suitable for CCS, and therefore geographically suitable. Power stations that are both technically and geographically suitable are aggregated by utility to identify the percentage of utilities' generation portfolio that is 'suitable' for CCS retrofit. Figure 37 shows global CCS geological suitability and policy support.

***Figure 37:*** *CCS geological suitability*[362]




*LRH-U7: Future Heat Stress*

The hypothesis is that physical climate change will exacerbate heat stress on power stations. Higher ambient local temperatures decrease power station efficiency and exacerbate water stress, which causes physical risks, such as forced closure or reduced operation, and social risks, such as unrest and increased potential for regulation.

There is strong evidence that warming risks should be taken into account. In Australia, there is evidence that climate change poses direct water-related risks to Australian coal-fired power generation. During a heat wave in the 2014 Australian summer, electricity demand increased in tandem with water temperatures. Loy Yang power station's generating ability was greatly reduced because it could not cool itself effectively[363]. This caused the spot price to surge to near the market cap price[364]. Inability to produce power at peak demand times has the capacity to significantly impact power stations' profits in competitive energy markets.

To assess vulnerability of power stations to climate change-related temperature increases, the Intergovernmental Panel on Climate Change's AR5 2035 geospatial dataset is used. This dataset gives a spatial representation of expected temperature change over in 2035.

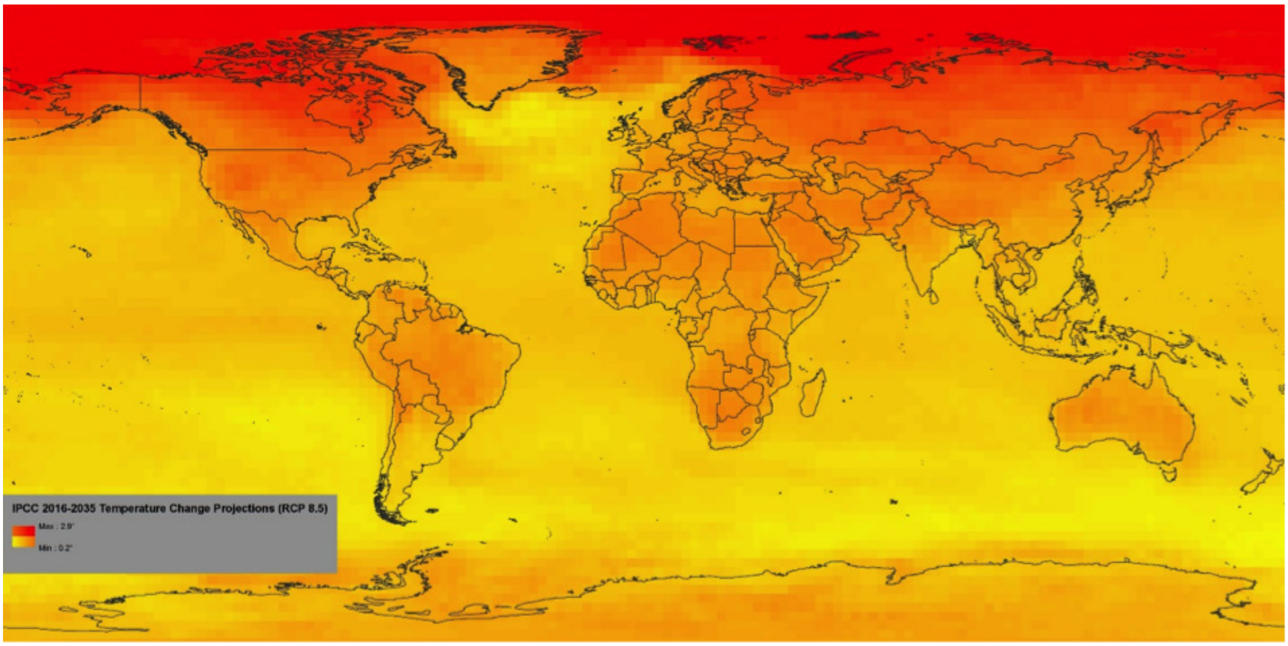
[362] Reproduced with permission of IEA GHG and Geogreen

[363] Australian Energy Market Operator (AEMO) (2014). Heatwave 13-17 January 2014.

[364] Robins, B. (2014). 'Electricity market: Heatwave generates interest in power', The Sydney Morning Herald.

Average local temperature change is matched with the location of each power station globally. Those power stations in the top quintile of temperature change are classified as 'at risk'. Power stations are then aggregated by utility to identify the percentage of capacity at risk from heat stress induced by climate change. Figure 38 shows global near-term future temperature changes.

***Figure 37:*** *2016-35 temperature change*[365]




### *5.2.2 National Risk Hypotheses*

The hypotheses below have been developed on a country-by-country basis, affecting all the generating assets in that country. A simple traffic light method has been used to conduct analysis for these risk hypotheses. Traffic-light methods are well suited to complex situations where more formal analysis is unavailable or unnecessary, and are particular prevalent in environmental and sustainability analysis, e.g. DEFRA[366], the World Bank[367]. The hypotheses developed below draw on the IEA NPS as a conservative scenario and add extra evidence to give a more complete policy outlook for coal-fired utilities. The time horizon for these risk indicators is near- to mid-term, using the IEA's 2020 projections where appropriate.

An effective traffic light method clearly describes threshold values or criteria for each colour that are testable by analysis or experiment[368]. Criteria are developed below for each hypothesis, with conclusions as to whether coal-fired utilities in that country are at high risk (red), medium risk (yellow) or low risk (blank). Based on each of these criteria, an aggregate outlook is given after scoring each (+2 for high risk criteria, +1 for medium risk criteria). These scores can be used for an aggregate outlook for coal-fired power generation in each country. Table  provides a summary of all the country-level environment-related risk hypotheses for coal-fired utilities.

[365] Data from IPCC AR5 WGII, RCP8.5 P50.

[366] UK Department for Food, Environment, and Rural Affairs (DEFRA) (2013). Sustainable Development Indicators. London, UK.

[367] The World Bank (2016). RISE Scoring Methodology. http://rise.worldbank.org/Methodology/Scoring-methodology.

[368] Halliday, R., Fanning, L., & Mohn, R. (2001). 'Use of the Traffic Light Method in Fishery Management Planning', Fisheries and Ocean Science, Canadian Science Advisory Secretariat. Dartmouth, Canada.

***Table 23:** Summary of national risk hypotheses*

| High Risk (+2) / Medium Risk (+1) / Low Risk (+0) | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| NRH-U1: Electricity Demand Outlook | Medium | Low | High | Low | Low | High | High | Medium | High | Medium |
| NRH-U2: Utility Death Spiral | High | Low | High | Low | Low | High | Low | Low | Medium | High |
| NRH-U3: Renewables Resource | High | Low | Low | Medium | Medium | Low | Medium | High | Medium | Medium |
| NRH-U4: Renewables Policy Support | Medium | High | High | Low | High | High | Low | Medium | Medium | High |
| NRH-U5: Renewables Generation Outlook | Medium | Medium | High | Low | Low | Medium | High | High | High | Low |
| NRH-U6: Gas Generation Outlook | Medium | High | Low | High | Medium | Medium | Low | Low | Low | High |
| NRH-U7: Gas Resource | High | High | Low | Medium | Low | Low | Low | Low | Low | High |
| NRH-U8: Falling Utilisation Rates | High | High | Medium | Low | High | Low | High | High | High | High |
| NRH-U9: Regulatory Water Stress | Low | Medium | Low | High | Medium | Low | Low | Medium | Low | Low |
| NRH-U10: CCS Legal Environment | Low | High | Medium | High | High | Medium | Medium | High | Low | Low |
| TOTAL (/20) | 12 | 12 | 10 | 8 | 9 | 9 | 8 | 11 | 9 | 12 |

*NRH-U1: Electricity Demand*

The hypothesis is that the greater the growth in demand for electricity, the less likely other forms for generation (e.g. solar, wind, gas, and nuclear) are to displace coal-fired power. Growth in overall electricity demand might allow coal-fired generators to maintain or increase their current share of power generation.

We examine electricity demand outlooks from the IEA WEO 2015. As described in Section 1.3, the NPS is used here as a conservative scenario. Due to the IEA's country groupings, single-country outlooks are not available for all countries. The outlook for Australia is comingled with outlooks for New Zealand and South Korea. The outlook for Indonesia is comingled with a number of other countries in southeast Asia. The outlooks for the UK, Germany, and Poland are identical, all having been derived from the outlook for the EU.

Countries which have 0% projected electricity demand growth between 2013 and 2020 are considered 'high risk'. Countries with 1% or 2% growth are considered 'medium risk'. Countries with >2% growth are considered 'low risk'.

***Table 24:** 2013-20 electricity demand outlook from IEA WEO 2015 NPS*[369]

| 2013 - 2020 | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| CAGR | 2% | 4% | 0% | 4% | 6% | 0% | 0% | 1% | 0% | 1% |
| RISK | 🟡 | 🟢 | 🔴 | 🟢 | 🟢 | 🔴 | 🔴 | 🟡 | 🔴 | 🟡 |

*NRH-U2: 'Utility Death Spiral'*

The hypothesis is that if utility death spirals (see Box 2) are taking place, coal-fired power stations are more likely to face lower wholesale electricity prices and other forms of power sector disruption.

The utility death spiral is a phenomenon which can lead to the rapid, unforeseen erosion of a coal-fired utility's business model. Companies experiencing the utility death spiral are likely to have to adapt to the new risks and opportunities of energy transition. A utility death spiral is arguably one of the reasons why German utility E.On SE decided to separate its renewable and conventional power interests, with its rival RWE AG to follow suit in December 2015. For the different countries in scope we have looked for evidence for whether power markets are experiencing a utility death spiral and these are summarised below.

***Table 25:** Countries showing evidence of the utility death spiral*

| Country | Reference | RISK |
|---|---|---|
| Australia | Strong evidence of the utility death spiral[370] | 🔴 |
| China | No evidence of the utility death spiral | 🟢 |
| Germany | Strong evidence of the utility death spiral[371] | 🔴 |
| Indonesia | No evidence of the utility death spiral | 🟢 |
| India | No evidence of the utility death spiral | 🟢 |
| Japan | Strong evidence of the utility death spiral[372] | 🔴 |
| Poland | No evidence of the utility death spiral | 🟢 |
| South Africa | No evidence of the utility death spiral | 🟢 |
| United Kingdom | Low evidence of the utility death spiral[373] | 🟡 |
| United States | Strong evidence of the utility death spiral[374] | 🔴 |

[369] IEA (2015). WEO 2015. Op. Cit.

[370] AER (2014). Op. Cit.

[371] Lacey, S. (2014). 'This Is What the Utility Death Spiral Looks Like', Greentech Media.

[372] Rising rates and falling costs leading to grid parity for solar PV, see Kimura, K. (2015). 'Grid Parity – Solar PV Has Caught Up with Japan's Grid', Japan Renewable Energy Foundation.

[373] Costello, M. & Jamison, S. (2015). Op. Cit.

[374] Moody's Investor Service (2014). 'Moody's: Warnings of a utility 'death spiral' from distributed generation premature', Global Credit Research. New York, US.

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*NRH-U3: Renewables Resource*

The hypothesis is that the availability of strong renewable resources is a key determinant of the competiveness of renewables relative to conventional generation. Countries with larger renewables resources could see larger and faster rates of deployment. This would result in coal-fired power stations being more likely to face lower wholesale electricity prices and other forms of power sector disruption.

Wind resource potential is drawn from Lu et al. (2009) and is normalised by 2014 total electricity generation. Solar resource potential is drawn from McKinsey & Company and SolarGIS. Where either solar resource exceeds 1400 kWh/kWP or wind resource exceeds ten times the annual electricity demand of the country, coal-fired power generation in the country is considered at 'medium risk' of displacement by renewables. Where both exceed these thresholds, coal-fired power is considered at 'high risk'.

***Table 26:*** *Renewables resources*

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Wind resource [TWh/TWh][375,376] | 405.0 | 7.8 | 6.5 | 4.4 | 3.3 | 3.8 | 22.0 | 31.7 | 29.8 | 20.5 |
| Solar resource [kWh/kWP][377,378] | 1425 | 1300 | 950 | 1400 | 1450 | 1175 | ~950 | 1500 | 875 | 1250 |
| RISK | red | green | green | yellow | yellow | green | yellow | red | yellow | yellow |

*NRH-U4: Renewables Policy Support*

The hypothesis is that countries with robust regimes for supporting renewables will see greater renewables deployment. This would result in coal-fired power stations being more likely to face lower wholesale electricity prices and other forms of power sector disruption.

Renewables deployment has become a policy priority as governments seek to mitigate the climate impact of power generation. Some countries offer stronger support regimes than others. Support for renewables can come at the detriment of coal-fired power generation, as renewable power displaces the market share of coal-fired power and potentially lowers wholesale market prices.

EY's renewables indicator is used to determine country-specific renewables support. EY's indicator is comprehensive and includes policy support and readiness. Further details of policy in individual countries policy are given in Section 4. Renewables support indicates a risk for coal-fired utilities. Where EY's aggregate ranking is above 60, the countries are considered 'high risk'. Where over 50 they are considered 'medium risk'.

[375] Lu, X., McElroy, M., & Kiviluoma, J.. (2009). 'Global potential for wind-generated electricity', PNAS 106: 10933-10938.
[376] BP plc (2015). Op. Cit.
[377] SolarGIS (2015). 'Global Horizontal Irradiation', GeoModel Solar. http://solargis.info/doc/free-solar-radiation-maps-GHI
[378] Frankel, D., Ostrowski, K., & Pinner, D. (2014). 'The disruptive potential of solar power', McKinsey Quarterly, McKinsey & Company.

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***Table 27:** Renewables policy support*[379]

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| EY: Renewable Energy Country Attractiveness Index | 56.0 | 75.6 | 66.3 | 41.8 | 62.15 | 64.5 | 45.8 | 53.2 | 58.5 | 73.3 |
| RISK | 🟡 | 🔴 | 🔴 | 🟢 | 🔴 | 🔴 | 🟢 | 🟡 | 🟡 | 🔴 |

*NRH-U5: Year-on-Year Renewables Growth*

The hypothesis is that rapid renewables deployment would result in coal-fired power stations being more likely to face lower wholesale electricity prices and other forms of power sector disruption.

High year-on-year renewables growth indicates that these pressures might be increasing in particular power markets. We use the growth in installed renewables capacity (GW) and the growth in the proportion of renewable power generation to estimate exposure to year-on-year renewables growth. Data for installed capacity of renewables were collected from a number of sources, but principally the annual REN21 Global Status Reports. Data for renewable and total power generation were drawn from the BP Statistical Energy Outlook 2015.

Where the CAGR in renewable power generation as a portion of total generation exceeds 10%, and where CAGR in renewable power capacity exceeds 10%, the country is considered 'high risk'. Where only one exceeds 10%, the country is 'medium risk'.

[379] EY (2015). Renewable Energy Country Attractiveness Index.

***Figure 39:** Proportion of total electricity generated by renewables*[380]

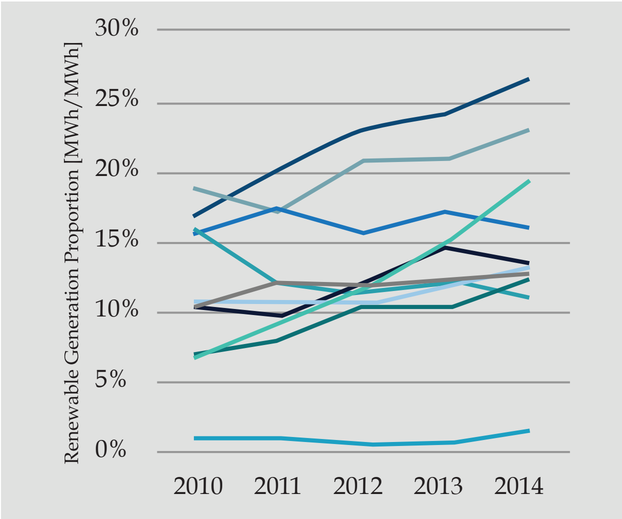
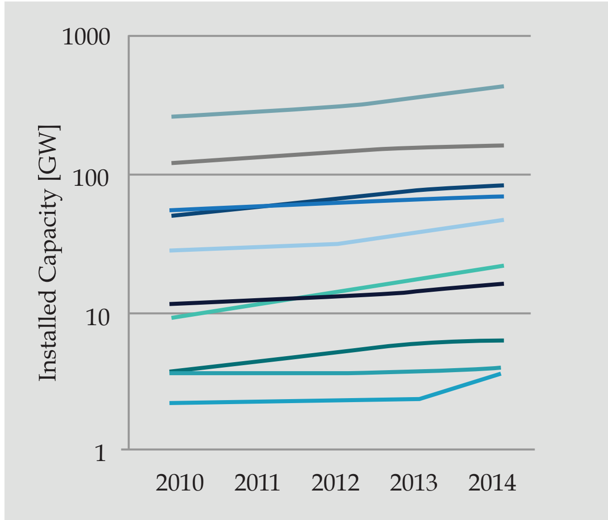



***Figure 40:** Total capacity of renewable power generation*[381]




Australia, China, India, Indonesia, United Kingdom, Germany, Japan, Poland, South Africa, United States

***Table 28:** Year-on-year growth of renewables capacity and generation*

| 2010 - 2014 CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Renewables Capacity | 11% | 13% | 14% | 2% | 7% | 15% | 15% | 14% | 23% | 8% |
| Renewables Generation | 8% | 6% | 12% | -8% | 1% | 6% | 16% | 25% | 30% | 7% |
| RISK | Yellow | Yellow | Red | Green | Green | Yellow | Red | Red | Red | Green |

*NRH-U6: Gas-fired Generation Outlook*

The hypothesis is that the growth of gas-fired generation, particularly in markets where electricity demand growth is lower or negative, could harm the economics of coal-fired generation and result is coal-to-gas switching.

Historic and projected gas-fired generation data are drawn from the IEA WEO. The NPS is chosen as a conservative scenario. If either historic or projected CAGR of gas-fired power generation is positive, then the outlook for coal-fired power in that country is considered 'medium risk'. If both are positive, then the outlook is considered 'high risk'.

[380] BP plc (2015). Op. Cit.
[381] REN21 (2015). Op. Cit.

**Table 29:** *Natural gas-fired power generation outlook*[382]

| CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| 2010-13 Historic | 11% | 10% | -13% | 2% | -18% | 10% | -13% | N/A | -13% | 4% |
| 2013-20 NPS | 0% | 17% | 0% | 2% | 6% | -4% | 0% | | 0% | 2% |
| RISK | 🟡 | 🔴 | 🟢 | 🔴 | 🟡 | 🟡 | 🟢 | 🟢 | 🟢 | 🔴 |

*NRH-U7: Gas Reserves and Production Growth*

The hypothesis is that the growth of gas-fired generation, particularly in markets where electricity demand growth is low or negative, could harm the economics of coal-fired generation and result in coal-to-gas switching. Gas-fired generation is more likely to be competitive in countries where there are large domestic reserves and growing domestic gas production.

Gas can compete directly with coal in the supply of dispatchable, baseload electricity. Gas-fired electricity also has the advantage of being less carbon intensive and more efficient than coal-fired power. We examine data on proven natural gas reserves and the growth in gas production drawn from the BP Statistical Energy Review 2015. Coal-fired utilities are more at risk in countries which have large reserves of gas and growing gas production. Countries which have either >1% of global reserves or a CAGR in gas production of >0% are considered 'medium risk'. Countries with both are considered 'high risk'.

**Table 30:** *Natural gas reserves and production growth*[383]

| CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Natural gas reserves | 2.0% | 1.8% | 0.0% | 1.5% | 0.8% | 0.0% | 0.1% | 0.0% | 0.1% | 5.2% |
| Production growth (2010-14 CAGR) | 5% | 8% | -8% | -4% | -11% | N/A | 0% | N/A | -11% | 5% |
| RISK | 🔴 | 🔴 | 🟢 | 🟡 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🔴 |

*NRH-U8: Falling Utilisation Rates*

The hypotheses is that under-utilised coal-fired power stations will be financially vulnerable and more prone to stranding.

382 Ibid.

383 IEA (2015). WEO 2015; IEA (2014). WEO 2014; IEA (2013). WEO 2013; IEA (2012). WEO 2012; IEA (2011). WEO 2011.

The entrance of new generating options may reduce the utilisation rates of coal-fired generating assets. The utilisation rate of a power generating asset is the ratio of its actual annual output to its maximum potential annual output according to its nameplate capacity. Competition on marginal costs, or must-run regulation for renewables, can displace coal-fired generation, reducing utilisation rates. Generating stations with falling utilisation rates are less able to cover fixed costs with operating profit. Generating stations in countries with continuously falling utilisation rates are considered 'at risk'.

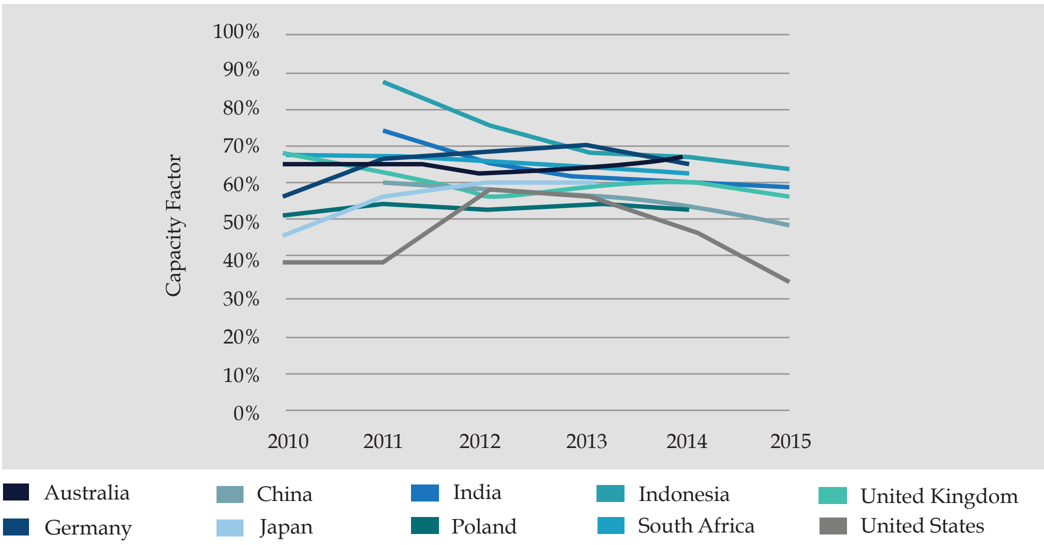
Utilisation rates have been identified for scope countries in Figure 41 and Table 31.

***Table 31:** Coal-fired utilisation rates showing data completion*[382]

| Country | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|
| Australia | 67% | 66% | 63% | 64% | 66% | |
| China | | 60% | 58% | 58% | 54% | 50%e |
| Germany | 57% | 66% | 68% | 70% | 66% | |
| Indonesia | | 88% | 76% | 69%e | 68%e | 65%e |
| India | | 74% | 66% | 62% | 61% | 59%e |
| Japan* | 47% | 57% | 60% | 60% | | |
| Poland* | 51% | 54% | 53% | 55% | 54% | |
| South Africa* | 68% | 68% | 65% | 64% | 63% | |
| United Kingdom | 40% | 41% | 57% | 57% | 48% | 34%$_{i}$ |
| United States | 68% | 64% | 57% | 60% | 61% | 56%$_{ii}$ |

* Comingled with all thermal generation, i Up to Q3 2015, ii Up to November 2015, e: Estimate.

***Figure 41:** Coal-fired utilisation rates*




Policy research has also been conducted to identify the countries where the marginal growth of either renewables or gas directly replaces existing or new coal-fired power capacity. A subjective judgement of risk to coal-fired utilities is made. See the policy summaries in Table 32 for detail.

[382] Data sources: various; Oxford Smith School calulation

***Table 32:*** *Power displaced by emerging renewables and gas*

| Country | Generation Displaced | Reference | RISK |
|---|---|---|---|
| Australia | Coal | Natural gas and renewables expected to continue past trend of displacing coal-fired power[384] | 🔴 |
| China | Coal | Renewables and natural gas deployment align well with Chinese interests in reducing conventional air pollution | 🔴 |
| Germany | Nuclear | Post-Fukushima, the political environment for nuclear power changed – nuclear power is now prioritised for decommissioning under the Energiewende, followed by coal[385] | 🟢 |
| Indonesia | Oil | Indonesia has many islands with disconnected grids powered by oil engines. Indonesia's immediate priority is to reduce oil-fired power[386] | 🟢 |
| India | Coal | India has little other generation which could be disrupted by renewables and gas | 🔴 |
| Japan | Oil | In Fukushima's aftermath, Japan's priority was to close nuclear power stations. Renewables, gas, and re-opening nuclear are clawing back reactivated oil-fired generating capacity[387] | 🟢 |
| Poland | Coal | Poland has little other generation which could be disrupted by renewables and gas | 🔴 |
| South Africa | Coal | South Africa has little other generation which could be disrupted by renewables and gas | 🔴 |
| United Kingdom | Coal | The UK government has committed to phasing out coal-fired power stations by 2025[388] | 🔴 |
| United States | Coal | Inexpensive natural gas and renewable energy policies ensures that both gas-fired and renewable power displace coal-fired power. | 🔴 |

Where both historic utilisation rates and policy research indicate risk, the country is considered 'high risk'. Where one of either indicates risk, the country is considered 'medium risk'.

[384] AER (2014). Op. Cit.
[385] Appunn, K. & Russell, R. (2015). Op. Cit.
[386] Sakya, I. (2012). Op. Cit.
[387] Iwata, M. & Hoenig, H. (2015). Op. Cit.
[388] UK Government (2015). Op. Cit.

***Table 33:** Utilisation rate risk hypothesis*

| CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Utilisation rate - Historic | Green | Yellow | Green | Yellow | Yellow | Green | Green | Yellow | Green | Green |
| Utilisation rate - Outlook | Yellow | Yellow | Green | Green | Yellow | Green | Yellow | Yellow | Yellow | Yellow |
| RISK | Yellow | Red | Green | Yellow | Red | Green | Yellow | Red | Yellow | Yellow |

*NRH-U9: Regulatory Water Stress*
The hypothesis is that coal-fired power stations in countries that have strict water use requirements and an awareness of water issues are more likely to be affected by water scarcity through direct or indirect water pricing.

Coal-fired power generation has a substantial water footprint, described in hypothesis LRH-U4: Water Stress. This water footprint exposes coal-fired power utilities to regulatory risks, as policymakers may take action to restrict or price a utility's access to water. Public opinion on the water footprint of power generation may also put pressure on policymakers to restrict water use, exposing utilities to a reputational risk as well.

The World Resources Institute (WRI) maintains the Aqueduct Water Risk Indicator maps. The WRI's Regulatory & Reputational Risk indicator aggregates indicators from the World Health Organization (WHO) concerning water access, the International Union for Conservation of Nature (IUCN) for threatened amphibians, and Google keyword searches for water supply media coverage[389]. With few exceptions, this indicator is provided at the national level.

WRI provides an indicator in five groupings, with low risk in group 1 and very high risk in group 5. In this report, WRI groups 1 and 2 will be considered 'low risk', group 3 will be considered 'medium risk' and group 4 and 5 'high risk'. Of the scope countries, only the United States has multiple subnational stress indicators, however none exist outside groups 1 and 2, allowing consistency with this method.

***Table 34:** Regulatory water stress*[390]

| CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Risk grouping | 1 | 3 | 1 | 4 | 3 | 1 | 2 | 3 | 2 | 1 |
| RISK | Green | Yellow | Green | Red | Yellow | Green | Green | Yellow | Green | Green |

[389] Gassert, F. et al. (2014). Op. Cit.
[390] IEA (2015) WEO 2015. Op. Cit.

*NRH-U10: CCS Legal Environment*

The hypothesis is that CCS could be a way for coal-fired power stations to keep running under stricter carbon constraints, but CCS will not happen without a supportive legal framework.

CCS faces substantial uncertainty with regards to current and future liabilities for the unique aspects of a CCS project, see Section 3.6.2. These uncertainties can present barriers to the development of CCS projects, which in turn present a risk to coal-fired utilities which may not have CCS as an option for future GHG mitigation.

Certain countries have been proactive in developing policy and law specifically for CCS. This progress is periodically evaluated by the Global CCS Institute and published as an indexed indicator. The institute groups countries into three performance bands, which are used here as an indicator for CCS liability risk. Band A, the most CCS-ready, is considered 'low risk', Band B 'medium risk', and Band C 'high risk'.

***Table 35:** CCS legal environment indicator*[391]

| CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Band | A | C | B | C | C | B | B | C | A | A |
| RISK | 🟢 | 🔴 | 🟡 | 🔴 | 🔴 | 🟡 | 🟡 | 🔴 | 🟢 | 🟢 |

[391] Global CCS Institute (2015). CCS Legal and Regulatory Indicator. Op. Cit.

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## 5.3 Summary of Top 100 Coal-Fired Power Utilities

Exposure to environment-related risk of the top 100 coal-fired power utilities is shown in Figure 42 below. For the Local Risk Hypotheses, Table 64 in Appendix A provides further details of the results. Table 36 shows the top 100 coal-fired utilities ranked by risk exposure, with the most exposed ranked the highest. Companies from the United States carry the most exposure to ageing plants (LRH-U2), CCS retrofitability (LRH-U6), and future heat stress (LRH-U7). Companies in China and India are most exposed to conventional air pollution concentration (LRH-U3) and physical water stress (LRH-U4).

***Figure 42:*** *LRH rankings for coal-fired utilities*

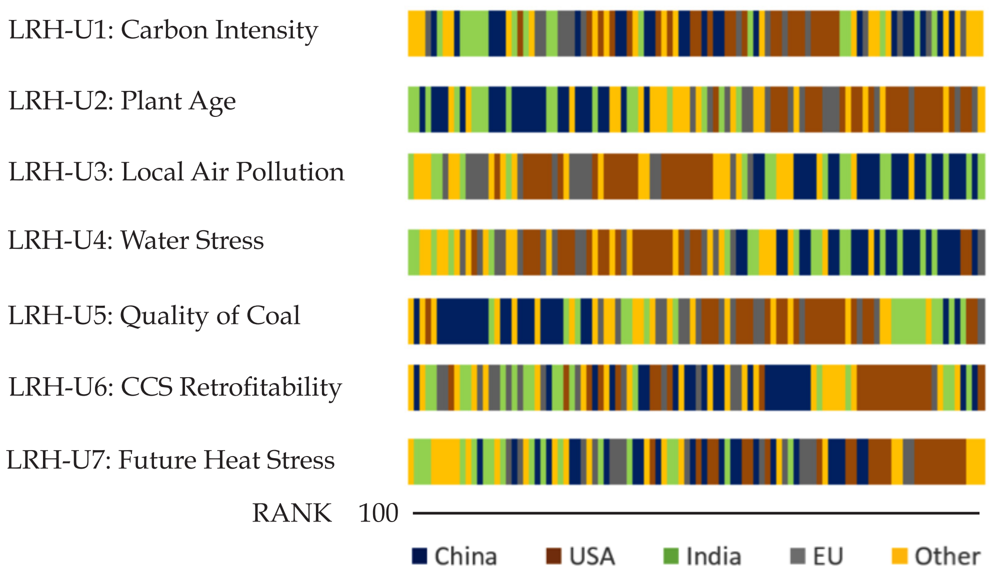


Figure 43 and Figure 44 show planned and under construction new coal-fired generating capacity as a proportion of existing capacity. Utilities in the United States have largely abandoned new coal-fired capacity. Utilities in China and India continue to build and plan power stations. Seven of the 16 Indian utilities in the top 100 are more than doubling their current coal-fired generating capacity. Other outliers include J-Power, Gazprom, Inter RAO UES, Taiwan's Ministry of Economic Affairs, Elektroprivreda Srbije, and Electricity of Vietnam.

***Figure 43:*** *Planned coal-fired capacity as a percentage of current capacity*

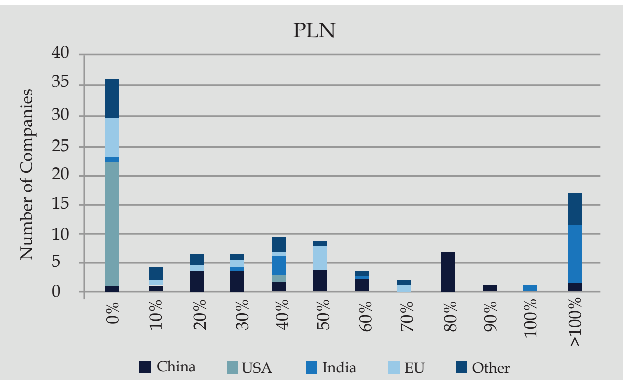


***Figure 44:*** *Coal-fired capacity under construction as a percentage of current capacity*

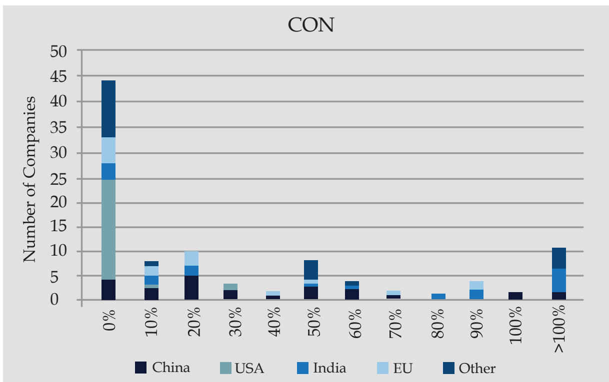

Figure 45 shows the ratios of (EBITDA less CAPEX) / debt repayment for the top 100 coal-fired power utilities. Companies with a ratio less than unity cannot currently service their existing debt. Companies with a negative ratio are expending CAPEX in excess of EBITDA. The five companies with a ratio less than -1 are Vattenfall Group, Eskom Holdings SOC Ltd, Comision Federal de Electricidad, Tauron Polska Energia SA, and Andhra Pradesh Power Gen Corp.

***Figure 45:*** *Histogram of (EBITDA-CAPEX)/interest*

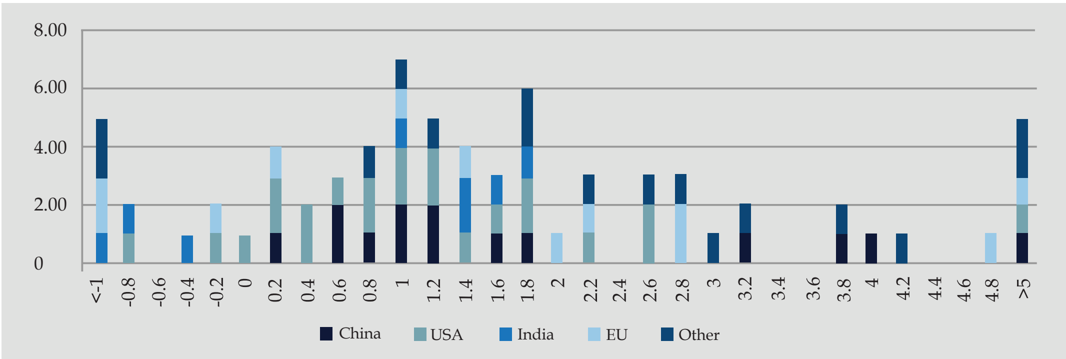


Figure 46 shows the current ratios of the top 100 coal-fired power utilities. European coal-fired utilities have higher current ratios than coal-fired utilities in the United States, which in turn have higher current ratios than Chinese coal-fired power utilities.

***Figure 46:*** *Histogram of current ratios*

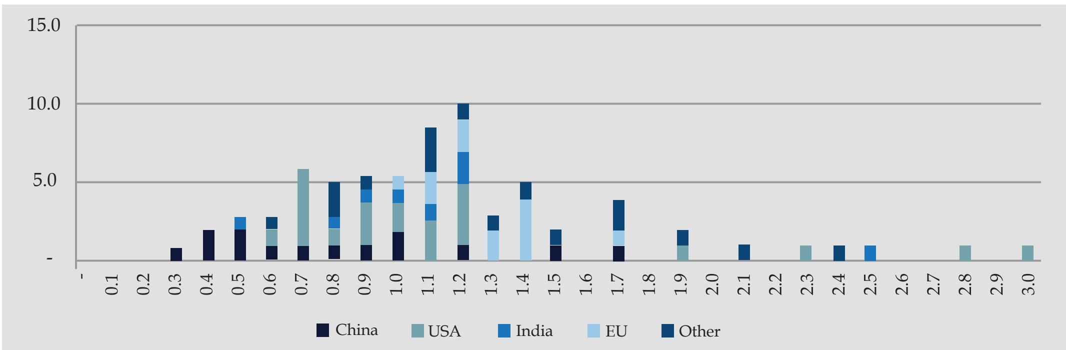


Figure 47 shows the debt-to-equity (D/E) ratios of the top 100 coal-fired power utilities. Utilities in the US are generally more leveraged than utilities in China or Europe. Outliers include Tohuku Electric Power Corp and AES Corp, the only public companies with D/E ratios over 300%.

***Figure 47:*** *Histogram of D/E ratios*

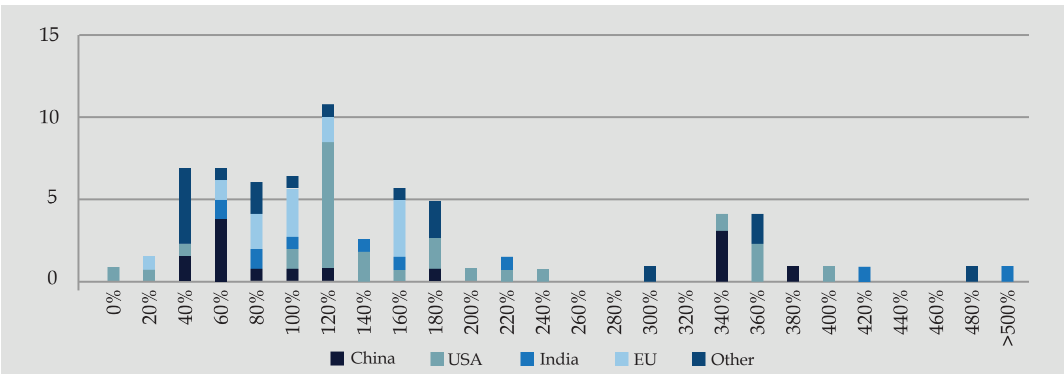

***Table 36:** Summary of environment-related risk exposure of top 100 coal-fired power utilities, companies*

| # | PARENT OWNER | COUNTRY | Coal-Fired Electricity: GENERATION [GWh] | CAPACITY: OPR [MW] | CAPACITY: CON [MW] | CAPACITY: PLN [MW] | DEBT/EQUITY | CURRENT RATIO | (EBITDA-CAPEX) /INTEREST | LRH-U1 'Carbon Intensity' [RANK]* | LRH-U2 'Plant Age' [RANK]* | LRH-U3 'Local Air Pollution' [RANK]* | LRH-U4 'Water Stress' [RANK]* | LRH-U5 'Quality of Coal' [RANK]* | LRH-U6 'CSS Retrofitability' [RANK]* | LRH-U7 'Future Heat Stress' [RANK]* | ASSET BASE | NRH-AGGREGATE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CHINA HUANENG GROUP CORP | China | 471,139 | 160,212 | 5,360 | 91,968 | 3.28 | 0.45x | 0.42x | 57 | 53 | 37 | 25 | 27 | 83 | 51 | CH-100% | 60% |
| 2 | CHINA GUODIAN CORP | China | 455,038 | 148,539 | 20,140 | 111,360 | 3.38 | 0.24x | 0.85x | 53 | 52 | 33 | 21 | 32 | 78 | 37 | CH-100% | 60% |
| 3 | CHINA DATANG CORP | China | 415,118 | 123,635 | 12,230 | 89,521 | 3.69 | 0.47x | 1.16x | 45 | 100 | 39 | 18 | 35 | 90 | 43 | CH-100% | 60% |
| 4 | CHINA HUADIAN GROUP CORP | China | 369,511 | 119,808 | 21,101 | 95,628 | 3.22 | 0.37x | 3.02x | 63 | 100 | 41 | 20 | 39 | 84 | 54 | CH-100% | 60% |
| 5 | CHINA POWER INVESTMENT CORP | China | 293,658 | 82,819 | 16,028 | 35,590 | - | - | - | 50 | 100 | 49 | 14 | 16 | 76 | 44 | CH-99% | 60% |
| 6 | SHENHUA GROUP CORP LTD | China | 292,107 | 89,021 | 42,520 | 67,710 | 0.49 | 0.96x | 0.62x | 87 | 100 | 42 | 29 | 30 | 96 | 47 | CH-100% | 60% |
| 7 | ESKOM HOLDINGS SOC LTD | South Africa | 214,924 | 36,678 | 19,375 | 3,000 | 1.69 | 1.09x | -10.67x | 20 | 36 | 92 | 100 | 100 | 1 | 27 | SA-100% | 55% |
| 8 | NTPC LTD | India | 208,588 | 41,532 | 46,520 | 91,056 | 1.24 | 1.16x | -0.48x | 80 | 49 | 40 | 40 | 24 | 71 | 65 | IN-100% | 45% |
| 9 | CHINA RESOURCES POWER HOLDINGS | China | 171,178 | 55,342 | 13,410 | 24,340 | 1.12 | 0.58x | 3.65x | 40 | 100 | 25 | 16 | 36 | 85 | 61 | CH-100% | 60% |
| 10 | KOREA ELECTRIC POWER CORP | Korea | 128,189 | 23,481 | 30,459 | 7,880 | 0.92 | 1.03x | 1.68x | 38 | 46 | 14 | 48 | 42 | 1 | 48 | OTHER | - |
| 11 | GUANGDONG YUDEAN GROUP CO LTD | China | 126,689 | 43,441 | 9,850 | 13,300 | - | - | - | 69 | 100 | 36 | 100 | 34 | 1 | 66 | CH-100% | 65% |
| 12 | NRG ENERGY INC | USA | 99,685 | 29,576 | - | - | 1.66 | 1.86x | 1.76x | 30 | 8 | 78 | 100 | 31 | 1 | 42 | US-94%, AU-6% | 60% |
| 13 | STATE GRID CORP OF CHINA | China | 97,603 | 22,218 | - | 10,000 | 0.53 | 0.39x | 0.00x | 15 | 48 | 32 | 11 | 14 | 66 | 30 | CH-100% | 60% |
| 14 | GDF SUEZ SA | France | 89,977 | 20,424 | 1,715 | 5,059 | 0.69 | 1.06x | 4.67x | 76 | 37 | 59 | 42 | 20 | 91 | 80 | NOTE-1 | 47% |
| 15 | VATTENFALL GROUP | Sweden | 83,646 | 15,719 | 1,730 | - | 0.97 | 1.35x | -1.16x | 84 | 47 | 53 | 100 | 9 | 79 | 57 | CH-81% | 60% |
| 16 | SOUTHERN CO | USA | 71,669 | 27,819 | 600 | - | 1.23 | 0.65x | -0.15x | 49 | 21 | 87 | 100 | 40 | 69 | 53 | US-100% | 60% |
| 17 | DUKE ENERGY CORP | USA | 67,730 | 22,492 | - | - | 1.07 | 0.97x | 1.68x | 51 | 17 | 71 | 100 | 41 | 67 | 50 | US-99% | 60% |
| 18 | PT PLN PERSERO | Indonesia | 66,467 | 16,763 | 6,730 | 18,350 | 3.42 | 0.84x | 0.88x | 19 | 100 | 30 | 33 | 33 | 87 | 89 | ID-100% | 40% |
| 19 | ENEL SPA | Italy | 62,916 | 17,937 | - | 2,900 | 1.03 | 0.99x | 2.65x | 37 | 24 | 68 | 46 | 23 | 1 | 56 | OTHER | - |
| 20 | AMERICAN ELECTRIC POWER CO INC | USA | 60,917 | 22,577 | - | - | 1.14 | 0.64x | 0.76x | 35 | 13 | 80 | 100 | 38 | 1 | 17 | US-100% | 60% |
| 21 | MINISTRY OF ECONOMIC AFFAIRS | Taiwan | 59,572 | 10,114 | 17,248 | - | - | - | - | 94 | 100 | 1 | 100 | 100 | 1 | 60 | OTHER | - |
| 22 | TENNESSEE VALLEY AUTHORITY | USA | 58,991 | 20,756 | - | - | 3.81 | 0.89x | 0.59x | 27 | 9 | 79 | 100 | 100 | 1 | 19 | US-100% | 60% |
| 23 | E.ON SE | Germany | 53,995 | 13,664 | 6,366 | 5,448 | 0.88 | 1.25x | 2.12x | 70 | 23 | 48 | 45 | 29 | 1 | 78 | DE-45%, UK-15% | 49% |
| 24 | ZHEJIANG ENERGY GROUP CO LTD | China | 53,906 | 13,992 | 7,490 | 2,660 | - | - | - | 92 | 100 | 15 | 37 | 100 | 1 | 58 | CH-100% | 60% |
| 25 | FORMOSA PLASTICS CORP | Taiwan | 52,212 | 9,328 | - | - | 0.38 | 2.35x | 10.37x | 67 | 100 | 43 | 44 | 100 | 1 | 100 | CH-43% | 60% |
| 26 | EDF GROUP | France | 51,803 | 17,288 | 1,000 | 375 | 1.5 | 1.22x | 1.36x | 74 | 34 | 65 | 39 | 100 | 72 | 69 | NOTE-2 | 45% |
| 27 | BEIJING ENERGY INVEST HOLDING | China | 51,504 | 13,180 | 2,020 | 2,720 | - | - | - | 61 | 100 | 58 | 26 | 100 | 89 | 25 | CH-100% | 60% |
| 28 | TATA GROUP | India | 46,454 | 8,468 | 1,320 | 21,145 | - | - | - | 90 | 100 | 1 | 34 | 19 | 1 | 85 | IN-100% | 45% |
| 29 | CLP GROUP | Hong Kong | 45,835 | 10,118 | 4,500 | 4,272 | 0.72 | 0.58x | 4.03x | 54 | 100 | 47 | 30 | 22 | 75 | 77 | NOTE-3 | 58% |
| 30 | ADANI POWER LTD | India | 45,703 | 8,220 | 600 | 13,760 | 9.31 | 0.46x | 1.29x | 91 | 100 | 27 | 100 | 17 | 1 | 86 | IN-100% | 45% |
| 31 | RWE AG | Germany | 42,639 | 10,793 | 4,268 | 4,926 | 1.59 | 1.16x | 0.89x | 31 | 22 | 18 | 100 | 5 | 1 | 88 | DE-96%, 4%UK | 50% |
| 32 | VEDANTA RESOURCES PLC | India | 39,973 | 6,448 | 3,720 | - | 1.47 | 1.13x | 0.94x | 78 | 100 | 50 | 15 | 25 | 70 | 26 | IN-100% | 45% |
| 33 | J-POWER | Japan | 39,407 | 6,805 | 2,900 | 12,072 | - | - | - | 98 | 100 | 61 | 32 | 100 | 1 | 91 | JP-98%, US-2% | 45% |
| 34 | HEBEI CONSTR & INVEST GROUP | China | 38,874 | 10,362 | 1,400 | 2,100 | - | - | - | 12 | 100 | 56 | 5 | 100 | 88 | 29 | CH-100% | 60% |
| 35 | SHANXI INTL ELEC GROUP CO LTD | China | 38,501 | 9,100 | 9,040 | 7,300 | - | - | - | 47 | 100 | 51 | 35 | 100 | 77 | 14 | CH-100% | 60% |
| 36 | DYNEGY HOLDINGS INC | USA | 37,808 | 14,541 | - | - | 2.29 | 2.24x | 1.05x | 28 | 5 | 75 | 100 | 100 | 1 | 22 | US-100% | 60% |
| 37 | RELIANCE INFRASTRUCTURE LTD | India | 36,846 | 9,320 | 7,920 | 5,040 | 0.88 | 1.04x | 1.33x | 95 | 100 | 38 | 6 | 100 | 1 | 52 | IN-100% | 45% |
| 38 | STATE DEV INVESTMENT CORP | China | 35,269 | 12,325 | 17,226 | 6,570 | 1.61 | 1.10x | 1.09x | 72 | 100 | 28 | 41 | 100 | 94 | 28 | CH-100% | 60% |
| 39 | AES CORP | USA | 35,246 | 11,216 | 2,356 | 3,542 | 3.2 | 1.10x | 1.07x | 36 | 29 | 69 | 38 | 100 | 1 | 68 | US-62% | 60% |
| 40 | PUBLIC POWER CORP (DEI) | Greece | 34,147 | 5,597 | - | 2,550 | 0.9 | 1.17x | 1.97x | 10 | 42 | 66 | 100 | 2 | 1 | 39 | OTHER | - |
| 41 | DTEK | Ukraine | 33,049 | 13,526 | 1,960 | 6,050 | - | - | - | 13 | 11 | 67 | 24 | 37 | 1 | 15 | OTHER | - |
| 42 | AGL ENERGY LTD | Australia | 32,727 | 5,238 | - | 2,000 | 0.45 | 1.46x | 2.09x | 7 | 20 | 86 | 100 | 26 | 1 | 100 | AU-100% | 60% |
| 43 | PGE POLSKA GRUPA ENERGETYCZNA | Poland | 32,687 | 8,784 | 7,595 | 3,934 | 0.12 | 1.60x | -0.40x | 41 | 35 | 70 | 100 | 7 | 1 | 21 | PD-100% | 40% |
| 44 | ISRAEL ELECTRIC CORP | Israel | 31,995 | 6,185 | - | 1,260 | 2.93 | 1.19x | 0.71x | 93 | 100 | 52 | 4 | 100 | 1 | 49 | OTHER | - |
| 45 | XCEL ENERGY INC | USA | 31,401 | 9,712 | - | - | 1.25 | 1.08x | 0.25x | 60 | 41 | 95 | 27 | 100 | 1 | 46 | US-100% | 60% |
| 46 | STEAG GMBH | Germany | 31,388 | 7,984 | - | - | - | - | - | 75 | 39 | 29 | 100 | 100 | 73 | 73 | DE-89% | 50% |
| 47 | BERKSHIRE HATHAWAY ENERGY COMPANY | USA | 30,613 | 11,875 | - | - | 0.34 | 1.05x | 8.78x | 42 | 32 | 90 | 17 | 100 | 1 | 1 | US-100% | 60% |
| 48 | DAMODAR VALLEY CORP (DVC) | India | 30,198 | 8,313 | 6,070 | 7,500 | 0.73 | 0.73x | 1.62x | 23 | 100 | 12 | 100 | 100 | 1 | 74 | IN-100% | 45% |
| 49 | MP POWER GENERATING CO LTD | India | 28,989 | 6,613 | - | 2,230 | - | - | - | 18 | 100 | 1 | 100 | 100 | 1 | 100 | IN-100% | 45% |

*NRHs have been aggregated into one indicator, in %.
Note-1: DE-14%, IN-10%, JP-7%, PD-5%, UK-9%, US-4%;
Note-2: PD-21%, CH-7%, UK-32%;
Note-3: AU-43%, CH-37%, IN-13%;
Note-4 to: ID-72%, JP-24%, AU-4%;

**Table 36:** *Summary of environment-related risk exposure of top 100 coal-fired power utilities, companies continued*

| # | PARENT OWNER | COUNTRY | Coal-Fired Electricity GENERATION [GWh] | CAPACITY OPR [MW] | CAPACITY CON [MW] | CAPACITY PLN [MW] | DEBT/EQUITY | CURRENT RATIO | (EBITDA-CAPEX) /INTEREST | LRH-U1 'Carbon Intensity' [RANK]* | LRH-U2 'Plant Age' [RANK]* | LRH-U3 'Local Air Pollution' [RANK]* | LRH-U4 'Water Stress' [RANK]* | LRH-U5 'Quality of Coal' [RANK]* | LRH-U6 'CSS Retrofitability' [RANK]* | LRH-U7 'Future Heat Stress' [RANK]* | ASSET BASE | NRH-AGGREGATE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | SHENERGY COMPANY LTD | China | 27,337 | 7,584 | 2,640 | - | 0.36 | 0.90x | 0.57x | 56 | 100 | 1 | 100 | 100 | 1 | 31 | CH-100% | 60% |
| 51 | JIANGSU GUOXIN INVEST GROUP | China | 27,304 | 16,665 | - | 3,100 | - | - | - | 11 | 100 | 31 | 19 | 100 | 95 | 84 | CH-100% | 60% |
| 52 | COMISION FEDERAL DE ELEC | Mexico | 27,259 | 4,700 | 2,100 | 1,146 | 4.79 | 1.08x | -1.28x | 16 | 100 | 97 | 100 | 100 | 1 | 24 | OTHER | - |
| 53 | CITIC PACIFIC LTD | China | 26,846 | 6,309 | - | 350 | 0.96 | 1.46x | 1.47x | 22 | 100 | 13 | 23 | 100 | 99 | 64 | CH-100% | 60% |
| 54 | TRANSALTA CORP | Canada | 26,173 | 5,078 | - | - | 1.05 | 1.31x | 1.72x | 77 | 33 | 91 | 100 | 100 | 1 | 55 | US-28% | 60% |
| 55 | FIRSTENERGY CORP | USA | 25,844 | 9,950 | - | - | 1.76 | 0.65x | 0.12x | 34 | 14 | 81 | 100 | 100 | 68 | 20 | US-100% | 60% |
| 56 | GUJARAT STATE ELEC CORP LTD | India | 25,757 | 6,094 | 740 | 2,400 | - | - | - | 44 | 100 | 16 | 9 | 12 | 81 | 33 | IN-100% | 45% |
| 57 | PPL CORP | USA | 25,334 | 8,385 | - | - | 1.95 | 0.67x | 0.73x | 68 | 44 | 96 | 100 | 100 | 80 | 35 | US-100% | 60% |
| 58 | DOMINION | USA | 24,647 | 6,583 | - | - | 2.07 | 0.61x | -0.30x | 43 | 6 | 76 | 100 | 100 | 1 | 67 | US-100% | 60% |
| 59 | ANDHRA PRADESH POWER GEN CORP | India | 24,602 | 6,980 | 600 | 12,800 | 4.14 | 0.98x | -2.43x | 89 | 51 | 45 | 31 | 100 | 98 | 82 | IN-100% | 45% |
| 60 | CHUBU ELECTRIC POWER CO INC | Japan | 24,545 | 4,100 | - | 4,265 | 1.64 | 0.73x | 6.22x | 100 | 100 | 100 | 100 | 100 | 1 | 100 | JP-100% | 45% |
| 61 | JINDAL STEEL & POWER LTD | India | 24,430 | 7,077 | - | 19,570 | 2.06 | 0.84x | 1.58x | 81 | 100 | 46 | 100 | 100 | 1 | 72 | IN-100% | 45% |
| 62 | TENAGA NASIONAL BERHAD (TNB) | Indonesia | 22,771 | 8,680 | - | 1,000 | 0.66 | 1.21x | 3.63x | 46 | 100 | 24 | 100 | 100 | 1 | 76 | OTHER | - |
| 63 | OOO SIBERIAN GENERATING CO | Russia | 21,894 | 8,308 | - | 340 | - | - | - | 5 | 31 | 63 | 100 | 15 | 1 | 12 | OTHER | - |
| 64 | ENERGY FUTURE HOLDINGS CORP | USA | 21,640 | 8,496 | - | - | -1.82 | 0.54x | 2.42x | 55 | 40 | 94 | 100 | 3 | 86 | 16 | US-100% | 60% |
| 65 | RIVERSTONE HOLDINGS | USA | 21,534 | 8,309 | - | - | 0 | 2.96x | - | 32 | 15 | 82 | 22 | 100 | 1 | 32 | US-100% | 60% |
| 66 | CEZ AS | Czech | 21,279 | 6,235 | 4,010 | - | 0.64 | 1.30x | 6.65x | 4 | 25 | 60 | 100 | 6 | 1 | 59 | PD-11% | 40% |
| 67 | NEYVELI LIGNITE CORP LTD | India | 20,946 | 4,615 | 6,960 | 18,775 | 0.43 | 2.47x | -0.89x | 64 | 100 | 17 | 1 | 4 | 92 | 79 | IN-100% | 45% |
| 68 | CHEUNG KONG INFRASTRUCTURE | Hong Kong | 20,753 | 6,306 | - | - | 0.26 | 2.00x | 3.00x | 65 | 100 | 10 | 43 | 28 | 1 | 87 | CH-100% | 60% |
| 69 | DTE ENERGY CO | USA | 20,622 | 7,909 | - | - | 1.08 | 1.19x | 1.34x | 29 | 3 | 73 | 100 | 100 | 1 | 1 | US-100% | 60% |
| 70 | HARYANA POWER GEN CO (HPGC) | India | 20,554 | 6,145 | - | 2,120 | - | - | - | 9 | 100 | 20 | 2 | 13 | 1 | 41 | IN-100% | 45% |
| 71 | ELECTRICITY OF VIETNAM (EVN) | Vietnam | 20,273 | 5,434 | 11,002 | 600 | - | - | - | 58 | 45 | 34 | 100 | 100 | 1 | 83 | OTHER | - |
| 72 | GREAT PLAINS ENERGY INC | USA | 19,533 | 5,647 | - | - | 1.11 | 1.00x | 0.84x | 62 | 16 | 83 | 100 | 100 | 1 | 1 | US-100% | 60% |
| 73 | WEST BENGAL POWER DEV CORP | India | 19,160 | 5,480 | 2,600 | 6,500 | - | - | - | 14 | 43 | 1 | 100 | 100 | 1 | 100 | IN-100% | 45% |
| 74 | HENAN INVESTMENT GROUP CO LTD | China | 18,830 | 6,530 | 6,640 | 1,670 | - | - | - | 17 | 100 | 26 | 8 | 100 | 82 | 36 | CH-100% | 60% |
| 75 | WISCONSIN ENERGY CORP | USA | 18,779 | 4,493 | - | - | 1.15 | 0.82x | 2.43x | 79 | 26 | 88 | 100 | 100 | 1 | 34 | US-100% | 60% |
| 76 | INTER RAO UES | Russia | 18,007 | 8,030 | 3,235 | 11,624 | 0.26 | 1.69x | 2.81x | 59 | 27 | 57 | 100 | 10 | 1 | 18 | OTHER | - |
| 77 | TAMIL NADU GEN & DIST CORP LTD | India | 16,842 | 4,320 | 3,590 | 6,880 | - | - | - | 73 | 100 | 1 | 13 | 100 | 97 | 100 | IN-100% | 45% |
| 78 | ZHEJIANG PROV ENERGY GROUP CO | China | 16,476 | 6,260 | 6,020 | 2,460 | 0.48 | 1.68x | 0.85x | 83 | 100 | 22 | 7 | 100 | 1 | 81 | CH-100% | 60% |
| 79 | DATONG COAL MINE GROUP CO LTD | China | 16,426 | 6,670 | 4,540 | 5,080 | - | - | - | 85 | 100 | 11 | 10 | 100 | 1 | 1 | CH-100% | 60% |
| 80 | TOHOKU ELECTRIC POWER CO | Japan | 15,663 | 2,701 | - | 1,800 | 3.48 | 0.71x | 2.74x | 99 | 100 | 99 | 100 | 100 | 1 | 75 | JP-100% | 45% |
| 81 | AMEREN CORP | USA | 15,222 | 5,829 | - | - | 1 | 0.80x | 0.82x | 26 | 4 | 74 | 100 | 100 | 1 | 1 | US-100% | 60% |
| 82 | RAJASTHAN RV UTPADAN NIGAM | India | 15,128 | 6,580 | 10,020 | 1,570 | - | - | - | 24 | 100 | 44 | 3 | 18 | 1 | 13 | IN-100% | 45% |
| 83 | SHENZHEN ENERGY GROUP CO LTD | China | 15,105 | 3,744 | - | 12,100 | 0.64 | 0.83x | 1.66x | 8 | 100 | 1 | 100 | 100 | 1 | 100 | CH-100% | 60% |
| 84 | SUMITOMO CORP | Japan | 14,876 | 5,514 | 500 | 7,545 | 1.58 | 1.65x | 2.56x | 82 | 50 | 19 | 100 | 100 | 100 | 90 | NOTE-4 | 42% |
| 85 | MAHARASHTRA STATE POWER GEN CO | India | 14,776 | 5,550 | 5,940 | 13,210 | - | - | - | 88 | 100 | 1 | 100 | 100 | 1 | 63 | IN-100% | 45% |
| 86 | CHINA PETRO & CHEM (SINOPEC) | China | 14,747 | 4,074 | 2,300 | 600 | 0.32 | 0.76x | 3.90x | 6 | 100 | 21 | 36 | 21 | 74 | 45 | CH-100% | 60% |
| 87 | ECU - ENERGY CO OF UKRAINE | Ukraine | 14,068 | 5,475 | - | - | - | - | - | 21 | 10 | 62 | 47 | 43 | 1 | 1 | OTHER | - |
| 88 | ENBW ENERGIE BADEN-WURTTEMBERG | Germany | 13,096 | 6,301 | 708 | - | 1.57 | 1.36x | 0.03x | 97 | 100 | 35 | 100 | 100 | 1 | 62 | DE-100% | 50% |
| 89 | TAURON POLSKA ENERGIA SA | Poland | 12,954 | 4,242 | 3,595 | 2,594 | 0.45 | 1.39x | -1.22x | 33 | 30 | 54 | 100 | 45 | 1 | 40 | PD-100% | 40% |
| 90 | ENTERGY CORP | USA | 12,880 | 4,997 | - | - | 1.51 | 1.19x | 1.48x | 48 | 28 | 89 | 100 | 100 | 1 | 1 | US-100% | 60% |
| 91 | ALLIANT ENERGY CORP | USA | 11,666 | 3,950 | - | - | 1.01 | 1.10x | 0.28x | 25 | 18 | 84 | 100 | 100 | 1 | 1 | US-100% | 60% |
| 92 | UTTAR PRADESH RAJYA VIDYUT | India | 11,270 | 3,490 | 5,690 | 3,845 | - | - | - | 86 | 100 | 1 | 100 | 100 | 1 | 71 | IN-100% | 45% |
| 93 | SCOTTISH AND SOUTHERN ENERGY | United Kingd | 11,049 | 4,206 | - | - | 1.1 | 1.01x | 2.65x | 71 | 2 | 72 | 100 | 100 | 1 | 100 | UK-100% | 45% |
| 94 | BASIN ELECTRIC POWER COOP | USA | 10,806 | 3,688 | - | - | 3.41 | 0.77x | -0.98x | 52 | 38 | 93 | 12 | 11 | 1 | 1 | US-100% | 60% |
| 95 | EUROSIBENERGO | Russia | 10,072 | 3,979 | - | - | - | - | - | 1 | 12 | 64 | 100 | 44 | 1 | 11 | OTHER | - |
| 96 | WENERGY-ANHUI PROV ENERGY | China | 10,054 | 4,345 | 1,800 | 3,320 | 0.5 | 0.67x | 7.29x | 96 | 100 | 23 | 28 | 100 | 93 | 70 | CH-100% | 60% |
| 97 | SANTEE COOPER | USA | 9,129 | 3,620 | - | - | 3.53 | 2.74x | 2.05x | 66 | 100 | 98 | 100 | 100 | 1 | 100 | US-100% | 60% |
| 98 | SALT RIVER PROJECT (AZ) | USA | 8,356 | 3,231 | - | - | 0.94 | 0.98x | 0.01x | 39 | 7 | 77 | 100 | 100 | 1 | 23 | US-100% | 60% |
| 99 | GAZPROM | Russia | 7,100 | 3,786 | 9,705 | 2,130 | 0.24 | 1.86x | 1.08x | 2 | 19 | 85 | 100 | 8 | 1 | 1 | OTHER | - |
| 100 | ELEKTROPRIVREDA SRBIJE (EPS) | Serbia | 2,041 | 446 | - | 6,439 | - | - | - | 3 | 1 | 55 | 100 | 1 | 1 | 38 | OTHER | - |

*: Companies are ranked by exposure, with 1 being the most at risk.

**: NRHs have been aggregated to a single outlook percentage based on the sum of high risk (+2) and medium risk (+1) evaluations relative to the maximum possible and weighted by asset locations.

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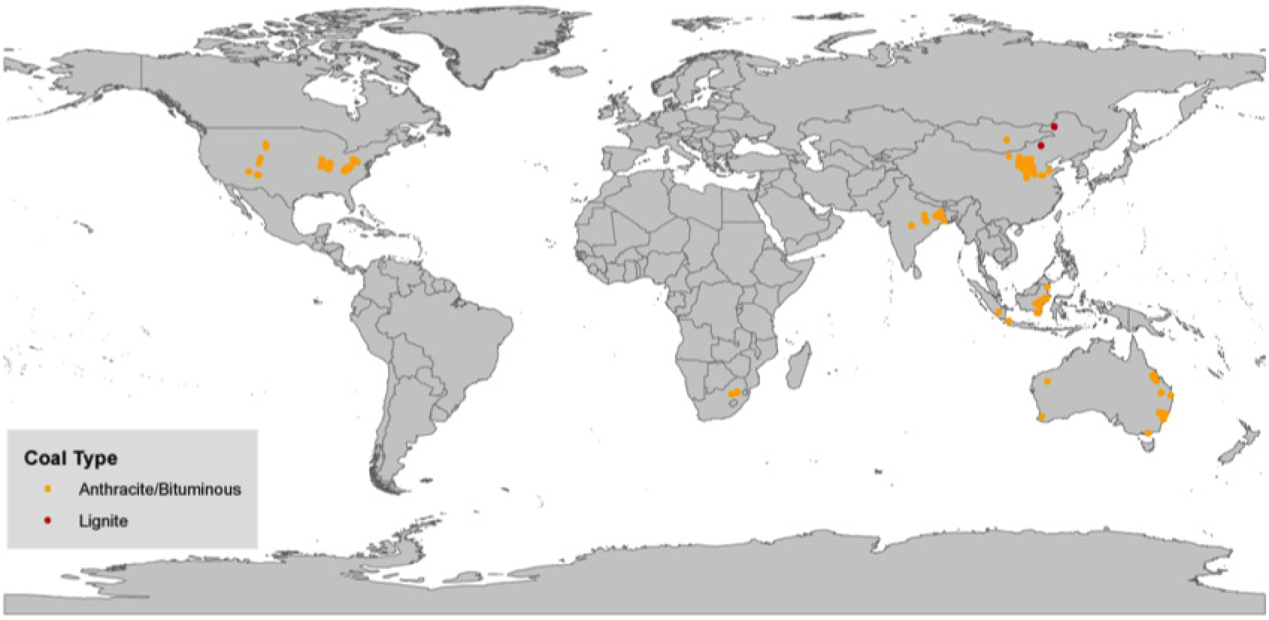
# 6 Thermal Coal Miners

The top 20 thermal coal miners by revenue, with thermal coal revenue ≥30%, are examined for their exposure to environment-related risks. First, the capital expenditure plans, ownership structures, and debt obligations of thermal coal miners are examined. Then a number of hypotheses pertaining to the environment-related risk exposure to the companies are developed and tested. With these hypotheses, an opinion is developed on the environment-related risks facing the companies' capital plans and debt obligations. Figure 48 shows the location of the mines of the world's top 20 thermal coal mining companies. The top 20 thermal coal mining companies in this study had US$85bn in revenue in 2014, approximately 60%[392] of all listed company thermal coal revenue.

***Figure 48:** Mines of the world's top 20 thermal coal mining companies with thermal coal revenue ≥30%*




[392] Approximate total revenue for top 44 thermal coal companies (>75% revenue from thermal coal) and top 16 'balanced' (i.e. met and thermal coal companies) taken from CTI & Energy Transition Advisors (2014). Coal Financial Trends. Assuming a 50/50 split for 'balanced' companies, total revenue for listed coal companies with market cap ≥US$200mn and thermal coal revenue ≥25% is approximately US$140bn.

# 6.1 Market Analysis

## *6.1.1 Capital Projects Pipeline*

The capital expenditure projections of the top 20 thermal coal mines is shown in Table 65 in Appendix B. Emerging environment-related risks may expose capital spending to risk of stranding.

## *6.1.2 Ownership Trends*

Table 66 in Appendix B shows ownership information for the top 20 thermal coal mining companies. For each company, the location of the head office, the ultimate corporate parent, corporate parent's ownership type, and the aggregate market value (in billion US$s) of the various holders' positions are shown.

Table 37 summarises ownership type of the coal mining companies' ultimate corporate parents. Across all companies, the ultimate corporate parents are 65% publicly owned companies, and 35% privately owned companies. At a regional level, China's coal mining companies are owned mostly by private firms. The US's and Indonesia's coal mining companies are all publicly owned. Of the three mining companies in India, two are publicly owned. The two remaining companies, Sasol and Banpu Public Company, are publicly owned. Table 66 shows all ownership data for thermal coal miners.

***Table 37:*** *Distribution of ownership for coal mining companies, by region**

| | Government | Private Company | Private Investment Firm | Public Company | Public Investment Firm |
|---|---|---|---|---|---|
| (A) Total | 0.0% | 35.0% | 0.0% | 65.0% | 0.0% |
| | (0) | (7) | (0) | (13) | (0) |
| (B) China | 0.0% | 85.7% | 0.0% | 14.3% | 0.0% |
| | (0) | (6) | (0) | (1) | (0) |
| (C) US | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| | (0) | (0) | (0) | (5) | (0) |
| (D) India | 0.0% | 33.3% | 0.0% | 66.7% | 0.0% |
| | (0) | (1) | (0) | (2) | (0) |
| (E) Indonesia | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| | (0) | (0) | (0) | (3) | (0) |
| (F) Other | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| | (0) | (0) | (0) | (2) | (0) |

*Numbers in parentheses represent the number of observations

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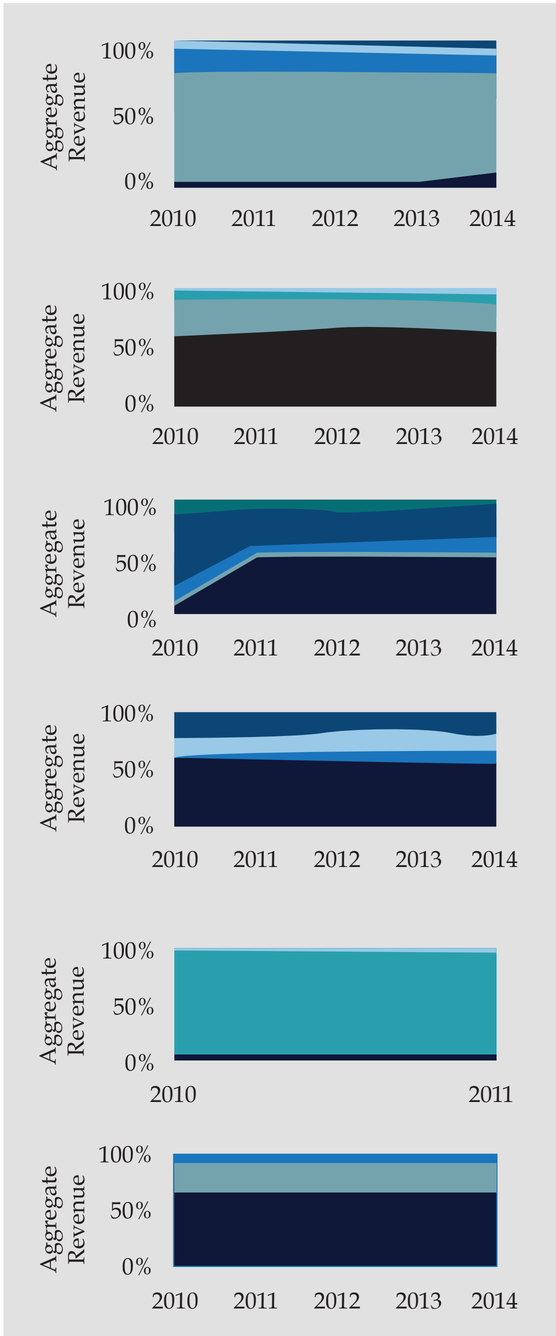
### *6.1.3 Diversification Trends*

Thermal coal miners might be more resilient to environment-related risks if their business activities are diversified. The revenue sources the top 20 thermal coal miners (by ultimate corporate parent) have been obtained from Trucost and weighted by company EBITDA, see Figure 49.

***Figure 49:*** *Coal mining diversification trends*[393]




**China** (6/7*) – Chinese coal miners have made the mainstay of their revenue from underground coal mining and a small portion of coal-fired power generation. Petrochemical and surface mining activities are slowly emerging.

*Number of companies for which data was available

**US** (4/5) – Underground mining is giving way to surface mining in the United States. Coal mining companies are also becoming increasingly involved in petrochemical activities.

**India** (3/3) – Indian thermal coal miners for which data are available have diversified activities: power generation, coal-fuelled or otherwise, and other activities. Most coal is surface mined.

**Indonesia** (3/3) – Indonesia's thermal coal miners conduct surface mining almost exclusively and are diversified into power generation with fuels other than coal and non-related business activities. Coal power generation activities have begun recently.

**South Africa** (1/1) – Most of the revenue of South Africa's thermal coal miners is derived from petrochemical processing activities. These companies are therefore highly exposed to the CPT risks discussed below.

**Thailand** (1/1) – The revenue of Banpu Public Company ltd has been shifting slowly from surface coal mining to underground coal mining, with consistent power generation revenue.

■ Surface Coal Mining ■ Underground Coal Mining ■ Coal Power Generation ■ Other
■ Other - Petrochem ■ Other - Mining ■ Other Power Generation

[393] Data from Trucost, November 2015; and MSCI, October 2015.

### *6.1.4 Bond Issuances*

For thermal coal mining companies, exposure to high levels of debt increases risk for both debt and equity holders as the priority of either is further diluted in the event of the company's insolvency. Table 67 in Appendix B shows bond issuances of the top 20 thermal coal mining companies.

To build a general picture of the future direction for the thermal coal mining industry, fixed-income securities are examined through ratio analysis. Table 68 in Appendix B presents financial ratios relating to: profitability, capital expenditures, liquidity, leverage, debt coverage, and the ability for utilities to service existing debt. Figure 50 illustrates the same ratios through time, including the 25th and 75th percentile ranges to capture the ratio distributions across firms. Analysis is conducted between 1995 and 2014 to represent the last 20 years of data[394]. The dataset for 2015 was limited, and is thus omitted to prevent bias in ratios. The majority of coal-mining companies were publicly traded, although some financial data for private miners were unavailable.

Box 8 presents credit rating evaluations for three of the top thermal coal mining companies.

***Box 8:** Environment-related risks and rating downgrades of thermal coal mining companies*

Ratings services such as Standard & Poor's and Moody's provide opinions of risk for investible companies. Ratings analyses were obtained from Standard & Poor's Rating Services (S&P) of the top 20 thermal coal mining companies which suffered credit downgrades due to climate or environmental factors between 2013 and 2015.

In December 2013, S & P lowered Alpha Natural Resource's Corporate Credit Rating to 'B' from 'B+', citing the health of thermal and met coal markets and Alpha's position as a producer in the Central Appalachian coal basin (footnote). S & P cites competition from US natural gas as causing the structural decline of coal mining in this basin. In August 2014, the outlook for Arch Coal was similarly reduced to 'negative' from 'stable' based on the weak outlook of the met and thermal coal markets (footnote). S & P cites Arch coal's production of 'clean', low-sulphur coal as making Arch Coal more resilient to environmental regulations for coal-fired power utilities.

The business risks analysed for thermal coal mining companies are generally related to market outlook, diversification, and cost position. S&P examines a company's cash position, including its profitability, leverage, and liquidity, to provide an opinion on the financial risk of the company.

From the analyses available of thermal coal miners, very little reference is made to environment-related risk factors. If at all, it is aggregated generally with 'regulatory' risk exposure. Reduced sales and prices are related to commodity cycles rather than any structural change in long-term demand. How environment and climate risks have entered S&P credit rating has been discussed in Box 7.

The available ratings are shown in Table 38.

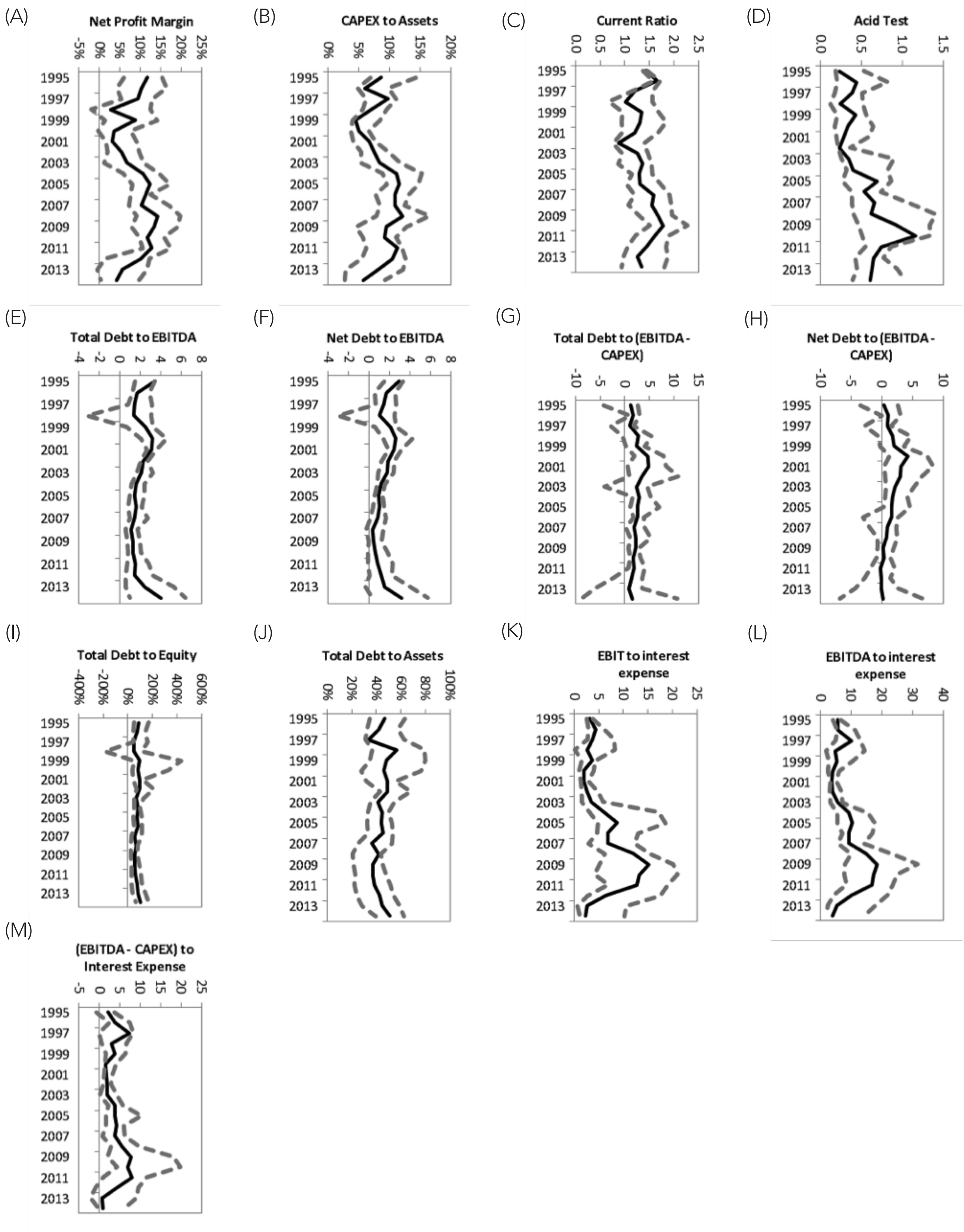
***Table 38:** Available credit ratings for thermal coal miners[395]*

| Company | Business Risk | Financial Risk | Rating | Date |
|---|---|---|---|---|
| Alpha Natural Resources Inc | Weak | Highly Leveraged | B/Stable/-- | 2014/06/10 |
| Arch Coal Inc | Fair | Highly Leveraged | B/Negative/-- | 2014/10/29 |
| China Shenhua Energy Co Ltd | Strong | Modest | AA-/Stable/-- | 2015/01/06 |

[394] Standard & Poor's RatingDirect (2013). Research Update: Arch Coal Inc. Corporate Credit Rating Lowered To 'B' From 'B+', Outlook Stable; Debt Ratings Lowered To 'B+' And 'CCC+'.

[395] Standard & Poor's RatingDirect (2014). Research Update: Alpha Natural Resources Inc. Corporate Credit Rating Lowered To 'B' From B+', Outlook Stable; Debt Ratings Lowered.

**Figure 50:** *Ratio analysis for all thermal coal mining companies, with median, 25th and 75th percentiles*



The first two ratios examined report general profitability and capital expenditure in the thermal coal mining industry, which are both relevant to the industries' ability to service its debt commitments. Profit margins are shown in Figure 50, Chart (A), which have been volatile through time, ranging from 2.8% to 14.2%. Since 2013, profit margins have remained as low as 4.4%. The spike in profit margins between 2004 and 2012 appears to coincide with the spike in global coal prices.

Capital expenditure represents the funds required to acquire, maintain, or upgrade existing physical assets. Chart (B) shows that capital expenditure, relative to total assets, has also been volatile through time, ranging from 4.5% to 12.2% of total assets. The ratio suggests that the coal mining industry is relatively expensive to maintain compared to the coal-fired power utilities. Equally, it could be the result of a smaller asset-base. Similar to the coal-fired utility industry, the peak in capital expenditure mostly occurs following the GFC. In 2013 and 2014, respective capital expenditure was 8.2% and 5.8%.

The current ratio and acid test are used as proxies for liquidity in the industry. The former measures the ability to service current liabilities using current assets, the latter measures the ability to service current liabilities using cash, near-cash equivalents, or short-term investments. Charts (C) and (D) show both liquidity ratios have increased through time. The coal mining industry has greater liquidity than the coal-fired power utility industry. The greatest liquidity in the coal mining industry occurs between 2007 and 2011, where the current ratios range between 1.56 and 1.78. The acid test ratio shows a similar trend, suggesting thermal coal mining firms are holding a greater amount of cash, near-cash equivalents, or short-term investments. Despite volatile profitability, the coal mining industry is relatively liquid in comparison to the coal-fired power utility industry.

Two financial leverage ratios are examined: the debt/equity ratio in Chart (I) and the debt/assets ratio in Chart (J). Chart (I) shows that the debt/equity ratio has been volatile across time. In particular, there is a large change in leverage ratios in the late-1990s, which coincides with a large number of firms entering the market. The leverage ratios have been on an upward trajectory towards parity since 2010, suggesting increasing use of debt to fund operations. Chart (J) shows debt typically represented less than half of total assets, but achieved parity in 2014. The increases in leverage suggest the industry is financing its growth with debt and/or may be retiring some equity, which can translate to greater financial risk, interest expenses, and volatile earnings.

Coverage ratios measure the industry's ability to meet its financial obligations. Three ratios are considered: 1) EBIT/interest, 2) EBITDA/interest, and 3) (EBITDA-CAPEX)/interest. Compared to the utility industry, coverage ratios have greater volatility. All three coverage ratios for the coal mining industry peak in 2009, when interest expenses were relatively low compared to operating income. Since 2009, the ratios have been on an accelerated downward trajectory. In 2014, Chart (K) shows that the operating income of the industry was only 2.28 times interest expense in 2014. Accounting for depreciation and amortization of assets, Chart (L) shows the 2014 EBITDA/interest ratio increases to 4.00, suggesting depreciation and amortization of assets. Capital expenditures also represents a major expense for the mining industry. When deducting annual CAPEX, Chart (M) shows that industry only just generates enough cash to meet interest payments. In 2013, the mining industry's interest expense was greater than (EBITDA-CAPEX), resulting in a ratio less than 1. The ratio remains less than unity in 2014. The ratios indicate that the mining industry becoming increasingly distressed and income is now beginning to trend below the cost of debt.

Four ratios represent the mining industry's ability to retire incurred debt. The ratios can be broadly interpreted as the amount of time needed to pay off all debt, ignoring interest, tax, depreciation and amortization.

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The ratios are divided into two groups: group 1 considers the numerators 'total debt' and 'net debt', where the latter subtracts cash and near-cash equivalents for total debt; group 2 considers the denominators EBITDA and (EBITDA-CAPEX), where the latter controls for capital expenditures.

In contrast to the utility industry, the mining industry's debt remains relatively low in comparison to earnings. Considering Charts (E) and (F), the 2014 ratios suggest the industry can pay off its debt between 3.20 and 4.06 years. The spread between the two ratios suggest that the industry is holding a reasonable amount of cash equivalents which can contribute to retiring debt. When deducting CAPEX, the ratios decline. Charts (G) and (H) suggest the industry could pay off its existing debt, subject to the conditions outlined above, between 1.56 and 0.22 years. Rapidly increasing levels of debt and high CAPEX represent major factors in the industry's ability to retire debt.

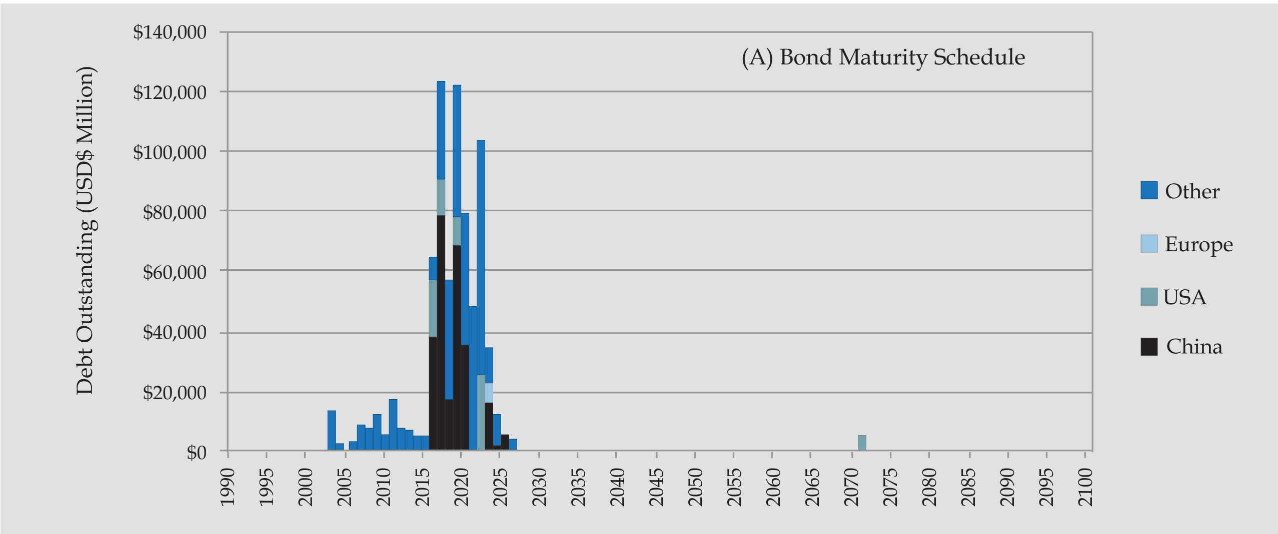
Figure 51 illustrates the maturity schedule for the thermal coal mining industry, using available data from 20 of the 30 thermal coal mining companies. The schedule is divided into total amount outstanding (USD) and the maturity dates of various contracts. Both graphs are delineated by major region, including: China, US, Europe, and 'other'.

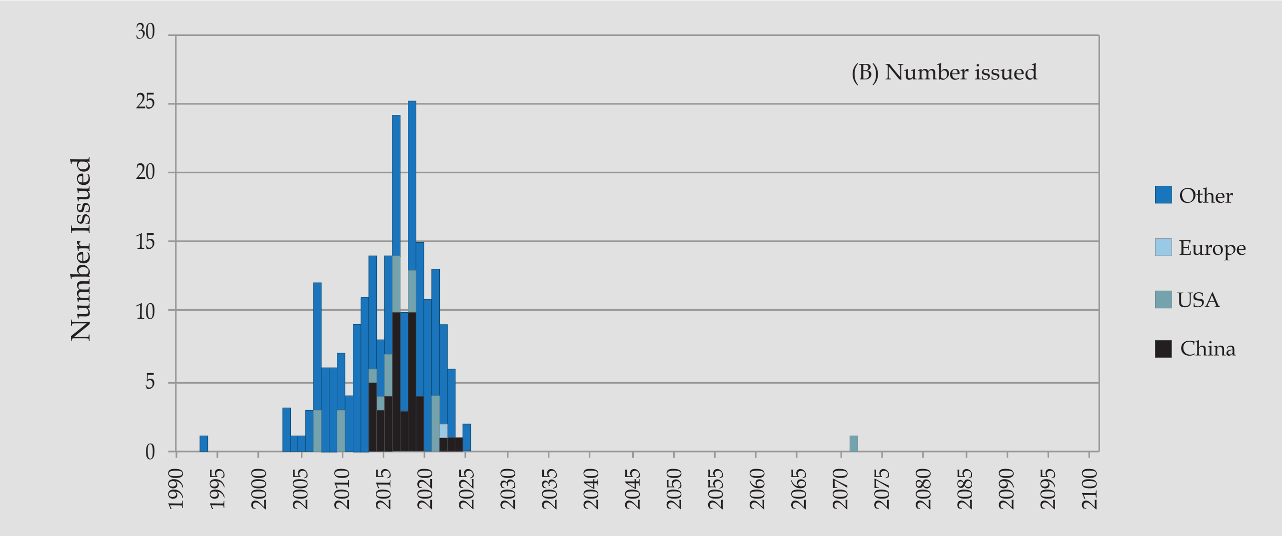
Plot (A) of Figure 51 shows that the majority of the total debt is due between 2016 and 2026. There is almost no borrowing beyond this date in our sample. Whereas borrowing for European and US thermal coal miners is low, companies in China and the other regions represent the majority of debt obligations. Plot (B) shows a similar trend. Companies in China and 'other regions' have issued a large number of contracts until 2025-26. This could signal that either the industry is unable to borrow, or prefers to issue debt which typically matures within 10 years. Table 39 shows that companies in the US and India represent the only two countries with perpetual debt in our sample.

***Table 39:*** *Thermal coal mining companies' perpetual debt*

| | China | US | Europe | Other |
|---|---|---|---|---|
| Amount outstanding (US$m) | 0 | $300 | 0 | $125 |
| Number issued | 0 | 1 | 0 | 1 |

***Figure 51:*** *Maturity schedules for industry debt: debt outstanding (A) and maturity dates (B)*






## 6.2 Investment Risk Hypotheses

In this section, we take a view on what the environment-related risks facing thermal coal miners could be and how they could affect asset values. We call these Local Risk Hypotheses (LRHs) or National Risk Hypotheses (NRHs) based on whether the risk factor in question affects all assets in a particular country in a similar way or not. For example, water stress has variable impacts within a country and so is an LRH, whereas a country-wide carbon price is an NRH. The hypotheses are coded for easier reference. For example, LRH-M1 refers to proximity to populations and protected areas and NRH-M1 refers to remediation liability exposure.

Hypotheses for different environment-related risks have been developed through an informal process. We produced an initial long list of possible LRHs and NRHs. This list was reduced to the more manageable number of LRHs and NRHs contained in this report. We excluded potential LRHs and NRHs based on two criteria. First, we received feedback from investors and other researchers in meetings, roundtables, and through correspondence, on the soundness, relevance, and practicality of each hypothesis. Second, we assessed the data needs and analytical effort required to link the hypotheses with relevant, up-to-date, and where possible, non-proprietary, datasets.

The current list of hypotheses and the datasets used to measure asset exposure to them are in draft form. Other datasets may have better correlations and serve as more accurate proxies for the issues we examine. Important factors may not be represented in our current hypotheses. We are aware of these potential shortcomings and in subsequent research intend to expand the number of hypotheses we have, as well as improve the approaches we have used to analyse them.

The summary table that shows the exposure of the top 20 thermal coal miners to each NRH and LRH can be found in Section 6.3.

### 6.2.1 Local Risk Hypotheses

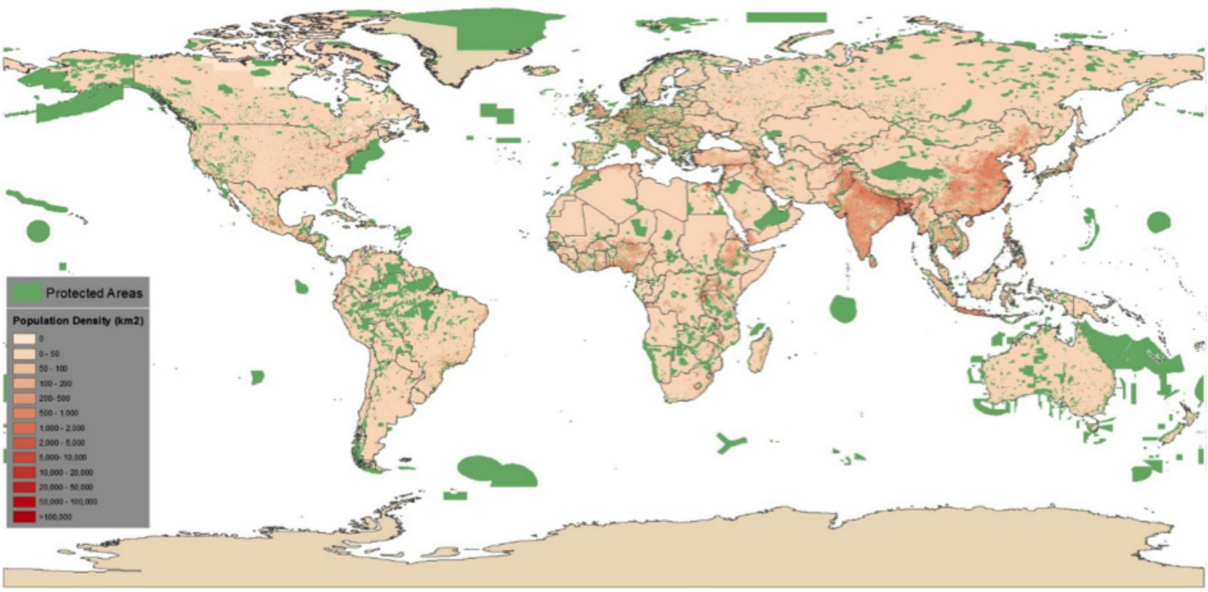
Local risk indicators have been developed to provide a view of environment-related risk exposure due to conditions local to each thermal coal mine. Risk indicators have been developed and informed by geographic analysis using publicly available datasets. Table 70 in Appendix B describes the local risk indicators aggregated for the top 20 thermal coal miners with more detail.

#### *6.2.1.1 LRH-M1: Proximity to Populations and Protected Areas*

Thermal coal mining has extensive local environmental impacts. Where a densely populated area or a sensitive ecosystem is exposed to these impacts, the mining company could be more vulnerable to reputational and regulatory risk. Policymakers may intervene to protect either the natural environment or local population. An example is the Carmichael Coal Mine and Rail Project in Australia which was assessed under the EPBC Act for its impact on protected species[396]. Media coverage of such impacts can affect a company's reputation, which may, in turn, influence its negotiation positions with contractors and suppliers or stock price compression multiples[397].

To assess exposure to this risk, the dataset of thermal coal mine assets developed by the Oxford Smith School has been geographically matched with the UNEP-WCMC World Database on Protected Areas and the SEDAC Gridded Population of the World version 3, 2015 dataset. Thermal coal mining companies are assessed for the number of mines they have within 40km of a protected area and the average local population density. The ranking within the top 20 thermal coal mining companies is averaged for both these categories to provide an aggregate view of risk exposure due to proximity to human populations and protected areas.

***Figure 52:** World population density and protected areas*




#### *6.2.1.2 LRH-M2: Water Stress*

The hypothesis is that thermal coal mines located in areas with high physical baseline water stress or in areas with water conflict or regulatory uncertainty are at greater risk of being forced to reduce or cease operation, of losing their licence to operate, or of having profits impaired by water pricing.

[396] Australian Government (2015). Carmichael Coal Mine and Rail Project, Department of the Environment.

[397] Ansar, A., Caldecott, B., & Tilbury, J. (2013). Stranded assets and the fossil fuel divestment campaign: what does divestment mean for the valuation of fossil fuel assets?, Smith School of Enterprise and the Environment, University of Oxford. Oxford, UK.

Water is used in coal mining for coal cutting and dust suppression, washing (beneficiation), and slurry pipeline transport[398]. Underground mining requires less water than surface mining, and coal washing and slurry transport can substantially increase the water footprint per unit of energy. Approximately 40% of mined coal in China is washed[399] and raising standards for advanced coal-fired power stations may exacerbate water demand from coal washing. Advanced combustion technologies require higher quality coals which can be created by upgrading lower quality coals through beneficiation.

The measure for water stress used in this report is Baseline Water Stress (BWS) from Aqueduct created by the World Resources Institute (WRI). BWS is defined as total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percentage of the total annual available flow within a given watershed. Higher values indicate greater competition for water among users. Extremely high water stress areas are determined by WRI as watersheds with >80% withdrawal to available flow ratios, 80-40% as high water stress, 40-20% as high to medium, 20-10% as medium to low, and <10% as low.[400]

All coal mines are mapped against the Aqueduct Baseline Water Stress geospatial datasets. Those mines that are in watersheds that have 'extremely high water risk'[401] for baseline water stress are identified as 'at risk'. Mines are then aggregated by mining company to identify the percentage of mines that are 'at risk'. Insufficient data is available to assess whether a mine washes coal on site, and these complexities are therefore omitted.

See Figure 35 for a graphic of global baseline water stress.

### 6.2.2 National Risk Hypotheses

The hypotheses below have been developed on a country-by-country basis, affecting all the coal mines in that country. A simple traffic light method has been used to conduct analysis for these risk hypotheses. They are well suited to complex situations where more formal analysis is unavailable or unnecessary and are often used in environmental and sustainability analysis, e.g. DEFRA[402], the World Bank[403]. The hypotheses developed below draw on the IEA NPS as a conservative scenario and add additional evidence to give a more complete policy outlook for coal-fired utilities.

An effective traffic light method clearly describes threshold values or criteria for each colour, which are testable by analysis or experiment [404]. Criteria are developed below for each hypothesis, with conclusions as to whether coal mining companies in a country are at high risk (red), medium risk (yellow) or low risk (blank). An aggregate outlook is arrived at after scoring each criteria (+2 for high risk criteria, +1 for medium risk criteria).

[398] Mielke, E. Anadon, L., & Narayanamurti, V. (2010). Water consumption of energy resource extraction, processing, and conversion, Harvard Kennedy School. Cambridge, US.

[399] Wang, W. (2013). 'China thermal coal washing rate remains low', China Coal Resource.

[400] Gassert, F. et al. (2014). Op. Cit.

[401] Baseline water stress measures the ratio of total annual water withdrawals to total available annual renewable supply, accounting for upstream consumptive use. Extremely high water risk signifies that >80% of renewable supply is withdrawn.

[402] DEFRA (2013). Op. Cit.

[403] The World Bank (2016). Op. Cit.

[404] Halliday, R. (2001). Op. Cit.

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***Table 40:** National-level environment related risk indicators*

High Risk (+2) · Medium Risk (+1) · Low Risk (+0)

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| NRH-M1: Remediation Liability Exposure | Medium | Low | Low | Low | Low | Low | Low | Low | Low | High |
| NRH-M2: Environmental Regulation | High | Low | Low | Low | Low | Low | Low | High | Low | Low |
| NRH-M3: New Mineral Taxes or Tariffs | Low | High | Low | High | Medium | Low | Low | Medium | Low | Low |
| NRH-M4: Type of Coal Produced | Medium | Low | High | Low | Medium | Low | High | Low | Medium | Low |
| NRH-M5: Domestic Demand Outlook | Medium | Medium | High | Low | Low | High | High | Medium | High | High |
| NRH-M6: Export Sensitivity | High | Low | Low | High | Low | Low | Low | Medium | Low | Medium |
| NRH-M7: Protests and Activism | High | Medium | Medium | Medium | High | Low | Medium | Medium | High | High |
| NRH-M8: Water Regulatory Stress | Low | Medium | Low | High | Medium | Low | Low | Medium | Low | Low |
| TOTAL (/16) | 9 | 5 | 5 | 7 | 5 | 2 | 5 | 7 | 5 | 7 |

*NRH-M1: Remediation Liability Exposure*

The hypothesis is that stricter remediation liability regulation or enforcement would negatively affect mine economics and potentially create new liabilities.

Coal miners are often liable for the remediation of land impacted by their mining activities. In some countries, thermal coal mining companies have been allowed to self-guarantee their ability to remediate their activities, which state regulators allow on the basis of the financial health of the company (see e.g. Section 4.10.4 and related report from the International Council on Mining & Metals [405]). Recently, policymakers have begun to re-examine the financial health of companies they allow to self-guarantee remediation. Additionally, even where self-guarantees are allowed, the amount of remediation liability that a thermal coal mining company must carry is regulated and might be increased by regulators who anticipate increasing remediation costs.

We examined scope countries for any change in remediation liability regulation or enforcement. The United States is identified as a 'high risk' country, where regulators in Wyoming are investigating whether Alpha Natural Resources, Arch Coal, and Peabody Energy may continue to self-guarantee their remediation liabilities [406]. In Australia, the governments of Queensland and New South Wales hold remediation bonds for coal miners in those states, but the value of the bonds may not be sufficient to cover remediation costs[407]. Australia is considered 'medium risk'.

*NRH-M2: Environmental Regulation*

The hypothesis is that stricter environmental regulation or enforcement would negatively affect mine economics and potentially create new liabilities.

[405] Miller, G. (2005). Op. Cit.

[406] Jarzemsky, M. (2015). Op. Cit.

[407] Main, L. & Schwartz, D. (2015). 'Industry insider warns taxpayers may foot bill for mine rehabilitation unless government, industry step up', ABC News.

The environmental impacts of thermal coal mining can be significant, including water, air, and land pollution and impacts on wildlife. Efforts by governments to protect the environment and natural capital can have material impacts on the ability of thermal coal mining companies to conduct their business, especially when that business has unmitigated environmental impacts. This hypothesis captures the potential impact of emerging environmental regulations on coal mining companies in the scope countries.

Australia and South Africa were found to have emerging environmental regulation which places thermal coal mining companies at 'high risk'. In Australia, some coal mining projects have been referred to new national regulations under the EPBC act [408]. In South Africa, biodiversity protection has become a national environmental priority, with policy development beginning to address conflicts between mining and biodiversity[409].

*NRH-M3: New Mineral Taxes and Tariffs*

The hypothesis is that new or higher mineral taxes, tariffs, and levies would negatively affect mine economics.

Governments use fiscal policies like taxes, export tariffs, levies, caps, and bans to influence industry activity. These policies may be implemented to remedy a market failure, to influence investment, or domestic market prices. New or existing fiscal policies could reduce thermal coal mine profitability.

Mineral taxes, royalties, export tariffs and other policies are examined in the scope countries. Where proposed mineral taxes or tariffs have been identified, these are noted in Table 41. Where the proposed policy is highly likely, thermal coal mining companies in that country are considered to be at 'high risk'. Where proposed policy is less certain, the companies are considered to be at 'medium risk'. See also the policy summaries in Section 4 for details.

***Table 41:** Countries with (and without) proposed mineral taxes and tariffs*

| Country | Reference | RISK |
|---|---|---|
| Australia | No emerging taxes or tariffs identified | 🟢 |
| China | New coal tax – 2% to 8%[410] | 🔴 |
| Germany | No emerging taxes or tariffs identified | 🟢 |
| Indonesia | Industry reforms, export bans and caps[411] | 🔴 |
| India | Proposed doubling of coal levy for the National Clean Energy Fund[412] | 🟡 |
| Japan | No emerging taxes or tariffs identified | 🟢 |
| Poland | No emerging taxes or tariffs identified | 🟢 |
| South Africa | Since 2012 the South African government has pursued mineral sector tax reform to raise government revenue[413] | 🟡 |
| United Kingdom | No emerging taxes or tariffs identified | 🟢 |
| United States | No emerging taxes or tariffs identified | 🟢 |

[408] Australian Government (2016). About the EPBC Act. https://www.environment.gov.au/epbc/about.
[409] OECD (2013). Op. Cit.
[410] Stratfor (2015). Op. Cit.
[411] Prior, S. & Riffdann, R. (2014). Op. Cit.
[412] Jaitley, A. (2015). Op. Cit.
[413] PMG Asset Management (2013) Op. Cit.

*NRH-M4: Type of Coal Produced*

The hypothesis is that mines producing lignite have fewer potential customers and therefore could be at higher risk due to a lack of diversification.

Lignite is less energy dense and contains more moisture than bituminous or sub-bituminous coal, making it a less-efficient energy source. It is too bulky export; an international market exists only for hard coals. The low price of imported coal may cause coal-fired power stations to import higher quality coal directly from international markets. Additionally, as pressure on coal-fired power stations increases to control conventional and greenhouse gas pollution, lignite-producing countries will be at a disadvantage relative to countries producing higher quality coals.

The type of coal mined in each scope country is taken from the IEA MCMR[414]. Countries with production of over 25% lignite coal by mass are considered 'high risk'. Countries with any production of lignite coal are considered 'medium risk'.

***Table 42:*** *Coal type produced*[415]

| 2014 | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| % Lignite | 12% | 0% | 96% | 0% | 7% | 0% | 47% | 0% | 8% | 0% |
| RISK | Yellow | Green | Red | Green | Yellow | Green | Red | Green | Yellow | Green |

*NRH-M5: Domestic Demand Outlook*

The hypothesis is that coal miners will be exposed to lower profit margins and higher costs if domestic demand for coal falls. Falling domestic demand for coal-fired power will increase the local and global over-supply of thermal coal. Thermal coal mining companies may have to accept lower prices from domestic buyers or will need to internalise transport costs and compete on the global market. Either option reduces the profitability of thermal coal mining.

***Table 43:*** *2013-2020 Coal power demand outlook from IEA WEO 2015 NPS*[416]

| 2013 - 2020 | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| CAGR | 0% | 1% | -3% | 8% | 5% | -1% | -3% | 0% | -3% | -2% |
| RISK | Yellow | Yellow | Red | Green | Green | Red | Red | Yellow | Red | Red |

[414] IEA (2015). Coal MTMR. Op. Cit.
[415] IEA (2015). Coal MTMR. Op. Cit.
[416] IEA (2015). WEO 2015. Op. Cit.

*NRH-M5: Export Sensitivity*

The hypothesis is that the more thermal coal a country exports, the more exposed its mining companies will be to the risk of falling global demand for coal. Even in the IEA's conservative NPS, total coal demand is only expected to grow at 0.4% through 2020[417]. Companies must pay transport costs, compete for transport infrastructure, and expose themselves to price volatility on international commodity markets.

Table 44 shows 2014 coal imports (exports) relative to each country's coal consumption. Australia and Indonesia are clear outliers. They are considered 'high risk'. The other coal exporters are South Africa and the United States which are considered 'medium risk'.

***Table 44:*** *2014 coal exports*[418]

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Imports (Exports) | (325%) | 7% | 22% | (663%) | 26% | 100% | 0% | (42%) | 75% | (9%) |
| RISK | 🔴 | 🟢 | 🟢 | 🔴 | 🟢 | 🟢 | 🟢 | 🟡 | 🟢 | 🟡 |

*6.2.2.1 NRH-M6: Protests and Activism*

The hypothesis is that mines targeted by protests and activism may suffer from reputational risk and temporary production disruptions due to disputes. They might also be at higher risk of policies and regulations that could harm the economics of mines in their country.

The local and global environmental impacts of the thermal coal value chain have attracted significant attention from civil society and activist groups around the world. Protests against coal assets create a reputational risk for the associated companies as local and national policymakers may feel more able to regulate company activities. Using data from Sourcewatch, non-violent direct action against thermal coal companies are delineated by country[419]. Comprehensive data were available from 2003 to 2013.

Figure 53 shows that the majority of protests occurred in the US, which experienced 115 coal-related protests between 2003 and 2013. Other significant activity occurred in the UK, Australia, and India. These countries are all considered 'high risk'. If any protests were observed in the sample at all, those countries are considered 'medium risk' – see Table 45.

[418] IEA (2015). Coal MTMR. Op. Cit.

[419] Coalswarm (2015). 'Non-violent direct actions against coal', Sourcewatch. http://www.sourcewatch.org/index.php/Nonviolent_direct_actions_against_coal

***Figure 53:*** *Cumulative number of protests, delineated by coal-based operation*

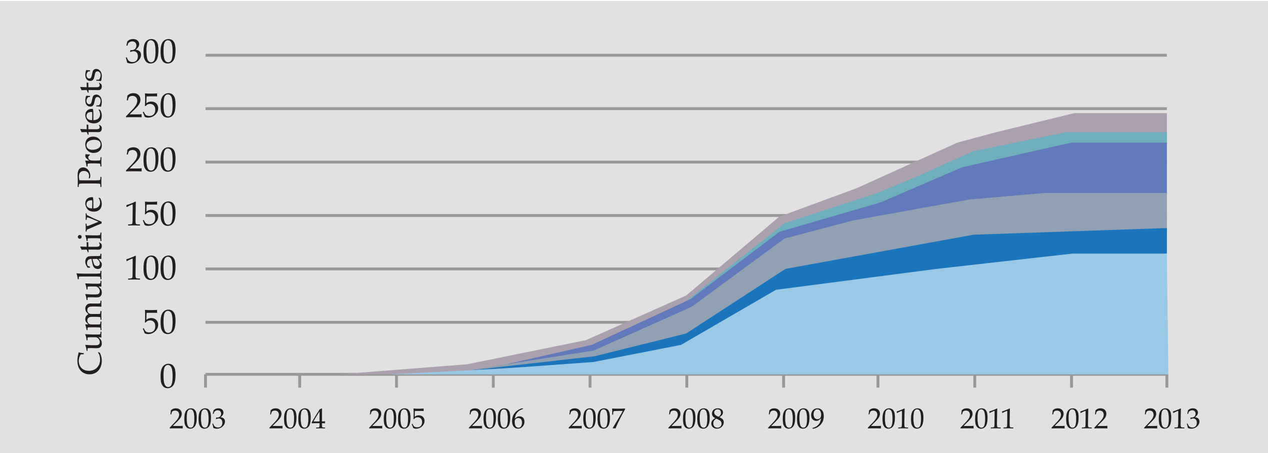



***Table 45:*** *Coal-related protest occurrence 2003 – 2013*[420]

| Protests | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| 2003 - 2013 | 35 | 3 | 2 | 2 | 49 | 0 | 1 | 2 | 22 | 115 |
| RISK | Red | Yellow | Yellow | Yellow | Red | Green | Yellow | Yellow | Red | Red |

*6.2.2.2 NRH-M7: Regulatory Water Stress*

Thermal coal mining has a substantial water footprint, described below in hypothesis LRH-2M: Water Stress. This water footprint exposes thermal coal mining companies to regulatory risks, as policymakers may take action to restrict utility access to water. Public opinion on the water footprint of power generation may also put pressure on policymakers to restrict water use, exposing utilities to a reputational risk as well.

This risk hypothesis is identical to the Regulatory Water Stress hypothesis described for coal-fired power utilities (see NRH-U9) and uses the same data and analysis, see above for details.

***Table 46:*** *Regulatory Water Stress*[421]

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Risk bin | 1 | 3 | 1 | 4 | 3 | 1 | 2 | 3 | 2 | 1 |
| RISK | Green | Yellow | Green | Red | Yellow | Green | Green | Yellow | Green | Green |

[420] Ibid.
[421] World Resources Institute (2016). 'Regulatory & Reputational Risk' in Water Risk Atlas, Aqueduct.

# 6.3 Summary of Top 20 Thermal Coal Mining Companies

***Table 47:*** *Environment-related risk indicators summary, top 20 thermal coal mining companies*

| PARENT OWNER | COUNTRY[ii] | 2014 THERMAL COAL REV [US$MN] | NUM | PROD [Mt (#)] | [% REV FROM COAL] | PROJECTED CAPEX / EBITDA | DEBT / EQUITY | CURRENT RATIO | (EBITDA-CAPEX) / INTEREST | LRH-M1: 'Proximity to Populations and Protected Areas' [Rank]* | LRH-M2: 'Water Stress' [Rank]* | ASSET BASE | NRH AGGREGATION** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CHINA SHENHUA ENERGY CO | CH | 14,006 | 11 | 107 (6) | 0.52 | 2.01 | 1.13 | 1.36x | - | 22 | 27 | CH-100% | 31% |
| SASOL | ZA | 11,050 | 23 | 305 (23) | 0.35 | 0.45 | 0.28 | 1.30x | 7.66x | 16 | 19 | CH-100% | 31% |
| COAL INDIA LTD | IN | 10,251 | 4 | 15 (1) | 0.97 | 3.55 | 1.02 | 1.98x | -4.01x | 13 | 23 | CH-4% | 31% |
| CHINA COAL ENERGY COMPANY | CH | 5,966 | 13 | 51 (13) | 0.85 | 2.82 | 1.09 | 1.63x | -6.26x | 14 | 20 | CH-100% | 31% |
| ADANI ENTERPRISES LTD | IN | 5,068 | 5 | 30 (5) | 0.9 | 1.62 | 0.69 | 0.89x | -2.66x | 28 | 30 | CH-5% | 31% |
| PEABODY ENERGY CORPORATION | US | 4,890 | 25 | 13 (4) | 0.7 | 1.13 | - | - | - | 24 | 28 | CH-25% | 31% |
| INNER MONGOLIA YITAI COAL CO., LTD. | CH | 3,397 | 23 | 73 (19) | 0.31 | 1.5 | 1.19 | 1.21x | -1.34x | 18 | 18 | AU-43%, CH-57% | 42% |
| YANZHOU COAL MINING COMPANY LIMITED | CH | 3,045 | 13 | 41 (11) | 1 | 0.29 | 0.92 | 1.01x | 18.26x | 6 | 6 | US-13% | 44% |
| PT ADARO ENERGY TBK | ID | 2,909 | 3 | 84 (3) | 0.66 | 1.63 | 1.41 | 0.40x | -0.28x | 4 | 16 | US-100% | 44% |
| ALPHA NATURAL RESOURCES | US | 2,837 | 12 | 264 (11) | 0.8 | 0.32 | -849%* | 2.66x | 0.59x | 5 | 17 | US-100% | 44% |
| PT UNITED TRACTORS | ID | 2,826 | 5 | 32 (5) | 0.46 | 0.67 | 0.76 | 0.52x | -1.11x | 8 | 8 | US-5% | 44% |
| BANPU PUBLIC COMPANY LIMITED | TH | 2,638 | 28 | 232 (28) | 0.72 | 0.31 | 4.81 | 1.02x | 0.23x | 7 | 12 | AU-39%, US-61% | 49% |
| ARCH COAL | US | 2,350 | 6 | 29 (6) | 0.94 | 0.39 | 0 | 1.88x | 121.77x | 27 | 13 | ID-6% | 44% |
| YANG QUAN COAL INDUSTRY (GROUP) CO., LTD. | CH | 2,337 | 4 | 56 (4) | 0.91 | 0.23 | 0.49 | 2.10x | 5.34x | 11 | 3 | ID-100% | 44% |
| SHANXI LU'AN ENVIRONMENTAL ENERGY DEVELOPMENT | CH | 2,324 | 1 | 6 (1) | 0.66 | 0.39 | 0.07 | 1.90x | 105.39x | 2 | 2 | ID-100% | 44% |
| ALLIANCE RESROUCE PARTNERS | US | 2,301 | 6 | 8 (2) | 0.55 | 0.28 | 1.42 | 1.08x | 2.71x | 12 | 9 | NOTE 1 | 38% |
| THE TATA POWER COMPANY | IN | 1,861 | 13 | 494 (8) | 0.89 | 0.46 | 0.01 | 3.15x | 1,728.94x | 29 | 7 | IN-100% | 31% |
| INDO TAMBANGRAYA MEGAH TBK PT | ID | 1,741 | 3 | 27 (1) | 0.31 | 0.19 | 1.95 | 0.69x | 2.40x | 30 | 14 | ID-3% | 44% |
| CONSOL ENERGY INC | US | 1,600 | 6 | 41 (6) | 0.58 | 0.75 | 0.22 | 2.58x | 7.10x | 9 | 10 | SA-100% | 44% |
| DATONG COAL INDUSTRY | CH | 1,356 | 10 | 39 (9) | 0.85 | 0.69 | 1.56 | 1.23x | 1.38x | 20 | 15 | ID-70%, CH-30% | 40% |

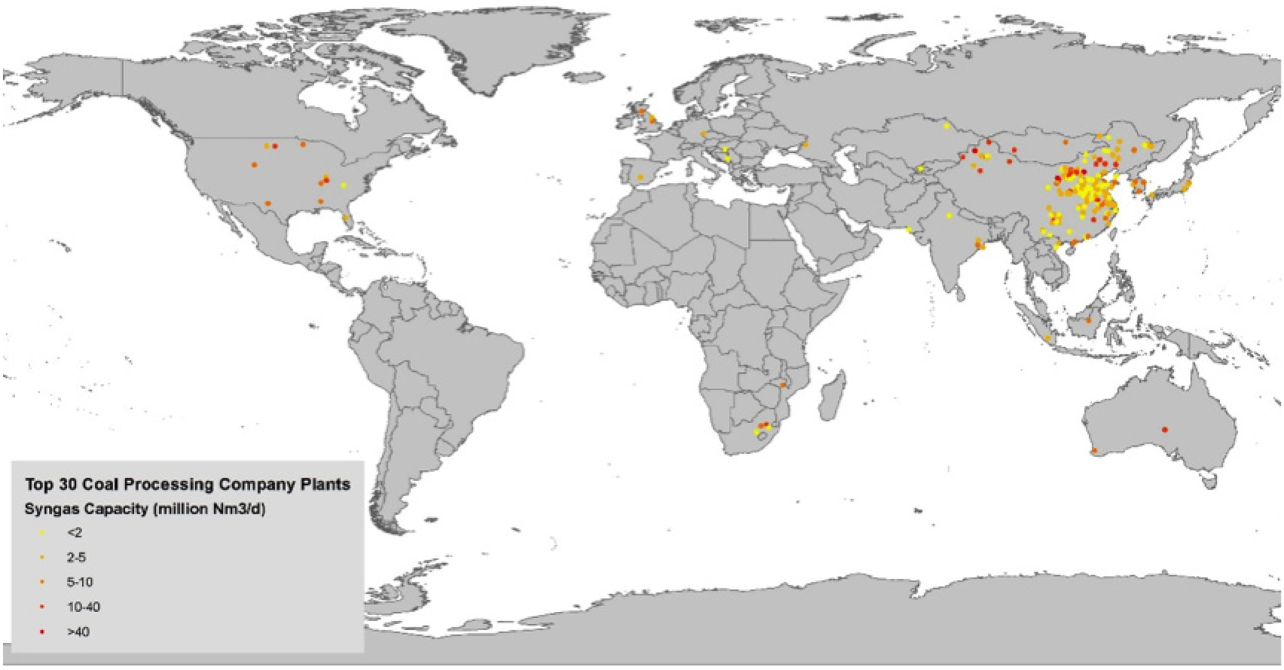
*: Companies are ranked by exposure, with 1 being the most at risk.

**: NRHs have been aggregated to a single outlook percentage based on the sum of high risk (+2) and medium risk (+1) evaluations relative to the maximum possible and weighted by asset locations.

# 7 Coal Processing Technology Companies

Coal processing technology companies are examined for their exposure to environment-related risks. First, the market for coal processing technology companies is outlined, including capital project pipelines, ownership structures, and debt obligations. Then a number of hypotheses pertaining to the companies' environment-related risk exposure are developed and tested. As many of these companies are new or emerging, evaluation of their risk exposure will provide valuable insight into the future potential of these technologies. Figure 54 shows the location of the plants of the global top 30 CPT companies. The top 30 CPT companies own 34% of CPT plants and produce 63% of CPT products on a syngas-nominal basis.

***Figure 54:** Top 30 coal processing technology plants*




## 7.1 Assessment of Available Information

The next section will discuss commercial uses of CTG/CTL/UCG technologies, capital expenditures and ownership trends globally, as well as other technical, economic and environmental factors that impact the value of coal-based energy processing companies. Considering the growing interest in coal conversion projects, the environment-related risks (e.g. related to GHG emissions and water intensity) of coal processing projects should be taken seriously if these projects are developed on a large-scale.

### **Box 9:** *Roundtable review of coal processing technologies – November 2015, London*

On November 10, 2015, Stranded Assets Programme at the Oxford Smith School held a roundtable discussion involving researchers, practitioners, and policymakers on the global state of coal-to-liquids (CTL), coal-to-gas (CTG), and underground coal gasification (UCG) technologies. A number of key points were raised during the meeting, detailed below.

Renewed interest in CPTs is motivated by:

- High LNG costs making CPT more attractive.
- China is strategically expanding these technologies for (i) energy security, (ii) reducing air pollution in major cities, and (iii) resolving potential employment issues for coal mine workers.
- CPT by-products such as hydrogen, methane, and syngas are important feedstocks for the chemicals industry and can be used for power generation.

However, there are potential investment issues:

- Most CTL/CTG/UCG projects are in development stages and may not come to fruition. In addition, after years of rapid growth the market may be saturated.
- These projects are capital intensive, requiring large upfront capital investments and four- to five-year construction periods.
- Limited research and development investment in these technologies hinders cost reductions and efficiency gains.

Concerns were raised over environment-related risks:

- CTL/CTG/UCG are water intensive, generating additional water stress in arid regions such as northwestern China, South Africa, and the western US. Water pricing could be another challenge.
- The high carbon intensity of these technologies is a serious challenge for countries' 2°C targets. Fugitive methane emissions and volatile organic compounds (VOC) will present an additional regulatory risk in countries like the US.
- Underground water, land, and crop pollution, as well as waste disposal are other serious environment-related risks that might create remediation liabilities (e.g. UCG demonstration plant in Chinchilla, Australia).
- Potential reputational risks due to negative media exposure and local protests. For instance, Friends of the Earth Scotland campaigned effectively for a moratorium on UCG projects in Scotland, arguing that these projects have high $CO_2$ emissions and could generate environmental pollution.

# 7.2 Market Analysis

## 7.2.1 Capital Projects and Ownership

The ownership trends of coal-based energy processing companies vary significantly by country. The majority of CPT plants are either in planning or under construction. Several projects have faced funding shortages or the withdrawal of companies due to low financial returns on trial projects, bureaucratic hurdles during planning and permitting stages, regulatory uncertainty, and environmental liabilities. A summary of key capital projects and their owners and funders is provided in Table 48. For extensive discussion of the role of CPTs in each country, see the policy summaries in Section 4.

**Table 48:** *CPTs capital projects*

| Country | Demonstration / operating projects | Pipeline projects | Key companies | Funding source |
|---|---|---|---|---|
| Australia | Monash Energy (CTL),<br>Arckaringa (CTL),<br>Chinchilla (UCG) - closed down in 2013 | Additional CTM project for Arckaringa | Anglo Coal, Shell, Altona Energy, Linc Energy | Private sector funding and government subsidies |
| China | Several CTG/CTL/UCG demonstration projects in place since 2010 | 50 new CTG plants in Northwestern China | Datang, China Guodian Corporation, China Power Investment, CNPC, CNOOC and Sinopec | Subsidies from local governments and loans from the Chinese Development Bank |
| India | UCG plant applications for Katha (Jharkhand), Thesgora (Madya Pradesh)<br>Tata Group's application for a CTL plant in Odisha rejected by government | New UCG pilot projects for West Bengal and Rajasthan | Coal India Limited, Tata Group, the Oil and Natural Gas Corporation Ltd (ONGC) and the Gas Authority of Indian Ltd. | Subsidies from local government, and private funding |
| South Africa | Operating 6 coal mines producing feedstock for Secunda Synfuels and Sasolburg Operations | New growth plans for the Project 2050, replacing 4 old coal mines for CTL projects | Sasol Ltd | Public and private funding; investment and pension funds |
| United States | Great Synfuels CTG Plant in North Dakota | 12 new CTL project proposals in Wyoming, Illinois, Arkansas, Indiana, Kentucky, Mississippi, Missouri, Ohio and West Virginia | Shell, Rentech, Baard, DKRW | Public and private funding |

Table 71 in Appendix C shows ownership information for the 30 coal-processing technology companies. For each company, the location of the head office, the ultimate corporate parent, corporate parent's ownership type, and the aggregate market value (in billion US$) of the various holders' positions is examined. Table 49 aggregates the data by region, illustrating the ownership distribution by region. Values presented represent total market value in US$bn.

Table 49 summarises ownership type of the CPT companies' ultimate corporate parents. Data for two companies were unavailable. Across the available 28 companies, the data shows that coal processing plants are 60.7% owned by private companies and 39.3% owned by public companies. The majority of the processing plants are Chinese-owned. In China, the proportion of private ownership is 80%, whereas only 20% of coal processing plants are ultimately owned by public companies. The sample contains two coal processing plants in the US; one privately owned and one publicly owned. The only Indian processing plant and plants across all 'other' regions were publicly owned. No European plants were included in the sample.

***Table 49:*** *Distribution of ownership for coal processing plants, by region*

| | Government | Private Company | Private Investment Firm | Public Company | Public Investment Firm |
|---|---|---|---|---|---|
| (A) Total | 0.0% | 60.7% | 0.0% | 39.3% | 0.0% |
| | (0) | (17) | (0) | (11) | (0) |
| (B) China | 0.0% | 80.0% | 0.0% | 20.0% | 0.0% |
| | (0) | (16) | (0) | (4) | (0) |
| (C) US | 0.0% | 50.0% | 0.0% | 50.0% | 0.0% |
| | (0) | (1) | (0) | (1) | (0) |
| (D) India | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| | (0) | (0) | (0) | (1) | (0) |
| (E) EU | - | - | - | - | - |
| | (0) | (0) | (0) | (0) | (0) |
| (F) Other | 0.0% | 0.0% | 0.0% | 100.0% | 0.0% |
| | (0) | (0) | (0) | (5) | (0) |

### 7.2.2 Bond Issuances

Coal-based energy processing companies' exposure to high levels of debt increases risk for both debt and equity holders of coal processing plants as the priority of either is further diluted in the event of the company's insolvency. Table 72 in Appendix B shows bond issuances of the top 30 coal processing companies.

To build a general picture of the future direction for bond issuances in the CPT industry, fixed-income securities are examined through ratio analysis. Table 73in Appendix B presents financial ratios relating to profitability, capital expenditures, liquidity, leverage, debt coverage, and the ability for utilities to service existing debt. Figure 55 illustrates the same ratios through time, including the 25th and 75th percentile ranges to capture the distribution of observed ratios across firms. The analysis was conducted for between 1995 and 2014 to represent the last 20 years of data[422]. The dataset for 2015 was limited, and was omitted from the analysis. Financial data were unavailable for many coal processing companies. Thus, the analysis is restricted to publicly traded companies.

Credit rating reports were unavailable for coal-processing technology companies.

[422] Data were taken from Thomson Reuters Datastream, November 2015 and Standard & Poor's Capital IQ, November 2015.

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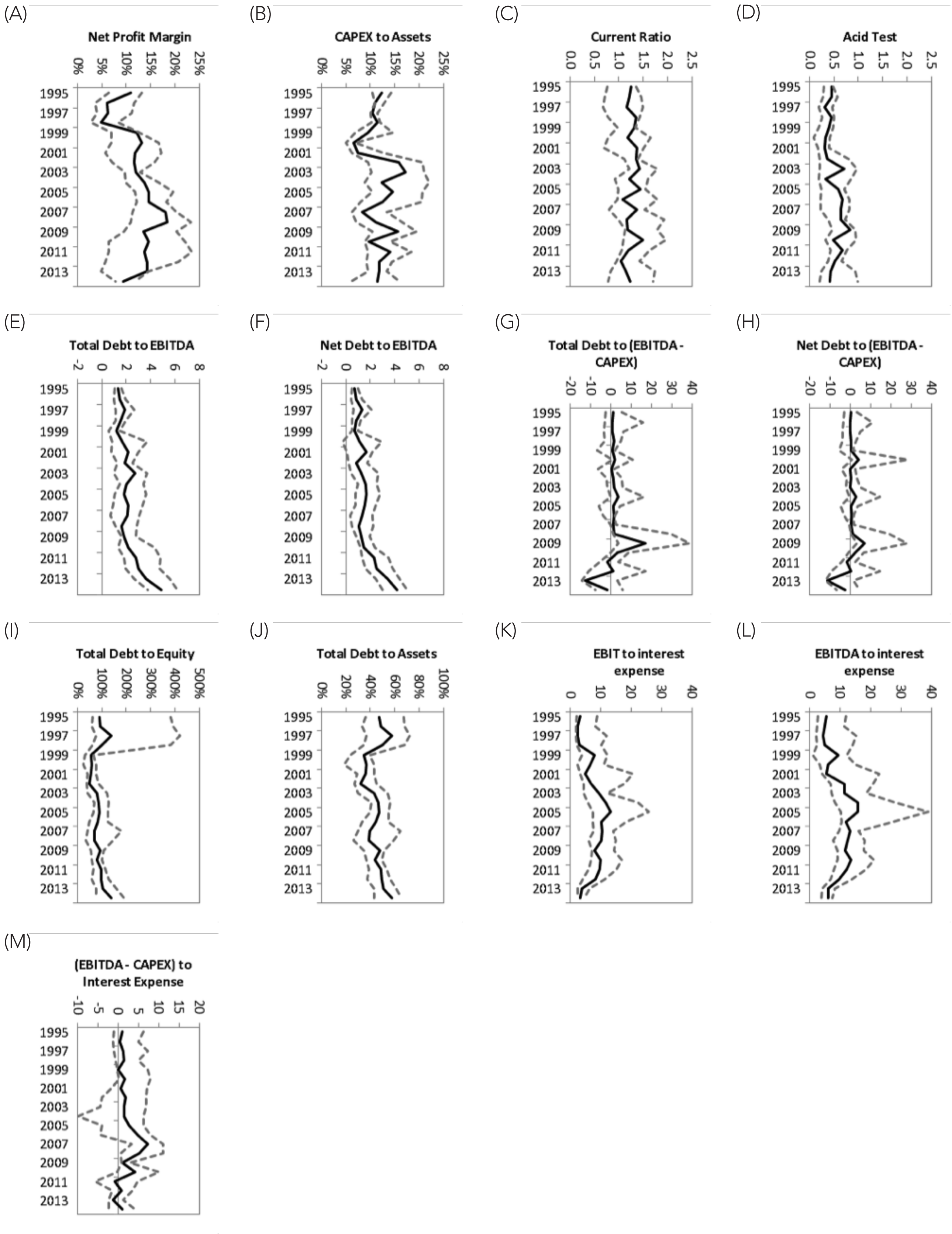
*__Figure 55:__ Ratio analysis for all CPT companies, with median, 25th, and 75th percentiles*



The first two ratios examined report general profitability and capital expenditure in the coal processing industry, which are both relevant to the industry's ability to service its debt commitments. Chart (A) presents the profit margins for the processing industry, which were generally greater than those observed in the power utility and mining industries. At its peak, the industry's profit margin was 18.4% in 2008. Despite the decline in recent years, the industry's 2014 profit margin is still 9.3%. Figure 55 shows a large spread between the net profit margin's 25th and 75th percentile. Examination of the data showed that some processing plants had negative net income post-GFC.

However, the industry's profit margin must be balanced against capital expenditure. Chart (B) shows that capital expenditures are both large and volatile, ranging from 4.9% to 17.2% of total assets. Since 2012, CAPEX has trended between 11.6-11.8% of total assets. Acquiring, upgrading, and maintaining existing physical assets are relatively costly for coal processing plants in comparison to the other two industries examined in this report.

The current ratio and acid test are used as proxies for liquidity in the industry. The former measures the ability to service current liabilities using current assets, the latter measures the ability to service current liabilities using cash, near-cash equivalents, or short-term investments. The coal processing and coal-mining industries have relatively higher liquidity than the coal-fired power utilities. Charts (C) and (D) show both liquidity ratios have remained relatively stable through time. The acid test shows that the holding of near-cash equivalents has also generally increased through time, but suffered a decline in recent years.

Two financial leverage ratios are examined: the debt/equity ratio in Chart (E) and the debt/assets ratio in Chart (F). Chart (E) shows that the debt/equity ratio has been volatile across time. The coal processing industry has leveraged its position in recent years. In 2014, debt represented 58% of total assets. While profitability remains high, the high financial leverage could be of concern in years with abnormally high capital expenditures.

Coverage ratios measure the processing industry's ability to meet its financial obligations. Three ratios are considered: 1) EBIT/interest, 2) EBITDA/interest, and 3) (EBITDA-CAPEX)/interest. Charts (G) and (H) show that the coal processing industry generates sufficient operating income to cover interest expenses. In 2014, EBIT was 3.31 times greater than interest expenses, while EBITDA was 6.06 times greater. As stated, CAPEX is a major concern for the processing industry. Ratios less than unity suggest that the industry does not generate sufficient income to cover interest expenses; this occurs frequently throughout the series. Of major concern are 2011 and 2013, where the ratio turns negative – indicating that CAPEX exceeded EBITDA or the company made an operating loss. In both years, the negative ratios are a result of increasing CAPEX and greater financial leverage.

Four ratios represent the processing industry's ability to retire incurred debt. The ratios can be broadly interpreted as the amount of time needed to pay off all debt, ignoring interest, tax, depreciation and amortisation. The ratios are delineated in two groups: group 1 considers the numerators: 'total debt' and 'net debt', where the latter subtracts cash and near-cash equivalents for total debt; group 2 considers the denominators: EBITDA and (EBITDA-CAPEX), where the latter controls for capital expenditures.

Charts (J) and (K) show that the time taken to pay off incurred debt increases. In 2014, at current EBITDA, total debt would take 4.91 years to retire, while net debt takes 4.17 years – subject to conditions outlined previously.

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Chart (L) shows that capital expenditures result in negative ratios, suggesting an inability to retire debt. The negative values observed from 2011, in conjunction with the CAPEX ratio in Chart (B), indicate that CAPEX has been greater than EBITDA. Further, Chart (M) shows that this inability to retire debt continues after exhausting near-cash assets.

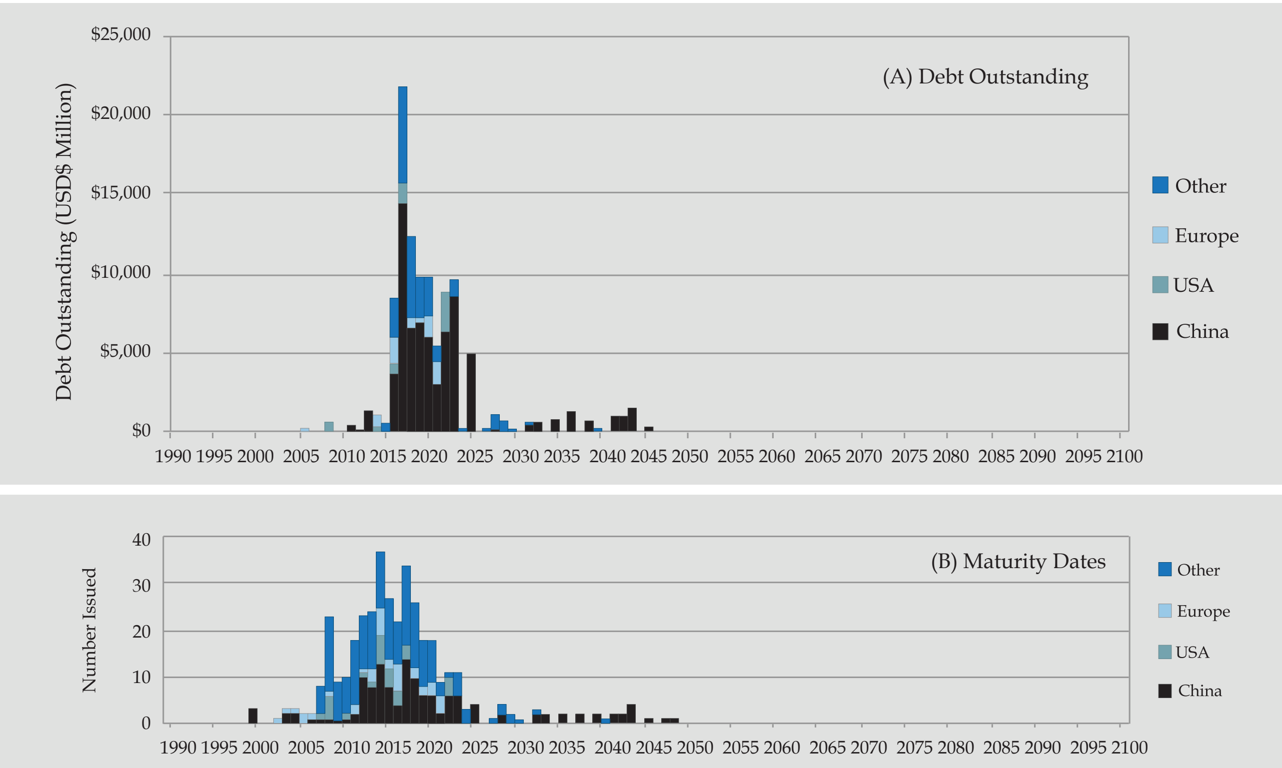
Figure 56 illustrates the maturity schedule for the coal processing industry, using available data from 12 of the 30 coal processing technology companies. The schedule is divided into total amount outstanding (US$) and the maturity dates of various contracts. Both graphs are delineated by major region, including: China, US, Europe, and 'other'.

Plot (A) of Figure 56 shows that the majority of the total debt is due between 2016 and 2023. There is little borrowing beyond this date in our sample. European and US coal processing companies have relatively little debt outstanding. In comparison, coal processing companies in China and 'other regions' issued a large proportion of debt until the 2010s and 2020s, while Chinese companies have some debt outstanding until 2045. Plot (B) shows a similar trend, with companies in China and 'other regions' issuing contracts until at least 2040. Table 50 shows that companies in the US and China have also issued some perpetual debt, however the number of contracts is relatively low.

***Table 50:** Coal-based energy processing companies' perpetual debt*

| | China | US | Europe | Other |
|---|---|---|---|---|
| Amount outstanding (US$m) | 181 | 300 | 0 | 0 |
| Number issued | 2 | 1 | 0 | 0 |

***Figure 56:** Maturity schedules for industry debt: amount outstanding (A) and maturity dates (B)*



# 7.3 Investment Risk Hypotheses

In this section, we take a view on what the environment-related risks facing coal-to-liquids and coal-to-gas processing plants could be and how they could affect asset values. We call these Local Risk Hypotheses (LRHs) or National Risk Hypotheses (NRHs) based on whether the risk factor in question affects all assets in a particular country in a similar way or not. For example, water stress has variable impacts within a country and so is an LRH, whereas a country-wide carbon price is an NRH. The hypotheses are coded for easier reference. For example, LRH-P1 refers to plant age and NRH-P1 refers to CPT policy support.

Hypotheses for different environment-related risks have been developed through an informal process. We produced an initial long list of possible LRHs and NRHs. This list was reduced to the more manageable number of LRHs and NRHs contained in this report. We excluded potential LRHs and NRHs based on two criteria. First, we received feedback from investors and other researchers in meetings, roundtables, and through correspondence, on the soundness, relevance, and practicality of each hypothesis. Second, we assessed the data needs and analytical effort required to link the hypotheses with relevant, up-to-date, and where possible, non-proprietary, datasets.

The current list of hypotheses and the datasets used to measure asset exposure to them are in draft form. Other datasets may have better correlations and serve as more accurate proxies for the issues we examine. Important factors may not be represented in our current hypotheses. We are aware of these potential shortcomings and in subsequent research intend to expand the number of hypotheses we have, as well as improve the approaches we have used to analyse them.

The summary table that shows the exposure of the top-30 coal processing technology companies to each NRH and LRH can be found in Section 7.4.

## 7.3.1 Local Risk Hypotheses

*LRH-P1: Plant Age*

Ageing CPT plants are more exposed to regulations that might force their closure. It is financially and politically simpler to regulate the closure of ageing plants. Once CPT plants have recovered capital costs and have exceeded their technical lives, the financial need to compensate is greatly reduced or eliminated[423]. Old CPT plants may also be more exposed to site remediation costs and significant worker liabilities (e.g. pension costs).

The age of each CPT plant is taken from the World Gasification Database. These are then aggregated to the company level, weighted by plant capacity.

*LRH-P2: Water Stress*

CPT plants located in areas with higher physical baseline water stress or in areas with regulatory uncertainty are at higher risk of being forced to reduce or cease operation, of losing their licence to operate, or of having profits impaired by water pricing.

[423] Caldecott, B. & Mitchell, J. (2014). Op. Cit.

CTL is highly water intensive. Studies from Hook[424], the US DOE[425], and RAND[426] estimate that coal liquefaction technologies require between five and 14 tonnes of freshwater per tonne of liquid fuel. For CTG, Yang and Jackson[427] finds that producing synthetic natural gas requires 50 to 100 times the amount of water needed to produce shale gas. See Section 2 for details.

Two WRI Aqueduct datasets are used to assess water stress-related risks to CPT plants. Aqueduct's measure of Baseline Water Stress (BWS) is the ratio of total annual withdrawals of water to availability of freshwater flow within a given watershed. Aqueduct produces the Regulatory and Reputational Risk indicator as a robust qualitative analysis of regulatory changes and social challenges to water use[428].

All CPT plants are mapped against the Aqueduct Baseline Water Stress and Regulatory and Reputational Risks geospatial datasets. Those plants that are in watersheds that have 'extremely high water risk' for baseline water stress are identified as 'at risk'. Those plants that are in watersheds that have 'extremely high regulatory and reputational risk' are identified as 'at risk'. In the case that a plant is 'at risk' for both indicators, it is classified as 'seriously at risk'.

Plants are then aggregated by CPT company to identify the percentage of capacity that is 'at risk' or 'seriously at risk'.

*LRH-P3: CCS Retrofitability*

CPT plants that are unsuitable for the retrofit of carbon capture and storage (CCS) technology are more at risk of premature closure in scenarios with stringent climate change policy. CCS retrofitability of CPT plants enables compatibility of the plants with 2°C warming scenarios of the IEA and IPCC[429].

Following the methodology of the OECD[430], CCS retrofitability is defined as an aggregate function of plant size, age, and efficiency. This analysis adds extra criteria of geographic proximity to suitable geological reservoirs, and a favourable national policy environment. The Global CCS Institute's Carbon Capture and Storage Policy Indicator is used to determine policy favourability for CCS.

The following approach is taken to identify the percentage of a CPT company's portfolio of plants that may be suitable for CCS retrofits. Suitable CPT plants are defined as those under 20 years of age and within 40km of highly geologically suitable areas.

CPT plant age is taken from the CoalSwarm dataset. Next, all CPT plants are mapped against the CCS geological suitability geospatial dataset[431] to identify whether they are within 40km of areas highly suitable for CCS; 40km has been suggested as an appropriate distance for assessing viable proximity to geological storage, e.g. by Bentham et al[432], NETL[433].

[424] Höök, M. (2014). Op. Cit.
[425] United States Department of Energy (DOE) (2013). Coal-to-liquids and Water Use, NETL. http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/ctl-water-use
[426] Bartis, J. Camm, F., Ortiz, D. (2008). Producing Liquid Fuels from Coal: Prospects and Policy Issues, RAND. Santa Monica, US.
[427] Yang, C. & Jackson, R. (2013). Op. Cit.
[428] World Resources Institute (2016). Op. Cit.
[429] Refers specifically to the IPCC AR5 430-480ppm, IEA ETP 2DS, and IEA WEO 450S.
[430] Finkenrath, M., et al. (2012). Op. Cit.
[431] Used with permission of IEA Greenhouse Gas R & D Programme and provided by Geogreen SA.
[432] Bentham, M. et al. (2014). 'Managing CO2 storage resources in a mature CCS future', Energy Procedia 63: 5310-5324.
[433] NETL (2011). Op. Cit.

Suitable plants are then aggregated by utility to identify the percentage of CPT companies' portfolios that are suitable for CCS retrofit.

### *7.3.2 National Risk Hypotheses*

***Table 51:*** *National-level environment related risk indicators*

| High Risk (+2) / Medium Risk (+1) / Low Risk (+0) | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| NRH-P1: CPT Policy Support | Low | Low | Medium | Medium | Low | Low | Medium | Low | High | Low |
| NRH-P2: Oil and Gas Demand Outlook | Medium | Low | High | Low | Low | High | High | Low | High | Medium |
| NRH-P3: Oil and Gas Indigenous Resources | Medium | High | Medium | Low | Low | Low | Low | Low | Low | High |
| NRH-P4: Other Local Environmental | Medium | Medium | Low | Low | Low | Low | Low | Medium | Low | Medium |
| NRH-P5: Regulatory Water Stress | Low | Medium | Low | High | Medium | Low | Low | Medium | Low | Low |
| NRH-P6: CCS Policy Outlook | Low | High | Medium | High | High | Medium | Medium | High | Low | Low |
| TOTAL (/14) | 3 | 6 | 5 | 5 | 3 | 3 | 4 | 4 | 3 | 4 |

*NRH-P1: CPT Policy Support*

The hypothesis is that CPTs are dependent on country-specific policy frameworks to succeed. Table 52 describes policy support for CPTs in each country. Where policy support is identified, the country is considered 'low risk'. Where specific policies have been enacted to prevent CPT projects, the country is considered 'high risk'. Where no policy information has been identified those countries are considered 'medium risk'.

***Table 52:*** *Countries with CPT policies*

| Country | Reference | RISK |
|---|---|---|
| Australia | Historic project uptake | Low |
| China | Extensive emerging CPT projects | Low |
| Germany | No information available | Medium |
| Indonesia | No information available | Medium |
| India | Emerging government support for CPT projects | Low |
| Japan | N/A | Low |
| Poland | No information available | Medium |
| South Africa | Historic government support of CPT | Medium |
| United Kingdom | UCG moratorium enacted in Scotland | High |
| United States | Historic government support of CPT projects | Medium |

*7.3.2.1 NRH-P2: Oil and Gas Demand Outlook*

The hypothesis is that strong oil and gas demand in the country where CPT plants are located creates more favourable demand conditions for plants, improving their economics.

Coal processing technology companies compete in gas and liquid fuel markets, and are thus exposed to competition from substitute or existing products in these markets. Where growth in oil or gas demand is strong, a market may be available for CPT products. Where growth is weak, CPT products will need to compete more with existing supply and imports, which may damage the viability of CPT business models.

We use scenario data from the IEA WEO2015. The CAGR of total primary energy demand (TPED) for both oil and gas is shown in Table 53. As explained in Section 1.3 the WEO NPS is taken as a conservative scenario. Where both oil and gas have a negative growth projection, the country is considered 'high risk'. Where only one has a negative growth projection it is considered 'medium risk'. Using the WEO projections suffers from the same challenge in disaggregating individual outlooks from regional outlooks. EU countries remain comingled together, Australia is comingled with South Korea and New Zealand, and Indonesia is comingled with other non-OECD Asian countries.

***Table 53:** Oil and gas outlook from IEA WEO 2015 NPS*[434]

| 2013-2020 CAGR | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| OIL | -0.3% | 2.9% | -1.5% | 1.8% | 3.8% | -3.3% | -1.5% | 0.6% | -1.5% | 0.0% |
| GAS | 1.3% | 8.5% | -0.6% | 2.0% | 3.7% | -2.9% | -0.6% | 4.2% | -0.6% | 1.1% |
| RISK | 🟡 | 🟢 | 🔴 | 🟢 | 🟢 | 🔴 | 🔴 | 🟢 | 🔴 | 🟡 |

*NRH-P3: Oil and Gas Indigenous Reserves*

Similar to the previous hypothesis, where CPTs need to compete with substantial indigenous oil and gas reserves, they may be less likely to get policy support and compete successfully for market share. Countries with indigenous reserves may have a greater interest in developing those reserves with conventional technology, rather than investing in CPTs.

This hypothesis uses data from the BP Statistical Energy Outlook 2015 to identify where countries have substantial oil and gas reserves, shown in Table 54. Where countries have over 1% global reserves of either oil or gas they are considered 'medium risk'. Where both exceed 1% they are considered 'high risk'.

[434] NPS from IEA (2015). WEO 2015. Op. Cit.

**Table 54:** *Oil and gas indigenous reserves*[435]

| 2014 Reserves % of world | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| OIL | 0.2% | 1.1% | 0.2% | 0.3% | <0.1% | <0.1% | <0.1% | <0.2% | 0.2% | 2.9% |
| GAS | 2% | 1.8% | 1.5% | 0.80% | <0.05% | <0.2% | 0.1% | <0.6% | 0.1% | 5.2% |
| RISK | Yellow | Red | Yellow | Green | Green | Green | Green | Green | Green | Red |

*NRH-P4: Other Local Environmental*

The hypothesis is that stricter environmental regulation or enforcement would negatively affect CPT plant economics and potentially create new liabilities.

CPT projects have local environmental impacts, see Section 0. In some countries these environmental impacts have become concerns for policymakers and the public. We identify where environmental impacts have been significant in the development of CPT projects. Subjective judgements are made as to whether the impacts should be considered 'high risk' or 'medium risk'.

**Table 55:** *Other local environmental risk factors for CPT companies*

| Country | Reference | RISK |
|---|---|---|
| Australia | Emerging environmental liability case from Linc Energy's UCG project in Chinchilla, Queensland.[436] | Yellow |
| China | CPT projects increase conventional air pollutants[437] | Yellow |
| Germany | No information available | Green |
| Indonesia | No information available | Green |
| India | No information available | Green |
| Japan | No information available | Green |
| Poland | No information available | Yellow |
| South Africa | CPT projects have come in conflict with water availability[438] | Yellow |
| United Kingdom | No information available | Green |
| United States | US EPA is issuing new regulations regarding the emission of methane and volatile organic compounds (VOCs) which will impact future CPT projects[439] | Yellow |

[435] BP plc (2015). Op. Cit.

[436] Bajkowski, J. (2014). 'Queensland government hits Underground Coal Gasification player Linc Energy with environmental damage charges', GovernmentNews.

[437] Hyder, Z., Ripepi, N., & Karmis, M.. (2014). 'A Life Cycle Comparison of Greenhouse Emissions for Power Generation from Coal Mining and Underground Coal Gasification', Mitigation and Adaptation Strategies for Global Change May:1-32.

[438] Shaio, T. & Maddocks, A. (2014). 'Finding Solutions for South Africa's Coal-Fired Energy and Water Problems', in Blog, World Resources Institute.

[439] US EPA (2015). 'Oil and Natural Gas Sector: Emission Standards for New and Modified Sources', Federal Register 80:56593-56698.

*NRH-P5: Regulatory Water Stress*

CPT plants have substantial water footprints, described below in hypothesis CPT-2 Water Stress. This water footprint exposes CPT companies to regulatory risks, as policymakers may take action to restrict processing plant access to water. Public opinion on the water footprint for CPT plants may also put pressure on policymakers to restrict water use, exposing CPT companies to a reputational risk as well.

The World Resources Institute (WRI) maintains the Aqueduct Water Risk Indicator maps. The WRI's Regulatory & Reputational Risk indicator aggregates indicators from the World Health Organization (WHO) concerning water access, the International Union for Conservation of Nature (IUCN) for threatened amphibians, and Google keyword searches for water supply media coverage[440]. With few exceptions, this indicator is provided at the national level.

This risk hypothesis is identical to the Regulatory Water Stress hypothesis described for coal-fired power utilities (see NRH-U9) and thermal coal miners (See NRH-M7) and uses the same data and analysis, see above for details.

***Table 56:** Regulatory water stress*[441]

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Risk bin | 1 | 3 | 1 | 4 | 3 | 1 | 2 | 3 | 2 | 1 |
| RISK | 🟢 | 🟡 | 🟢 | 🔴 | 🟡 | 🟢 | 🟢 | 🟡 | 🟢 | 🟢 |

*7.3.2.2 NRH-P6: CCS Legal Environment*

The hypothesis is that CCS could be a way for CPT plants to keep running under stricter carbon constraints, but CCS will not happen without a supportive legal framework.

CPT has several technical synergies with CCS, presenting a pathway for GHG emissions mitigation using coal as an energy resource. CCS currently faces substantial uncertainty with regards to current and future liabilities for the unique aspects of a CCS project, see Section 3.6.2. These uncertainties can present barriers to the development of CCS projects, which in turn present a risk to CPT projects who may not have CCS as an option for future GHG mitigation.

Certain countries have been proactive in developing policy and legal interpretations specifically for CCS. This progress is periodically evaluated by the Global CCS Institute periodically and published as an indexed indicator. The institute groups countries into three performance bands, which are used here as an indicator for CCS liability risk. Band A, the most CCS-ready, is considered 'low risk', Band B 'medium risk', and Band C 'high risk'.

[440] Gassert, F. et al. (2014). Op. Cit.

[441] World Resources Institute (2016). Op. Cit.

***Table 57:** CCS legal environment indicator*[442]

| | Australia | China | Germany | Indonesia | India | Japan | Poland | South Africa | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|
| Band | A | C | B | C | C | B | B | C | A | A |
| RISK | 🟢 | 🔴 | 🟡 | 🔴 | 🔴 | 🟡 | 🟡 | 🔴 | 🟢 | 🟢 |

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# 7.4 Summary of CPT Companies

***Table 58:** Summary of hypothesis risks for CPT companies*

| COMPANY | COUNTRY | CAPACITY [kNm3/day] OPR | CON | PLN | DEBT / EQUITY | CURRENT RATIO | (EBITDA – CAPEX) / INTEREST | [RANK]* LRH-P1: 'Plant Age' | LRH-P2: 'Water Stress' | LRH-P3: 'CCS Retrofitability' | NRH AGGREGATION** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SASOL | South Africa | 90,260 | - | - | - | - | - | 9 | 1 | 30 | 43% |
| DATANG | China | 48,550 | 3336 | 73442 | - | - | - | 3 | 15 | 1 | 43% |
| SHENHUA GROUP | China | 43,360 | - | 72000 | 0.43 | 1.18x | 0.00x | 2 | 5 | 30 | 43% |
| YITAI COAL OIL MANUFACTURING CO (INNER MONGOLIA YITAI GROUP) | China | 33,700 | - | - | 2.71 | 0.34x | 0.91x | 10 | 18 | 29 | 43% |
| SINOPEC | China | 29,481 | 840 | 63400 | 1.79 | 0.41x | -1.86x | 5 | 24 | 30 | 43% |
| CHINACOAL GROUP | US | 24,100 | 5000 | - | - | - | - | 17 | 12 | 30 | 43% |
| DAKOTA GASIFICATION CO | China | 13,900 | 36000 | - | 0.58 | 1.30x | 6.46x | 12 | 25 | 25 | 43% |
| QINGHUA GROUP | China | 13,860 | - | - | - | - | - | 5 | 19 | 1 | 43% |
| YANKUANG GROUP | China | 13,415 | 2000 | - | - | - | - | 7 | 17 | 30 | 43% |
| GUANGHUI ENERGY CO | China | 12,600 | - | - | - | - | - | 13 | 3 | 30 | 43% |
| PUCHENG CLEAN ENERGY CHEMICAL CO | China | 12,100 | - | - | - | - | - | 3 | 14 | 30 | 43% |
| XINHU GROUP | China | 12,000 | - | - | - | - | - | 5 | 26 | 30 | 43% |
| WISON (NANJING) CLEAN ENERGY CO | China | 11,932 | - | - | - | - | - | 14 | 22 | 28 | 43% |
| TOKYO ELECTRIC POWER COMPANY (TEPCO) | Japan | 11,566 | - | - | 0.49 | 0.96x | 0.62x | 8 | 23 | 26 | 43% |
| TOKYO ELECTRIC POWER COMPANY (TEPCO) | China | 9,975 | 8400 | - | 0.32 | 0.76x | 3.90x | 11 | 12 | 27 | 43% |
| SANWEI RESOURCE GROUP | China | 9,744 | - | 3125 | - | - | - | 15 | 27 | 1 | 43% |
| INNER MONGOLIA ZHUOZHENG COAL CHEMICAL CO | China | 9,040 | - | - | - | - | - | 6 | 2 | 1 | 43% |
| TIANJIN BOHAI CHEMICAL GROUP | China | 8,787 | 68000 | - | - | - | - | 3 | 20 | 1 | 43% |
| KOREA SOUTH EAST POWER CO (KOSEP) | South Korea | 8,400 | - | - | - | - | - | 2 | 28 | 1 | 43% |
| KOREA SOUTHERN POWER CO (KOSPO) | South Korea | 8,400 | - | - | - | - | - | 16 | 16 | 30 | 43% |
| JINDAL STEEL & POWER LTD | India | 8,025 | 84136 | 19020 | 1.73 | 0.61x | -0.82x | 3 | 29 | 30 | 43% |
| JIEHUA CHEMICAL | China | 8,000 | 9420 | 113080 | - | - | - | 1 | 21 | 1 | 43% |
| POSCO | South Korea | 6,934 | - | - | 2.06 | 0.84x | 1.58x | 4 | 7 | 30 | 36% |
| HUALU HENGSHENG CHEMICALS | China | 6,890 | - | - | 2.86 | 1.17x | 4.79x | 2 | 6 | 30 | 21% |
| JIANGSU LINGGU CHEMICAL CO | China | 6,090 | - | 2046 | 0.22 | 2.58x | 7.10x | 19 | 3 | 30 | 29% |
| HARBIN YILAN COAL GASIFICATION | China | 5,750 | - | - | 0.88 | 1.03x | 4.11x | 2 | 30 | 30 | - |
| ANHUI HUAYI CHEMICAL CO | China | 5,040 | - | - | 1.3 | 0.98x | -6.41x | 2 | 10 | 30 | - |
| XINJIANG XINLIANXIN FERTILIZER CO. LTD. | China | 5,040 | - | 56400 | 0.61 | 1.43x | 3.96x | 2 | 8 | 30 | - |
| YANTAI WANHUA | China | 5,040 | - | - | - | - | - | 18 | 9 | 1 | 29% |
| EAST CHINA ENERGY | US | 5,000 | - | 51000 | - | - | - | 5 | 11 | 1 | 29% |

*: Companies are ranked by exposure, with 1 being the most at risk.

**: NRHs have been aggregated to a single outlook percentage based on the sum of high risk (+2) and medium risk (+1) evaluations relative to the maximum possible and weighted by asset locations.

# 8 Indirect Impacts

Beyond thermal coal assets and the companies that own them, other sectors directly or indirectly dependent on them could be positively or negatively affected by the environment-related risks we have examined in this report. These could include shipping, freight railways, ports, power networks, pipelines, insurers, banks, institutional investors, upstream oil and gas producers, and renewables generators. Research and analysis of the exposure of these companies from risks facing the thermal coal value chain are well beyond the scope of this report, however, some of the potential indirect impacts are discussed below. We briefly review the implications for transport, financial institutions, and labour.

## 8.1 Transport

Approximately 90% of internationally traded coal is transported by ship[443]. In 2015, shipping fleets of 750mn dry weight tonnes (dwt) were engaged in the transportation of coal[444]. Bulker vessels range in size from 10,000dwt to 80,000dwt, implying a global coal shipping fleet of approximately 10,000 vessels[445]. In 2009, freight rates dropped substantially. Bulker charter rates have remained low since because of the significant amount of new build orders placed just before 2009. These orders have kept the bulk market oversupplied[446].

Environment-related risks have the potential to reduce international trade of coal, reducing demand for bulkers. It is highly likely that any such decrease in demand for bulkers would drive charter rates downward. If this happens near the bulker market trough, preliminary research suggests that vessel stranding is highly likely[447]. The total value of vessel stranding and the financial entities that it will impact will likely be determined by which entities financed the least efficient vessels, which are typically built at market peak, and when those vessels were built[448].

While internationally traded coal is transported by ship, most domestically traded and consumed relies on transport by rail. Over half of all US rail freight is transporting coal[449]. Freight rail carriers and export terminals will face pressure to adapt to new commodities or business models as environment-related risks decrease the amount of coal that is transported and consumed around the world. These risks have yet to be examined.

## 8.2 Workers and Labour Organisations

In 1920, two in every hundred US workers was a coal miner[450]. By 2013, coal miners had fallen to 0.06% of the US workforce or approximately 80,000 people[451]. In the UK, the first country to use coal for electricity (in 1882), by 1920 there were 1.2 million people employed as coal miners[452].

[443] IEA (2015). Coal MTMR. Op. Cit.

[444] Ibid.

[445] Ibid.

[446] Ibid.

[447] Smith, T. et al. (2015). Stranded Assets in Shipping. Conference Proceedings Shipping in Changing Climates Conference 2015, Glasgow, UK.

[448] Mitchell, J. & Rehmatulla, N. (2015). Dead in the Water: an analysis of industry practices and perceptions on vessel efficiency and stranded ship assets. Conference Proceedings Shipping in Changing Climates Conference 2015, Glasgow.

[449] American Association of Railroads (2015). Freight rail traffic data. https://www.aar.org/Pages/Freight-Rail-Traffic-Data.aspx.

[450] Coalswarm (2015). 'Coal and jobs in the United States', Sourcewatch. http://www.sourcewatch.org/index.php/Coal_and_jobs_in_the_United_States#Total_coal-related_jobs.

[451] Ibid.

[452] Stevenson & Cook (1988). The Longman Handbook of Modern British History 1714-1980.

By 2015 the number of working in coal mines fell below 3,000[453]. The transition away from coal mining as a major source of employment in the US and UK has taken many decades and it has not been straightforward or uncontroversial. The infamous UK miners' strike in the 1980s being one illustration of the disruption and social upheaval associated with the decline of coal mining.

The Paris Agreement and INDCs imply that carbon intensive sectors will need to quickly decline in order to achieve climate targets. But the faster the pace of decarbonisation, the greater the likely challenges associated with stranded assets in different sectors - a faster transition towards a low carbon economy, all things being equal, may increase the risk of political opposition. For example, the mere prospect of stranded carbon assets could result in the mobilisation of groups to oppose INDCs, which might result in these groups actively or passively frustrating or destabilising INDC implementation.

The issue of stranded labour frustrating INDC implementation is not generally considered by policymakers and this should be a priority for future research. The decline of large sectors, including coal, would create labour tensions that need to be managed in a much more sophisticated and purposeful way than has happened in the past. While very little was done in the 1980s UK to proactively pre-empt opposition to change in coal mining communities[454], we now have the data and analytics to do much more. We can know which assets will have to close, by when, who owns them, who is employed by them, which communities will be affected, and the impacts on the supply chain. With this information much more sensitive low carbon transition plans can be created that are designed to pre-empt opposition. This will improve the robustness of such plans and make them more likely to succeed.

## 8.3 Banks and Financial Institutions

This report has examined the direct exposure of companies in the thermal coal value chain to environment-related risks. Banks and the finance industry are exposed as owners of the debt and equity of companies in the thermal coal value chain. Their investors are in turn exposed to the same environment-related risks.

A recent report from the CEE Bankwatch Network examines spending on fossil fuel projects by the European Bank for Reconstruction and Development (EBRD) and the European Investment Bank (EIB). Bankwatch alleges that between 2007 and 2014 the EIB and EBRD spent €3.2bn and €990m on fossil fuel projects respectively in European neighbourhood countries[455]. Bankwatch argues that EU development funds should be allocated in alignment with the EU's own energy and climate goals.

In 2013, Banktrack.org examined the exposure of top commercial banks to investments in coal mining, and found Citigroup, Morgan Stanley, and Bank of America had the highest exposures with approximately €7bn each in loans and underwriting[456]. Bank of America, Crédit Agricole, and Citigroup have all announced their intention to end or substantially reduce financing of coal mining[457].

[453] UK Department of Energy and Climate Change (2015). See: https://www.gov.uk/government/collections/coal-statistics
[454] Stevenson & Cook (1988). Op. Cit.
[455] Kochladze, M. & Sikorova, K. (2015). European public money for the energy sector in countries of the European Neighbourhood Policy, 2007-2014, CEE Bankwatch Network. Liben, Czech Republic.
[456] Schücking, H. et al. (2013). Banking on Coal, urgewald; BankTrack; CEE Bankwatch Network; Polska Zielona Sieć
[457] Rainforest Action Network (2015). 'Citigroup Becomes Third Major Bank to Cut Financing to Coal Industry', EcoWatch.

# 9 Implications for disclosure and reporting

Financial disclosure and reporting is critical for the functioning of efficient capital markets. Disclosure and reporting comes from a wide array of voluntary and regulated activities, but generally seeks to resolve principal-agent problems of information asymmetry and agency[458]. Information asymmetry between investors and companies leads to the inefficient allocation of capital as investors do not know the relative merits of each company. Disclosure resolves agency problems as investors are able to evaluate the performance of the managers they have delegated to run their companies. Greater disclosure has been empirically observed to improve market liquidity, lower costs of capital, increase market valuations, and improve investment efficiency[459].

Companies with securities listed on regulated exchanges must submit the required information periodically to the regulator. This information is provided to the public so that they can make informed investment decisions. Companies may also voluntarily submit information to the regulator, public, or private investors. The Economist writes that it is the symmetry of information between investors that is important for functioning capital markets, not the degree of transparency[460].

In policy design, mandated disclosure or transparency is increasingly used in lieu of other regulations to incentivize or elicit changes in corporate behaviour[461]. The evidence for this approach to policy design is built largely on the informal and non-mandatory compliance literature base[462], as well as literature on consumer choice[463], corporate social responsibility[464], and company stakeholder obligations[465]. Where voluntary disclosure regimes have been successfully implemented by and for investors, the results linking ESG performance to corporate operating and financial performance are convincing[466].

## 9.1 Climate Change Risk Disclosure

Climate change risk disclosure has currently achieved acceptance as an objective in non-financial information disclosure. In these reports, climate change impacts are included as risk factors or topics of management discussion and analysis[467]. Non-financial disclosures may be regulated[468] however their content is discretionary to company management.

Voluntary sustainability and climate change risk reporting platforms have made progress attracting disclosure from early adopters. Frameworks from organisations like the CDP (formerly the Carbon Disclosure Project) and the Global Reporting Initiative connect investors with sustainability performance data from companies worldwide. A wide variety of reporting frameworks exist.

[458] Healy, P. & Palepu, K. (2001). 'Information asymmetry, corporate disclosure, and the capital markets: A review of the empirical disclosure literature', Journal of Accounting and Economics, 31: 405-440

[459] Leuz, C. & Wysocki, P. (2015). 'The Economics of Disclosure and Financial Reporting Regulation: Evidence and Suggestions for Future Research' SSRN.

[460] The Economist (2009) 'Full Disclosure: The case for transparency in financial markets is not so clear-cut', Economist.

[461] Leuz, C. & Wysocki, P. (2015). Op. Cit.

[462] US EPA (2014). 'Chapter 4: Regulatory and Non-Regulatory Approaches to Pollution Control' in Guidelines for Preparing Economic Analyses. Washington, US.

[463] For example, Brouhle, K. & Khanna, M. (2007). 'Information and the Provision of Quality Differentiated Products', Economic Inquiry, 45: 377-394.

[464] For example, Lyon, T. (2002). 'Voluntary Approaches to Environmental Protection: A Survey' (with John W. Maxwell), in Economic Institutions and Environmental Policy: Past, Present and Future.

[465] For example, Pargal, S., Hettige, H., Singh, M., et al. (1996). 'Formal and Information Regulation of Industrial Pollution', The World Bank Economic Review, 11:433-450.

[466] Clark, G., Feiner, A., & Veihs, M. (2015). From the Stockholder to the Stakeholder, University of Oxford, Arabesque Partners. London, UK.

[467] Securities and Exchange Commission (2010). Commission Guidance Regarding Disclosure Related to Climate Change.

[468] EU (2014). 'Directive 2014/95/EU', Official Journal of the European Union, 57:1-10; Institut RSE Management (2012). The Grenelle II Act in France: a milestone towards integrated reporting.

As accounting standards have become more globally aligned under the International Financial Reporting Standards, an opportunity has emerged to align account standards with sustainability risk disclosure. Organisations like the Sustainable Accounting Standards Board and the Climate Disclosure Standards Board are helping to align sustainability reporting with financial rigor. The challenge for investors remains that the multitude of standards produces insufficient 'decision-ready' information, and preparing and interpreting the reporting is burdensome for both companies and investors[469].

In November 2015, the World Federation of Exchanges (WFE) issued their guidance on ESG reporting[470]. WFE issued a list of 34 recommended ESG metrics to it 64 member exchanges, including 10 environmental metrics specifically. Many of the WFE's member exchanges already adopt some form of sustainability reporting[471].

Also in late 2015, the Financial Stability Board launched its Task Force on Climate-Related Financial Disclosures (TCFD). The Task Force is to develop consistent, comparable, reliable, clear, and efficient climate-related disclosures and is expected to release its recommendations by the end of 2016[472].

## 9.2 Insights from our research

As part of this research project we have undertaken a comprehensive data integration process, bringing together a wide range of different datasets and sources for the first time. This is a work in progress, but our work to date has highlighted some of the challenges associated with turning an understanding of environment-related factors facing particular sectors into analysis that is decision-relevant for financial institutions. These experiences are germane to extant processes on disclosure and corporate reporting, particularly the TCFD.

To take one specific example, without accurate geo-location data for assets it is very hard to accurately overlay spatial datasets or to use remote sensing and satellite data to further research assets. Existing datasets for coal-fired power stations only have precise geo-location data for 30% of power stations and only regional or city level geo-location data for the remaining power stations. This means that spatial datasets representing certain types of risk (e.g. air pollution) are not uniformly accurate – they become less useful for power stations with inaccurate geo-location data. It also means that when, for example, we wanted to use satellite imagery to identify the type of cooling technology installed on a power station (for assets where cooling data was missing from existing datasets), we could only do this for assets with accurate coordinates. Unfortunately, tracking down power stations on satellite imagery when the geo-location data is inaccurate is challenging and time consuming. This means that we have only been able to secure 71% coverage for the type of cool technology installed on coal-fired power stations, though we aim to improve this through further work.

One simple way around this particular problem would be for companies that are signed up to voluntary or mandatory reporting frameworks to disclosure the precise coordinates of their key physical assets. But a more general principle would be for companies, especially those with portfolios of large physical assets, to disclose asset specific characteristics so that researchers and analysts can undertake their own research on the risks and opportunities facing company portfolios.

[469] Thistelthwaite, J. (2015). The challenges of counting climate change risks in financial markets, Center for International Gonvernance Innovation. Waterloo, Canada.

[470] World Federation of Exchanges (2015). Exchange Guidance & Recommendation – October 2015, WFE Sustainability Working Group.

[471] Ibid.

[472] Financial Stability Board (2015). FSB to establish Task Force on Climate-related Financial Disclosures, Press Release.

Natural resources companies, particularly those involved in upstream fossil fuel production, appear reluctant to disclose any asset specific information, instead suggesting that their investors should simply trust their judgement.[473] We would suggest that this is a highly questionable approach and one that the TCFD and other related processes should take on. Introducing a new 'Principle of Asset-level Disclosure' into reporting frameworks would significantly enhance the ability of investors to understand the environmental performance of companies.

More generally, it is noteworthy that very little of our analysis has actually depended on existing corporate reporting or data disclosed through voluntary disclosure frameworks. This is both a cause for hope and concern. It demonstrates that significant strides can be made to understand company exposure to environment-related risks even in the absence of consistent, comprehensive, and timely corporate reporting on these issues. But it also highlights how existing frameworks on environment-related corporate disclosure might be asking the wrong questions – they generally attempt to support and enable top down analysis, but might not do enough to support a bottom up, asset-specific approach. Reporting needs to link back to a fundamental understanding of risk and opportunity and to specific assets within company portfolios, especially for companies with portfolios of large physical assets (e.g. power stations, mines, oil and gas fields, processing plants, and factories). In the absence of that, what is reported may not be actionable from an investor perspective.

The other task is to reduce the cost of accessing and using data that can underpin the analytical approach we have used here. Where possible we use non-proprietary datasets, but this is insufficient. The cost is really the cost of data integration – to have all the relevant data points on asset characteristics merged from a variety of data sources, as well as overlays that allow us to measure the relative exposure of assets to different risks and opportunities. The costs associated with assuring datasets and finding novel datasets are also significant. Fortunately, these are all areas where costs can be reduced and this could be a significant public good.

## 9.3 Company Data Intelligence Service

An initiative to find and integrate all the relevant asset-specific data points for companies in key sectors would almost certainly yield much more (and probably more accurate) investor-relevant information that what is currently disclosed. The initiative, call it the Company Data Intelligence Service (CDIS), would have the benefit of transcending mandatory and voluntary schemes as all companies would be in scope. CDIS would seek out data on company assets in key sectors, make this public where possible, and give companies the opportunity to correct mistakes and provide enhanced disclosure. It would operate in a completely transparent and accountable way and could collaborate with researchers and civil society to track down, assure, and release data on company assets.

Critically, CDIS would not be dependent on companies disclosing data. Such a public goods initiative focused on putting into the public domain accurate and relevant information to improve the analysis of company environmental performance, would not be particularly costly – it would certainly be much cheaper, quicker, and more plausible than all companies actually disclosing all the asset specific data needed for bottom analyses of environment-related factors.

[473] See Rook, D. & Caldecott, B.L. (2015) Evaluating capex risk: new metrics to assess extractive industry project portfolios. Working Paper. Smith School of Enterprise and the Environment, University of Oxford. Oxford, UK.

CDIS could support the development of new techniques and approaches to secure data that was hard to get or inaccessible due to cost or other barriers, whether through 'big data' or remote sensing, and foster the developments of new techniques to analyse data. CDIS could also have the task of integrating all existing environment-related corporate reporting into one system, allowing for analysis of data provided via a wide range of initiatives.

Through our research process it has become clear to us that the current company-level reporting paradigm – where some companies annually disclose data; where reported data might not actually be relevant for assessing real exposure to environment-related risk and opportunity; where reported data may be inaccurate and out of date; where companies that report spend a significant amount of time filling in forms for different reporting systems; and where third parties spend significant effort trying to assure reported data – could be significantly improved. Current reporting is slow moving, unable to achieve universal coverage of companies, and currently disconnected to the requirements of bottom up analysis. While current reporting efforts are an incredibly important contribution that we commend, much more can be done and more cost-effectively. In addition to putting more emphasis on asset specific disclosures in current and emerging reporting regimes, the development of a public goods CDIS-type initiative is something that the TFCD should consider recommending as part of its deliberations.

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# Appendix A: Top Coal-Fired Power Utilities Tables

***Table 59:** Top 100 coal-fired utilities: Capital planning and general information*

| COAL-FIRED GENERATION [GWh] | PARENT OWNER | COUNTRY | TOTAL CAP [MW] | FLEET EMISSIONS INTENSITY [kg.CO2/MWh] | CAPEX PROJ [$Usmn] |
|---|---|---|---|---|---|
| 471,139 | CHINA HUANENG GROUP CORP | China | 192,987 | 828 | N/A |
| 455,038 | CHINA GUODIAN CORP | China | 162,572 | 879 | N/A |
| 415,118 | CHINA DATANG CORP | China | 123,635 | 974 | N/A |
| 369,511 | CHINA HUADIAN GROUP CORP | China | 144,693 | 820 | N/A |
| 293,658 | CHINA POWER INVESTMENT CORP | China | 98,430 | 848 | N/A |
| 292,107 | SHENHUA GROUP CORP LTD | China | 93,608 | 897 | N/A |
| 214,924 | ESKOM HOLDINGS SOC LTD | South Africa | 44,122 | 944 | N/A |
| 208,588 | NTPC LTD | India | 43,719 | 900 | 3,782 |
| 171,178 | CHINA RESOURCES POWER HOLDINGS | China | 58,778 | 899 | 2,424 |
| 128,189 | KOREA ELECTRIC POWER CORP | Korea | 70,342 | 471 | 11,375 |
| 126,689 | GUANGDONG YUDEAN GROUP CO LTD | China | 47,276 | 816 | N/A |
| 99,685 | NRG ENERGY INC | USA | 59,794 | 804 | 648 |
| 97,603 | STATE GRID CORP OF CHINA | China | 43,188 | 596 | N/A |
| 89,977 | GDF SUEZ SA | France | 90,428 | 483 | 6,848 |
| 83,646 | VATTENFALL GROUP | Sweden | 40,349 | 528 | N/A |
| 71,669 | SOUTHERN CO | USA | 52,706 | 659 | 4,467 |
| 67,730 | DUKE ENERGY CORP | USA | 64,413 | 537 | 8,123 |
| 66,467 | PT PLN PERSERO | Indonesia | 31,515 | 844 | N/A |
| 62,916 | ENEL SPA | Italy | 72,845 | 513 | 7,003 |
| 60,917 | AMERICAN ELECTRIC POWER CO INC | USA | 36,037 | 789 | 4,266 |
| 59,572 | MINISTRY OF ECONOMIC AFFAIRS | Taiwan | 26,167 | 676 | N/A |
| 58,991 | TENNESSEE VALLEY AUTHORITY | USA | 37,426 | 670 | N/A |
| 53,995 | E.ON SE | Germany | 62,928 | 419 | 3,959 |
| 53,906 | ZHEJIANG ENERGY GROUP CO LTD | China | 20,391 | 768 | N/A |
| 52,212 | FORMOSA PLASTICS CORP | Taiwan | 10,056 | 906 | 253 |
| 51,803 | EDF GROUP | France | 137,395 | 149 | 12,795 |
| 51,504 | BEIJING ENERGY INVEST HOLDING | China | 20,210 | 689 | N/A |
| 46,454 | TATA GROUP | India | 9,770 | 1033 | N/A |
| 45,835 | CLP GROUP | Hong Kong | 17,266 | 710 | 957 |
| 45,703 | ADANI POWER LTD | India | 8,264 | 914 | 184 |
| 42,639 | RWE AG | Germany | 22,274 | 611 | 2,463 |
| 39,973 | VEDANTA RESOURCES PLC | India | 6,712 | 913 | 1,406 |
| 39,407 | J-POWER | Japan | 19,175 | 616 | N/A |
| 38,874 | HEBEI CONSTR & INVEST GROUP | China | 10,647 | 1042 | N/A |
| 38,501 | SHANXI INTL ELEC GROUP CO LTD | China | 10,375 | 901 | N/A |
| 37,808 | DYNEGY HOLDINGS INC | USA | 27,314 | 820 | N/A |
| 36,846 | RELIANCE INFRASTRUCTURE LTD | India | 9,860 | 847 | 83 |
| 35,269 | STATE DEV INVESTMENT CORP | China | 14,464 | 794 | N/A |
| 35,246 | AES CORP | USA | 27,369 | 512 | 977 |
| 34,147 | PUBLIC POWER CORP (DEI) | Greece | 13,905 | 527 | N/A |
| 33,049 | DTEK | Ukraine | 14,359 | 1338 | N/A |
| 32,727 | AGL ENERGY LTD | Australia | 8,338 | 920 | 370 |
| 32,687 | PGE POLSKA GRUPA ENERGETYCZNA | Poland | 18,705 | 682 | 1,642 |
| 31,995 | ISRAEL ELECTRIC CORP | Israel | 13,783 | 693 | N/A |
| 31,401 | XCEL ENERGY INC | USA | 20,057 | 726 | 2,700 |
| 31,388 | STEAG GMBH | Germany | 8,581 | 1121 | N/A |
| 30,613 | BERKSHIRE HATHAWAY ENERGY COMPANY | USA | 29,922 | 466 | N/A |
| 30,198 | DAMODAR VALLEY CORP (DVC) | India | 8,584 | 1336 | N/A |
| 28,989 | MP POWER GENERATING CO LTD | India | 7,549 | 964 | N/A |

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*Table 59:* (Table continued)

| COAL-FIRED GENERATION [GWh] | PARENT OWNER | COUNTRY | TOTAL CAP [MW] | FLEET EMISSIONS INTENSITY [kg.CO2/MWh] | CAPEX PROJ [$Usmn] |
|---|---|---|---|---|---|
| 27,337 | SHENERGY COMPANY LTD | China | 12,208 | 687 | 95 |
| 27,304 | JIANGSU GUOXIN INVEST GROUP | China | 18,146 | 904 | N/A |
| 27,259 | COMISION FEDERAL DE ELEC | Mexico | 37,572 | 537 | N/A |
| 26,846 | CITIC PACIFIC LTD | China | 6,809 | 982 | 3,913 |
| 26,173 | TRANSALTA CORP | Canada | 10,012 | 691 | 313 |
| 25,844 | FIRSTENERGY CORP | USA | 16,022 | 644 | 2,861 |
| 25,757 | GUJARAT STATE ELEC CORP LTD | India | 7,164 | 660 | N/A |
| 25,334 | PPL CORP | USA | 8,996 | 918 | 3,489 |
| 24,647 | DOMINION | USA | 21,714 | 420 | 4,468 |
| 24,602 | ANDHRA PRADESH POWER GEN CORP | India | 8,857 | 940 | N/A |
| 24,545 | CHUBU ELECTRIC POWER CO INC | Japan | 30,939 | 288 | 2,414 |
| 24,430 | JINDAL STEEL & POWER LTD | India | 7,116 | 849 | 464 |
| 22,771 | TENAGA NASIONAL BERHAD (TNB) | Indonesia | 16,182 | 384 | 2,256 |
| 21,894 | OOO SIBERIAN GENERATING CO | Russia | 8,308 | 2464 | N/A |
| 21,640 | ENERGY FUTURE HOLDINGS CORP | USA | 14,311 | 263 | N/A |
| 21,534 | RIVERSTONE HOLDINGS | USA | 17,816 | 597 | 18 |
| 21,279 | CEZ AS | Czech | 13,857 | 494 | 1,073 |
| 20,946 | NEYVELI LIGNITE CORP LTD | India | 4,665 | 1091 | N/A |
| 20,753 | CHEUNG KONG INFRASTRUCTURE | Hong Kong | 6,478 | 1167 | 56 |
| 20,622 | DTE ENERGY CO | USA | 12,590 | 619 | 2,293 |
| 20,554 | HARYANA POWER GEN CO (HPGC) | India | 6,209 | 1579 | N/A |
| 20,273 | ELECTRICITY OF VIETNAM (EVN) | Vietnam | 19,313 | 543 | N/A |
| 19,533 | GREAT PLAINS ENERGY INC | USA | 8,213 | 817 | 612 |
| 19,160 | WEST BENGAL POWER DEV CORP | India | 5,480 | 958 | N/A |
| 18,830 | HENAN INVESTMENT GROUP CO LTD | China | 6,530 | 1028 | N/A |
| 18,779 | WISCONSIN ENERGY CORP | USA | 7,250 | 1095 | 1,419 |
| 18,007 | INTER RAO UES | Russia | 57,614 | 93 | 416 |
| 16,842 | TAMIL NADU GEN & DIST CORP LTD | India | 7,108 | 531 | N/A |
| 16,476 | ZHEJIANG PROV ENERGY GROUP CO | China | 6,260 | 1188 | N/A |
| 16,426 | DATONG COAL MINE GROUP CO LTD | China | 6,670 | 5331 | N/A |
| 15,663 | TOHOKU ELECTRIC POWER CO | Japan | 13,845 | 376 | 2,355 |
| 15,222 | AMEREN CORP | USA | 11,236 | 878 | N/A |
| 15,128 | RAJASTHAN RV UTPADAN NIGAM | India | 7,350 | 1004 | N/A |
| 15,105 | SHENZHEN ENERGY GROUP CO LTD | China | 6,894 | 765 | 344 |
| 14,876 | SUMITOMO CORP | Japan | 8,441 | 858 | 1,465 |
| 14,776 | MAHARASHTRA STATE POWER GEN CO | India | 8,938 | 612 | N/A |
| 14,747 | CHINA PETRO & CHEM (SINOPEC) | China | 4,554 | 1089 | 19,607 |
| 14,068 | ECU - ENERGY CO OF UKRAINE | Ukraine | 5,476 | 1017 | N/A |
| 13,096 | ENBW ENERGIE BADEN-WURTTEMBERG | Germany | 10,824 | 638 | 926 |
| 12,954 | TAURON POLSKA ENERGIA SA | Poland | 4,549 | 872 | 1,009 |
| 12,880 | ENTERGY CORP | USA | 33,706 | 169 | 2,631 |
| 11,666 | ALLIANT ENERGY CORP | USA | 6,994 | 835 | 1,159 |
| 11,270 | UTTAR PRADESH RAJYA VIDYUT | India | 3,503 | 1584 | N/A |
| 11,049 | SCOTTISH AND SOUTHERN ENERGY | UK | 12,231 | 241 | 2,169 |
| 10,806 | BASIN ELECTRIC POWER COOP | USA | 4,751 | 1264 | N/A |
| 10,072 | EUROSIBENERGO | Russia | 19,219 | 152 | N/A |
| 10,054 | WENERGY-ANHUI PROV ENERGY | China | 4,401 | 1288 | 56 |
| 9,129 | SANTEE COOPER | USA | 5,227 | 727 | N/A |
| 8,356 | SALT RIVER PROJECT (AZ) | USA | 7,609 | 605 | N/A |
| 7,100 | GAZPROM | Russia | 27,620 | 735 | 25,472 |
| 2,041 | ELEKTROPRIVREDA SRBIJE (EPS) | Serbia | 2,094 | 416 | N/A |

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## *Table 60: Ownership of coal-fired power utilities*[474]

| | PARENT OWNER | COUNTRY | TICKER | UTLTIMATE PARENT (IF DIFFERENT) | OWNERSHIP | INSIDERS [US$bn] | INSTITUTIONS [US$bn] | CORPORATE [US$bn] | ESOP [US$bn] | STATE [US$bn] | PUBLIC/OTHER [US$bn] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CHINA HUANENG GROUP CORP | China | - | - | PrC | - | - | - | - | - | - |
| 2 | CHINA GUODIAN CORP | China | - | - | PrC | - | - | - | - | - | - |
| 3 | CHINA DATANG CORP | China | - | - | PrC | - | - | - | - | - | - |
| 4 | CHINA HUADIAN GROUP CORP | China | - | - | PrC | - | - | - | - | - | - |
| 5 | CHINA POWER INVESTMENT CORP | China | - | State Power Investment Group Corp. | PrC | - | - | - | - | - | - |
| 6 | SHENHUA GROUP CORP LTD | China | - | - | PrC | - | - | - | - | - | - |
| 7 | ESKOM HOLDINGS SOC LTD | South Africa | - | - | PrC | - | - | - | - | - | - |
| 8 | NTPC LTD | India | NSEI:NTPC | - | PbC | 0 | 2.8 | - | - | 12.73 | 1.36 |
| 9 | CHINA RESOURCES POWER HOLDINGS | China | SEHK:836 | China Resources National Corporation | PrC | 0.01 | 1.3 | 5.74 | - | - | 2.06 |
| 10 | KOREA ELECTRIC POWER CORP | Korea | KOSE:A01576( | - | PbC | 0 | 16.88 | - | - | 4.9 | 5.15 |
| 11 | GUANGDONG YUDEAN GROUP CO LTD | China | - | - | PrC | - | - | - | - | - | - |
| 12 | NRG ENERGY INC | USA | NYSE:NRG | - | PbC | 0.02 | 3.35 | - | - | - | - |
| 13 | STATE GRID CORP OF CHINA | China | - | - | PrC | - | - | - | - | - | - |
| 14 | GDF SUEZ SA | France | ENXTPA:ENG | - | PbC | 0 | 10.78 | 1.02 | 1.36 | 13.79 | 15.13 |
| 15 | VATTENFALL GROUP | Sweden | - | - | PrC | - | - | - | - | - | - |
| 16 | SOUTHERN CO | USA | NYSE:SO | - | PbC | 0.02 | 21.88 | - | - | - | 20.37 |
| 17 | DUKE ENERGY CORP | USA | NYSE:DUK | - | PbC | 0.05 | 27.7 | - | - | - | 20.78 |
| 18 | PT PLN PERSERO | Indonesia | - | - | PrC | - | - | - | - | - | - |
| 19 | ENEL SPA | Italy | BIT:ENEL | - | PbC | - | 10.26 | - | - | 11.15 | 19.13 |
| 20 | AMERICAN ELECTRIC POWER CO INC | USA | NYSE:AEP | - | PbC | 0.01 | 19.71 | - | - | - | 8.46 |
| 21 | MINISTRY OF ECONOMIC AFFAIRS | Taiwan | - | - | Gov | - | - | - | - | - | - |
| 22 | TENNESSEE VALLEY AUTHORITY | USA | - | - | Gov | - | - | - | - | - | - |
| 23 | E.ON SE | Germany | DB:EOAN | - | PbC | - | 5.88 | - | - | - | 12.33 |
| 24 | ZHEJIANG ENERGY GROUP CO LTD | China | - | - | PrC | - | - | - | - | - | - |
| 25 | FORMOSA PLASTICS CORP | Taiwan | TSEC:1301 | - | PbC | 0.76 | 3.67 | 3.34 | - | 0.21 | 6.06 |
| 26 | EDF GROUP | France | ENXTPA:EDF | - | PbC | 0 | 1.56 | - | 0.38 | 21.92 | 2.08 |
| 27 | BEIJING ENERGY INVEST HOLDING | China | - | Beijing Energy Investment (Group) Co. Ltd. | PrC | - | - | - | - | - | - |
| 28 | TATA GROUP | India | - | - | PrC | - | - | - | - | - | - |
| 29 | CLP GROUP | Hong Kong | SEHK:2 | - | PbC | 0 | 2.87 | 7.23 | - | - | 11 |
| 30 | ADANI POWER LTD | India | BSE:533096 | S.B. Adani Family Trust | PrC | 0.59 | 0.36 | 0.6 | - | - | - |
| 31 | RWE AG | Germany | DB:RWE | - | PbC | - | 2.29 | 1.13 | - | - | 4.09 |
| 32 | VEDANTA RESOURCES PLC | India | LSE:VED | - | PbC | 0.74 | 0.22 | - | 0.01 | - | 0.11 |
| 33 | J-POWER | Japan | - | - | PrC | - | - | - | - | - | - |
| 34 | HEBEI CONSTR & INVEST GROUP | China | - | - | PrC | - | - | - | - | - | - |
| 35 | SHANXI INTL ELEC GROUP CO LTD | China | - | Jinneng Co., Ltd. | PrC | - | - | - | - | - | - |
| 36 | DYNEGY HOLDINGS INC | USA | NYSE:DYN | - | PbC | 0 | 1.34 | 0.05 | - | - | - |
| 37 | RELIANCE INFRASTRUCTURE LTD | India | BSE:500390 | - | PbC | 0 | 0.5 | 0.86 | - | 0 | 0.42 |
| 38 | STATE DEV INVESTMENT CORP | China | - | - | PrC | - | - | - | - | - | - |
| 39 | AES CORP | USA | NYSE:AES | - | PbC | 0.01 | 6.18 | - | - | - | - |
| 40 | PUBLIC POWER CORP (DEI) | Greece | ATSE:PPC | - | PbC | - | 0.26 | - | - | 0.36 | 0.25 |
| 41 | DTEK | Ukraine | - | - | PrC | - | - | - | - | - | - |
| 42 | AGL ENERGY LTD | Australia | ASX:AGL | - | PbC | 0.02 | 1.39 | 0.02 | - | - | 6.95 |
| 43 | PGE POLSKA GRUPA ENERGETYCZNA | Poland | WSE:PGE | - | PbC | 0 | 1.11 | - | - | 3.44 | 1.34 |
| 44 | ISRAEL ELECTRIC CORP | Israel | - | - | PrC | - | - | - | - | - | - |
| 45 | XCEL ENERGY INC | USA | NYSE:XEL | - | PbC | 0.04 | 13.37 | - | - | - | 5.07 |
| 46 | STEAG GMBH | Germany | - | ** | PrC | - | - | - | - | - | - |
| 47 | BERKSHIRE HATHAWAY ENERGY COMPANY | USA | NYSE:BRK.A | - | PbI | 67.06 | 148.84 | - | - | - | 114.5 |
| 48 | DAMODAR VALLEY CORP (DVC) | India | - | - | PrC | - | - | - | - | - | - |
| 49 | MP POWER GENERATING CO LTD | India | - | M.S.E.B. Holding Co.Ltd | PrC | - | - | - | - | - | - |
| 50 | SHENERGY COMPANY LTD | China | SHSE:600642 | Shenergy (Group) Company Limited | PrC | 0.03 | 0.29 | 2.81 | - | - | 2.16 |
| 51 | JIANGSU GUOXIN INVEST GROUP | China | - | - | PrC | - | - | - | - | - | - |
| 52 | COMISION FEDERAL DE ELEC | Mexico | - | - | PrC | - | - | - | - | - | - |
| 53 | CITIC PACIFIC LTD | China | SEHK:267 | CITIC Group Corporation | PrC | - | 3.35 | 40.17 | - | - | 7.9 |
| 54 | TRANSALTA CORP | Canada | TSX:TA | - | PbC | 0 | 0.47 | - | - | - | 0.4 |
| 55 | FIRSTENERGY CORP | USA | NYSE:FE | - | PbC | 0.04 | 10.51 | - | - | - | 2.8 |
| 56 | GUJARAT STATE ELEC CORP LTD | India | - | Gujarat Electricity Board | PrC | - | - | - | - | - | - |
| 57 | PPL CORP | USA | NYSE:PPL | - | PbC | 0.01 | 16.49 | - | - | - | 6.29 |
| 58 | DOMINION | USA | NYSE:D | - | PbC | 0.15 | 25.51 | 0 | - | - | 14.55 |
| 59 | ANDHRA PRADESH POWER GEN CORP | India | - | - | PrC | - | - | - | - | - | - |
| 60 | CHUBU ELECTRIC POWER CO INC | Japan | TSE:9502 | - | PbC | 0 | 3.12 | 0 | 0.27 | 0.06 | 6.65 |
| 61 | JINDAL STEEL & POWER LTD | India | NSEI:JINDALS | - | PbC | 0.02 | 0.42 | 0.59 | - | - | 0.24 |
| 62 | TENAGA NASIONAL BERHAD (TNB) | Indonesia | KLSE:TENAG | - | PbC | 0 | 8.53 | - | - | 0.25 | 3.17 |
| 63 | OOO SIBERIAN GENERATING CO | Russia | - | Linea Ltd. | PrC | - | - | - | - | - | - |
| 64 | ENERGY FUTURE HOLDINGS CORP | USA | - | Texas Energy Future Holdings Limited Partr | PrC | 0.25 | - | 114.77 | - | - | - |

[474] Data taken from Standard & Poor's Capital IQ, November 2015.

## *Table 60:* *(Table continued)*

| | PARENT OWNER | COUNTRY | TICKER | UTLTIMATE PARENT (IF DIFFERENT) | OWNERSHIP* | INSIDERS [US$bn] | INSTITUTIONS [US$bn] | CORPORATE [US$bn] | ESOP [US$bn] | STATE [US$bn] | PUBLIC/OTHER [US$bn] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | XCEL ENERGY INC | USA | NYSE:XEL | - | PbC | 0.04 | 13.37 | - | - | - | 5.07 |
| 46 | STEAG GMBH | Germany | - | ** | PrC | - | - | - | - | - | - |
| 47 | BERKSHIRE HATHAWAY ENERGY COMPANY | USA | NYSE:BRK.A | - | PbI | 67.06 | 148.84 | - | - | - | 114.5 |
| 48 | DAMODAR VALLEY CORP (DVC) | India | - | - | PrC | - | - | - | - | - | - |
| 49 | MP POWER GENERATING CO LTD | India | - | M.S.E.B. Holding Co.Ltd | PrC | - | - | - | - | - | - |
| 50 | SHENERGY COMPANY LTD | China | SHSE:600642 | Shenergy (Group) Company Limited | PrC | 0.03 | 0.29 | 2.81 | - | - | 2.16 |
| 51 | JIANGSU GUOXIN INVEST GROUP | China | - | - | PrC | - | - | - | - | - | - |
| 52 | COMISION FEDERAL DE ELEC | Mexico | - | - | PrC | - | - | - | - | - | - |
| 53 | CITIC PACIFIC LTD | China | SEHK:267 | CITIC Group Corporation | PrC | - | 3.35 | 40.17 | - | - | 7.9 |
| 54 | TRANSALTA CORP | Canada | TSX:TA | - | PbC | 0 | 0.47 | - | - | - | 0.4 |
| 55 | FIRSTENERGY CORP | USA | NYSE:FE | - | PbC | 0.04 | 10.51 | - | - | - | 2.8 |
| 56 | GUJARAT STATE ELEC CORP LTD | India | - | Gujarat Electricity Board | PrC | - | - | - | - | - | - |
| 57 | PPL CORP | USA | NYSE:PPL | - | PbC | 0.01 | 16.49 | - | - | - | 6.29 |
| 58 | DOMINION | USA | NYSE:D | - | PbC | 0.15 | 25.51 | 0 | - | - | 14.55 |
| 59 | ANDHRA PRADESH POWER GEN CORP | India | - | - | PrC | - | - | - | - | - | - |
| 60 | CHUBU ELECTRIC POWER CO INC | Japan | TSE:9502 | - | PbC | 0 | 3.12 | 0 | 0.27 | 0.06 | 6.65 |
| 61 | JINDAL STEEL & POWER LTD | India | NSEI:JINDALS | - | PbC | 0.02 | 0.42 | 0.59 | - | - | 0.24 |
| 62 | TENAGA NASIONAL BERHAD (TNB) | Indonesia | KLSE:TENAG | - | PbC | 0 | 8.53 | - | - | 0.25 | 3.17 |
| 63 | OOO SIBERIAN GENERATING CO | Russia | - | Linea Ltd. | PrC | - | - | - | - | - | - |
| 64 | ENERGY FUTURE HOLDINGS CORP | USA | - | Texas Energy Future Holdings Limited Partr | PrC | 0.25 | - | 114.77 | - | - | - |
| 65 | RIVERSTONE HOLDINGS | USA | SGX:AP4 | - | PbC | 0.42 | 0.05 | - | - | - | 0.13 |
| 66 | CEZ AS | Czech | SEP:CEZ | - | PbC | - | 1.32 | - | - | 6.31 | 1.34 |
| 67 | NEYVELI LIGNITE CORP LTD | India | BSE:513683 | - | PbC | 0 | 0.08 | - | - | 1.97 | 0.02 |
| 68 | CHEUNG KONG INFRASTRUCTURE | Hong Kong | SEHK:1038 | CK Hutchison Holdings Limited | PbC | 0 | 3.02 | 17.53 | - | - | 2.54 |
| 69 | DTE ENERGY CO | USA | NYSE:DTE | - | PbC | 0.07 | 9.51 | - | - | - | 4.76 |
| 70 | HARYANA POWER GEN CO (HPGC) | India | - | NTPC Ltd. | PbC | - | - | - | - | - | - |
| 71 | ELECTRICITY OF VIETNAM (EVN) | Vietnam | - | - | PrC | - | - | - | - | - | - |
| 72 | GREAT PLAINS ENERGY INC | USA | NYSE:GXP | - | PbC | 0.02 | 3.58 | - | - | - | 0.6 |
| 73 | WEST BENGAL POWER DEV CORP | India | - | - | PrC | - | - | - | - | - | - |
| 74 | HENAN INVESTMENT GROUP CO LTD | China | - | - | PrI | - | - | - | - | - | - |
| 75 | WISCONSIN ENERGY CORP | USA | NYSE:WEC | - | PbC | 0.03 | 11.3 | - | - | - | 4.85 |
| 76 | INTER RAO UES | Russia | MICEX:IRAO | - | PbC | 0 | 0.07 | 1.12 | - | 0 | 0.11 |
| 77 | TAMIL NADU GEN & DIST CORP LTD | India | - | - | Gov | - | - | - | - | - | - |
| 78 | ZHEJIANG PROV ENERGY GROUP CO | China | - | Zhejiang Provincial Energy Group Company | PrC | - | - | - | - | - | - |
| 79 | DATONG COAL MINE GROUP CO LTD | China | - | - | PrC | - | - | - | - | - | - |
| 80 | TOHOKU ELECTRIC POWER CO | Japan | TSE:9506 | - | PbC | 0 | 1.23 | 0 | 0.17 | 0.31 | 4.27 |
| 81 | AMEREN CORP | USA | NYSE:AEE | - | PbC | 0.03 | 7.31 | - | - | - | 3.33 |
| 82 | RAJASTHAN RV UTPADAN NIGAM | India | - | - | PrC | - | - | - | - | - | - |
| 83 | SHENZHEN ENERGY GROUP CO LTD | China | SZSE:000027 | - | PbC | 0.03 | 0.12 | 1.57 | - | 2.95 | 1.5 |
| 84 | SUMITOMO CORP | Japan | TSE:8053 | - | PbC | 0.01 | 5.01 | 0.47 | - | - | 7.24 |
| 85 | MAHARASHTRA STATE POWER GEN CO | India | - | - | PrC | - | - | - | - | - | - |
| 86 | CHINA PETRO & CHEM (SINOPEC) | China | SEHK:386 | China Petrochemical Corporation | PrC | 0 | 7.2 | 51.46 | - | - | 13.49 |
| 87 | ECU - ENERGY CO OF UKRAINE | Ukraine | - | - | PrC | - | - | - | - | - | - |
| 88 | ENBW ENERGIE BADEN-WURTTEMBERG | Germany | DB:EBK | - | PbC | - | - | 6.05 | - | 0.06 | 0.02 |
| 89 | TAURON POLSKA ENERGIA SA | Poland | WSE:TPE | - | PbC | 0 | 0.33 | 0.13 | - | 0.37 | 0.41 |
| 90 | ENTERGY CORP | USA | NYSE:ETR | - | PbC | 0.02 | 10.6 | - | - | - | 1.37 |
| 91 | ALLIANT ENERGY CORP | USA | NYSE:LNT | - | PbC | 0 | 4.87 | - | - | - | 2.35 |
| 92 | UTTAR PRADESH RAJYA VIDYUT | India | - | - | PrC | - | - | - | - | - | - |
| 93 | SCOTTISH AND SOUTHERN ENERGY | UK | LSE:SSE | - | PbC | 0.01 | 17.14 | 0.01 | 0.17 | 0.35 | 4.37 |
| 94 | BASIN ELECTRIC POWER COOP | USA | - | - | PrC | - | - | - | - | - | - |
| 95 | EUROSIBENERGO | Russia | - | - | PrC | - | - | - | - | - | - |
| 96 | WENERGY-ANHUI PROV ENERGY | China | SZSE:000543 | - | PbC | 0.01 | 0.55 | 1.12 | - | - | 0.79 |
| 97 | SANTEE COOPER | USA | - | - | Gov | - | - | - | - | - | - |
| 98 | SALT RIVER PROJECT (AZ) | USA | - | - | Gov | - | - | - | - | - | - |
| 99 | GAZPROM | Russia | MICEX:GAZP | - | PbC | 0.01 | 17.22 | 5.47 | - | 17.74 | 4.21 |
| 100 | ELEKTROPRIVREDA SRBIJE (EPS) | Serbia | - | - | PrC | - | - | - | - | - | - |

*Gov: Government Institution; PrC: Private company; PrI: Private Investment Firm; PbC, Public company; PbI Public Investment Firm.

** Ksbg Kommunale Beteiligungsgesellschaft Gmbh & Co. Kg

## *Table 61:* Bond issuances of coal-fired power utilities

| | PARENT OWNER | COUNTRY | AVG. MATURITY | PERPETUITIES [US$mn] | DEBENTURES [US$mn] | TOTAL DEBT/EBITDA | CAPACITY [MW] |
|---|---|---|---|---|---|---|---|
| 1 | CHINA HUANENG GROUP CORP | China | 2021 | - | 6,408 | 6.3 | 160,212 |
| 2 | CHINA GUODIAN CORP | China | 2018 | 400 | 4,915 | 6.2 | 148,539 |
| 3 | CHINA DATANG CORP | China | 2019 | 1,569 | 4,048 | 6.9 | 123,635 |
| 4 | CHINA HUADIAN GROUP CORP | China | 2017 | - | 1,899 | 6 | 119,808 |
| 5 | CHINA POWER INVESTMENT CORP | China | 2021 | - | 6,375 | 8.9 | 82,819 |
| 6 | SHENHUA GROUP CORP LTD | China | 2018 | - | 19,232 | 3.1 | 89,021 |
| 7 | ESKOM HOLDINGS SOC LTD | South Africa | 2026 | - | 14,810 | 14.6 | 36,678 |
| 8 | NTPC LTD | India | 2023 | - | 3,753 | 5.9 | 41,532 |
| 9 | CHINA RESOURCES POWER HOLDINGS | China | 2019 | 750 | 1,582 | 3.1 | 55,342 |
| 10 | KOREA ELECTRIC POWER CORP | Korea | 2021 | - | 27,545 | 3.4 | 23,481 |
| 11 | GUANGDONG YUDEAN GROUP CO LTD | China | 2020 | - | 1,413 | none | 43,441 |
| 12 | NRG ENERGY INC | USA | 2021 | 1,000 | 44,666 | 6.4 | 29,576 |
| 13 | STATE GRID CORP OF CHINA | China | 2021 | - | 86,657 | none | 22,218 |
| 14 | GDF SUEZ SA | France | 2026 | 4,101 | 37,325 | 3.6 | 20,424 |
| 15 | VATTENFALL GROUP | Sweden | 2035 | - | 8,456 | 5.1 | 15,719 |
| 16 | SOUTHERN CO | USA | 2032 | 865 | 24,293 | 4.1 | 27,819 |
| 17 | DUKE ENERGY CORP | USA | 2028 | 255 | 40,625 | 4.8 | 22,492 |
| 18 | PT PLN PERSERO | Indonesia | 2025 | - | 10,572 | 2.9 | 16,763 |
| 19 | ENEL SPA | Italy | 2031 | 500 | 59,955 | 3.7 | 17,937 |
| 20 | AMERICAN ELECTRIC POWER CO INC | USA | 2026 | 821 | 15,789 | 4.3 | 22,577 |
| 21 | MINISTRY OF ECONOMIC AFFAIRS | Taiwan | 0 | - | - | none | 10,114 |
| 22 | TENNESSEE VALLEY AUTHORITY | USA | 2033 | - | 24,481 | 6.3 | 20,756 |
| 23 | E.ON SE | Germany | 2026 | 89 | 29,999 | 2.1 | 13,664 |
| 24 | ZHEJIANG ENERGY GROUP CO LTD | China | 2017 | - | 300 | none | 13,992 |
| 25 | FORMOSA PLASTICS CORP | Taiwan | 2025 | - | 1,000 | 5.4 | 9,328 |
| 26 | EDF GROUP | France | 2031 | 16,862 | 101,097 | 3.6 | 17,288 |
| 27 | BEIJING ENERGY INVEST HOLDING | China | 2017 | - | 2,098 | none | 13,180 |
| 28 | TATA GROUP | India | 2018 | 35 | 140 | none | 8,468 |
| 29 | CLP GROUP | Hong Kong | 2023 | 500 | 3,708 | 3.4 | 10,118 |
| 30 | ADANI POWER LTD | India | 2020 | - | 1,864 | 8 | 8,220 |
| 31 | RWE AG | Germany | 2033 | 1,140 | 23,959 | 4.2 | 10,793 |
| 32 | VEDANTA RESOURCES PLC | India | 2018 | - | 10,333 | 5.7 | 6,448 |
| 33 | J-POWER | Japan | 0 | - | - | none | 6,805 |
| 34 | HEBEI CONSTR & INVEST GROUP | China | 2023 | - | 1,927 | none | 10,362 |
| 35 | SHANXI INTL ELEC GROUP CO LTD | China | 0 | - | - | none | 9,100 |
| 36 | DYNEGY HOLDINGS INC | USA | 0 | - | - | 9.5 | 14,541 |
| 37 | RELIANCE INFRASTRUCTURE LTD | India | 0 | - | - | 7.8 | 9,320 |
| 38 | STATE DEV INVESTMENT CORP | China | 2021 | - | 4,709 | 5.8 | 12,325 |
| 39 | AES CORP | USA | 2025 | 88 | 25,905 | 5.4 | 11,216 |
| 40 | PUBLIC POWER CORP (DEI) | Greece | 2018 | - | 1,492 | 4 | 5,597 |
| 41 | DTEK | Ukraine | 2018 | - | 1,660 | 9.2 | 13,526 |
| 42 | AGL ENERGY LTD | Australia | 2030 | - | 1,875 | 4 | 5,238 |
| 43 | PGE POLSKA GRUPA ENERGETYCZNA | Poland | 2019 | - | 536 | 0.6 | 8,784 |
| 44 | ISRAEL ELECTRIC CORP | Israel | 2023 | - | 10,317 | 8.9 | 6,185 |
| 45 | XCEL ENERGY INC | USA | 2030 | 71 | 13,726 | 4.2 | 9,712 |
| 46 | STEAG GMBH | Germany | 0 | - | - | 23.8 | 7,984 |
| 47 | BERKSHIRE HATHAWAY ENERGY COMPANY | USA | 2030 | 37 | 41,763 | 5.9 | 11,875 |
| 48 | DAMODAR VALLEY CORP (DVC) | India | 0 | - | - | 16.1 | 8,313 |
| 49 | MP POWER GENERATING CO LTD | India | 0 | - | - | none | 6,613 |
| 50 | SHENERGY COMPANY LTD | China | 2018 | - | 392 | 3.1 | 7,584 |
| 51 | JIANGSU GUOXIN INVEST GROUP | China | 2018 | - | 2,103 | none | 16,665 |
| 52 | COMISION FEDERAL DE ELEC | Mexico | 2028 | - | 10,498 | 18.4 | 4,700 |
| 53 | CITIC PACIFIC LTD | China | 2023 | 2,548 | 26,511 | 2.4 | 6,309 |
| 54 | TRANSALTA CORP | Canada | 2022 | 591 | 3,621 | 4.8 | 5,078 |
| 55 | FIRSTENERGY CORP | USA | 2028 | 25 | 28,033 | 6.9 | 9,950 |
| 56 | GUJARAT STATE ELEC CORP LTD | India | 0 | - | - | none | 6,094 |
| 57 | PPL CORP | USA | 2030 | 94 | 21,228 | 4.1 | 8,385 |
| 58 | DOMINION | USA | 2028 | 201 | 29,528 | 5.2 | 6,583 |
| 59 | ANDHRA PRADESH POWER GEN CORP | India | 0 | - | - | 14 | 6,980 |
| 60 | CHUBU ELECTRIC POWER CO INC | Japan | 2019 | - | 9,396 | 5.1 | 4,100 |
| 61 | JINDAL STEEL & POWER LTD | India | 0 | - | - | 8.1 | 7,077 |
| 62 | TENAGA NASIONAL BERHAD (TNB) | Indonesia | 2022 | - | 458,016 | 2.3 | 8,680 |
| 63 | OOO SIBERIAN GENERATING CO | Russia | 2023 | - | 231 | none | 8,308 |
| 64 | ENERGY FUTURE HOLDINGS CORP | USA | 2021 | 3,600 | 66,073 | 23.6 | 8,496 |
| 65 | RIVERSTONE HOLDINGS | USA | 0 | - | - | 0 | 8,309 |
| 66 | CEZ AS | Czech | 2024 | - | 6,362 | 2.6 | 6,235 |
| 67 | NEYVELI LIGNITE CORP LTD | India | 0 | - | - | 3.2 | 4,615 |
| 68 | CHEUNG KONG INFRASTRUCTURE | Hong Kong | 2021 | 300 | 2,677 | 8.6 | 6,306 |
| 69 | DTE ENERGY CO | USA | 2028 | 612 | 68,208 | 3.7 | 7,909 |
| 70 | HARYANA POWER GEN CO (HPGC) | India | 0 | - | - | none | 6,145 |

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## *Table 61:* *(Table continued)*

| | PARENT OWNER | COUNTRY | AVG. MATURITY | PERPETUITIES [US$mn] | DEBENTURES [US$mn] | TOTAL DEBT/EBITDA | CAPACITY [MW] |
|---|---|---|---|---|---|---|---|
| 71 | ELECTRICITY OF VIETNAM (EVN) | Vietnam | 2016 | - | 89 | none | 5,434 |
| 72 | GREAT PLAINS ENERGY INC | USA | 2027 | 39 | 3,982 | 4.5 | 5,647 |
| 73 | WEST BENGAL POWER DEV CORP | India | 0 | - | - | none | 5,480 |
| 74 | HENAN INVESTMENT GROUP CO LTD | China | 2020 | - | 1,014 | none | 6,530 |
| 75 | WISCONSIN ENERGY CORP | USA | 2037 | - | 9,494 | 5.9 | 4,493 |
| 76 | INTER RAO UES | Russia | 0 | - | - | 1.6 | 8,030 |
| 77 | TAMIL NADU GEN & DIST CORP LTD | India | 0 | - | - | -3.7 | 4,320 |
| 78 | ZHEJIANG PROV ENERGY GROUP CO | China | 2018 | - | 2,469 | 3 | 6,260 |
| 79 | DATONG COAL MINE GROUP CO LTD | China | 2019 | - | 424 | none | 6,670 |
| 80 | TOHOKU ELECTRIC POWER CO | Japan | 2019 | - | 8,829 | 6.1 | 2,701 |
| 81 | AMEREN CORP | USA | 2027 | 315 | 6,660 | 3.9 | 5,829 |
| 82 | RAJASTHAN RV UTPADAN NIGAM | India | 0 | - | - | none | 6,580 |
| 83 | SHENZHEN ENERGY GROUP CO LTD | China | 0 | - | - | 3.5 | 3,744 |
| 84 | SUMITOMO CORP | Japan | 2021 | - | 5,009 | 1.9 | 5,514 |
| 85 | MAHARASHTRA STATE POWER GEN CO | India | 0 | - | - | none | 5,550 |
| 86 | CHINA PETRO & CHEM (SINOPEC) | China | 2019 | - | 21,860 | 1.7 | 4,074 |
| 87 | ECU - ENERGY CO OF UKRAINE | Ukraine | none | none | none | none | 5,475 |
| 88 | ENBW ENERGIE BADEN-WURTTEMBERG | Germany | 2045 | - | 5,895 | 5 | 6,301 |
| 89 | TAURON POLSKA ENERGIA SA | Poland | 0 | - | - | 2.4 | 4,242 |
| 90 | ENTERGY CORP | USA | 2028 | 320 | 11,643 | 3.7 | 4,997 |
| 91 | ALLIANT ENERGY CORP | USA | 2030 | 228 | 3,653 | 4.4 | 3,950 |
| 92 | UTTAR PRADESH RAJYA VIDYUT | India | 0 | - | - | none | 3,490 |
| 93 | SCOTTISH AND SOUTHERN ENERGY | United Kingdom | 2026 | 3,279 | 13,313 | 3.2 | 4,206 |
| 94 | BASIN ELECTRIC POWER COOP | USA | 2041 | - | 200 | 13.9 | 3,688 |
| 95 | EUROSIBENERGO | Russia | 0 | - | - | none | 3,979 |
| 96 | WENERGY-ANHUI PROV ENERGY | China | 0 | - | - | 1.7 | 4,345 |
| 97 | SANTEE COOPER | USA | 2035 | - | 9,203 | none | 3,620 |
| 98 | SALT RIVER PROJECT (AZ) | USA | 2031 | - | 5,179 | none | 3,231 |
| 99 | GAZPROM | Russia | 2022 | - | 46,144 | 1.6 | 3,786 |
| 100 | ELEKTROPRIVREDA SRBIJE (EPS) | Serbia | none | none | none | none | 446 |

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***Table 62:** Ratio analysis for coal-fired power utilities*

| Year | Count | (A) Net Profit Margin | (B) CAPEX to Assets | (C) Current Ratio | (D) Acid Test | (E) Total Debt to Equity | (F) Total Debt to Assets | (G) EBIT to interest expense | (H) EBITDA to interest expense | (I) (EBITDA-CAPEX) to interest expense | (J) Total Debt to EBITDA | (K) Net Debt to EBITDA | (L) Total Debt to (EBITDA - CAPEX) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 33 | 11.80% | 5.50% | 0.92x | 0.19x | 94.70% | 48.50% | 3.69x | 5.74x | 2.87x | 2.50x | 2.42x | 3.59x |
| 1996 | 34 | 10.90% | 4.80% | 0.94x | 0.21x | 90.30% | 46.90% | 3.77x | 5.61x | 3.51x | 2.41x | 2.32x | 2.95x |
| 1997 | 37 | 9.60% | 5.50% | 0.99x | 0.24x | 92.70% | 47.10% | 3.88x | 5.81x | 2.92x | 2.53x | 2.27x | 2.96x |
| 1998 | 41 | 8.80% | 5.40% | 0.93x | 0.25x | 91.50% | 47.10% | 3.48x | 5.53x | 2.68x | 2.42x | 2.22x | 2.92x |
| 1999 | 44 | 9.70% | 5.40% | 0.95x | 0.30x | 88.60% | 46.10% | 3.32x | 5.47x | 2.31x | 2.96x | 2.54x | 2.70x |
| 2000 | 45 | 9.90% | 5.50% | 0.87x | 0.31x | 90.30% | 45.20% | 4.01x | 6.38x | 2.47x | 2.65x | 2.46x | 4.82x |
| 2001 | 45 | 8.20% | 6.00% | 0.92x | 0.36x | 99.50% | 49.80% | 3.62x | 5.15x | 2.15x | 2.94x | 2.71x | 4.07x |
| 2002 | 47 | 9.90% | 6.10% | 0.91x | 0.33x | 105.70% | 52.20% | 3.28x | 5.26x | 2.51x | 3.32x | 2.82x | 4.51x |
| 2003 | 49 | 9.00% | 4.90% | 1.02x | 0.37x | 93.20% | 47.60% | 3.93x | 6.72x | 3.34x | 3.03x | 2.66x | 5.09x |
| 2004 | 50 | 9.00% | 4.80% | 1.13x | 0.42x | 94.60% | 48.60% | 4.23x | 6.59x | 3.35x | 2.91x | 2.58x | 4.53x |
| 2005 | 51 | 8.90% | 5.50% | 1.18x | 0.46x | 93.50% | 46.90% | 4.40x | 6.27x | 4.20x | 3.08x | 1.73x | 3.59x |
| 2006 | 54 | 10.40% | 6.20% | 1.07x | 0.45x | 85.70% | 43.30% | 4.32x | 7.17x | 3.37x | 3.15x | 1.76x | 4.13x |
| 2007 | 55 | 11.00% | 7.50% | 1.00x | 0.44x | 78.20% | 43.10% | 4.92x | 7.37x | 2.50x | 2.61x | 2.02x | 4.70x |
| 2008 | 56 | 8.90% | 8.50% | 1.00x | 0.38x | 111.20% | 52.60% | 3.73x | 5.85x | 1.23x | 3.26x | 2.64x | 4.06x |
| 2009 | 56 | 8.70% | 7.30% | 1.05x | 0.37x | 112.00% | 51.80% | 4.28x | 5.69x | 2.18x | 3.57x | 2.68x | 3.67x |
| 2010 | 56 | 9.30% | 6.10% | 1.14x | 0.39x | 116.50% | 51.20% | 4.59x | 6.57x | 2.60x | 3.18x | 2.42x | 5.08x |
| 2011 | 56 | 7.50% | 6.80% | 1.06x | 0.33x | 115.20% | 53.30% | 3.78x | 5.72x | 2.01x | 3.74x | 3.29x | 6.33x |
| 2012 | 56 | 6.80% | 6.10% | 1.02x | 0.41x | 110.30% | 52.30% | 2.73x | 4.65x | 1.17x | 4.16x | 3.78x | 6.10x |
| 2013 | 56 | 8.20% | 6.20% | 1.02x | 0.42x | 116.10% | 53.00% | 3.08x | 5.37x | 1.16x | 3.97x | 3.66x | 6.05x |
| 2014 | 56 | 7.70% | 5.50% | 1.06x | 0.48x | 111.30% | 52.30% | 3.43x | 5.58x | 1.42x | 3.85x | 3.20x | 8.34x |

***Table 63:*** *Column descriptions for local risk hypotheses table*

| Label | Unit | Description |
|---|---|---|
| NUM | - | Total number of coal-fired power stations |
| CAP | [MW] | Total power station capacity |
| CO2 | [$kgCO_2$/MWh] | Average emissions intensity of generated power weighted by plant capacity |
| AGE | [Years] | Average plant age weighted by plant capacity |
| PM | [$\mu g_{PM}/m^3$] | Average plant exposure to 100km PM concentration weighted by plant capacity |
| PAT | [%] | Absence of pollution abatement technologies weighted by plant capacity |
| NOX | [$10^{15}$ $mol_{NO2}/cm^2$] | Average plant exposure to 100km $NO_2$ concentration weighted by plant capacity |
| HG | [$g_{HG}/km^2$] | Average plant exposure to 100km Hg concentration weighted by plant capacity |
| BWS | [%] | Baseline physical water stress weighted by plant capacity |
| CWT | [%] | Proportion of once-through cooling |
| FWS | [%] | Future physical water stress weighted by plant capacity |
| QUC | [%] | Lignite-fired capacity as a percentage of total capacity |
| CCS | [%] | Access to CCS-suitable geological reservoir weighted by total capacity |
| FHS | [$\Delta^o$C] | Average 2035 temperature increase weighted by plant capacity |

## *Table 64: Summary table of local risk hypotheses for coal-fired power stations*

| ## | PARENT OWNER | COUNTRY | NUM | CAP [MW] | UTI-1 CO2 | UTI-2 AGE | UTI-3 PM | PAT | NOX | HG | UTI-4 BWS | CWT | FWS | UTI-5 QUC | UTI-6 CCS | UTI-7 FHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CHINA HUANENG GROUP CORP | China | 115 | 160,212 | 957 | 12 | 41 | 0.61 | 568 | 586 | 0.57 | 0.33 | 0.65 | 0.1 | 0.18 | 1.01 |
| 2 | CHINA GUODIAN CORP | China | 118 | 148,539 | 959 | 12 | 42 | 0.65 | 520 | 451 | 0.55 | 0.34 | 0.61 | 0.04 | 0.13 | 1.02 |
| 3 | CHINA DATANG CORP | China | 92 | 123,635 | 966 | 13 | 44 | 0.57 | 580 | 580 | 0.54 | 0.37 | 0.62 | 0.04 | 0.26 | 1.03 |
| 4 | CHINA HUADIAN GROUP CORP | China | 96 | 119,808 | 946 | 12 | 43 | 0.56 | 587 | 387 | 0.62 | 0.36 | 0.66 | 0.02 | 0.19 | 1.01 |
| 5 | CHINA POWER INVESTMENT CORP | China | 65 | 82,819 | 964 | 13 | 41 | 0.45 | 503 | 450 | 0.58 | 0.39 | 0.62 | 0.31 | 0.08 | 1.05 |
| 6 | SHENHUA GROUP CORP LTD | China | 54 | 89,021 | 909 | 10 | 34 | 0.54 | 465 | 368 | 0.59 | 0.24 | 0.71 | 0.07 | 0.37 | 1.07 |
| 7 | ESKOM HOLDINGS SOC LTD | South Africa | 12 | 36,678 | 1013 | 32 | 7 | 0 | 1118 | 1839 | 0.22 | 0 | 0.24 | 0 | 0 | 1.08 |
| 8 | NTPC LTD | India | 25 | 41,532 | 925 | 15 | 30 | 0.57 | 247 | 425 | 0.34 | 0.08 | 0.36 | 0.14 | 0.04 | 0.84 |
| 9 | CHINA RESOURCES POWER HOLDINGS | China | 41 | 55,342 | 970 | 9 | 55 | 0.74 | 582 | 649 | 0.54 | 0.38 | 0.57 | 0.04 | 0.2 | 0.93 |
| 10 | KOREA ELECTRIC POWER CORP | Korea | 15 | 23,481 | 974 | 18 | 19 | 0.93 | 541 | 157 | 0.3 | 0 | 0.31 | 0.01 | 0 | 0.91 |
| 11 | GUANGDONG YUDEAN GROUP CO LTD | China | 30 | 43,441 | 936 | 14 | 28 | 0.63 | 372 | 538 | 0.12 | 0 | 0.13 | 0.04 | 0 | 0.84 |
| 12 | NRG ENERGY INC | USA | 22 | 29,576 | 978 | 43 | 7 | 0 | 271 | 67 | 0.29 | 0 | 0.32 | 0.06 | 0 | 1.1 |
| 13 | STATE GRID CORP OF CHINA | China | 44 | 22,218 | 1029 | 18 | 32 | 0.66 | 410 | 336 | 0.7 | 0.47 | 0.75 | 0.34 | 0.01 | 1.08 |
| 14 | GDF SUEZ SA | France | 30 | 20,424 | 930 | 22 | 10 | 0.34 | 319 | 177 | 0.3 | 0.05 | 0.35 | 0.18 | 0.27 | 0.81 |
| 15 | VATTENFALL GROUP | Sweden | 14 | 15,719 | 921 | 22 | 12 | 0.43 | 430 | 190 | 0.35 | 0 | 0.29 | 0.59 | 0.13 | 0.97 |
| 16 | SOUTHERN CO | USA | 17 | 27,819 | 965 | 37 | 6 | 0 | 169 | 60 | 0.1 | 0 | 0.11 | 0.02 | 0.02 | 0.98 |
| 17 | DUKE ENERGY CORP | USA | 17 | 22,492 | 961 | 36 | 7 | 0.01 | 195 | 47 | 0.24 | 0 | 0.25 | 0.01 | 0.01 | 1.04 |
| 18 | PT PLN PERSERO | Indonesia | 35 | 16,763 | 1014 | 10 | 10 | 0.68 | 239 | 351 | 0.34 | 0.21 | 0.41 | 0.04 | 0.22 | 0.68 |
| 19 | ENEL SPA | Italy | 16 | 17,937 | 974 | 32 | 9 | 0.14 | 219 | 61 | 0.17 | 0.01 | 0.26 | 0.14 | 0 | 1.07 |
| 20 | AMERICAN ELECTRIC POWER CO INC | USA | 17 | 22,577 | 975 | 42 | 7 | 0 | 236 | 103 | 0.08 | 0 | 0.1 | 0.03 | 0 | 1.12 |
| 21 | MINISTRY OF ECONOMIC AFFAIRS | Taiwan | 2 | 10,114 | 896 | 22 | 13 | 1 | 302 | 287 | 0.22 | 0 | 0.15 | 0 | 0 | 0.69 |
| 22 | TENNESSEE VALLEY AUTHORITY | USA | 11 | 20,756 | 982 | 46 | 7 | 0 | 151 | 40 | 0.06 | 0 | 0.06 | 0 | 0 | 1.07 |
| 23 | E.ON SE | Germany | 21 | 13,664 | 934 | 34 | 10 | 0.47 | 534 | 120 | 0.27 | 0.01 | 0.31 | 0.07 | 0 | 0.91 |
| 24 | ZHEJIANG ENERGY GROUP CO LTD | China | 11 | 13,992 | 899 | 7 | 34 | 0.92 | 509 | 756 | 0.25 | 0.14 | 0.36 | 0 | 0 | 0.88 |
| 25 | FORMOSA PLASTICS CORP | Taiwan | 10 | 9,328 | 938 | 16 | 17 | 0.54 | 343 | 258 | 0.31 | 0.05 | 0.31 | 0 | 0 | 0.72 |
| 26 | EDF GROUP | France | 22 | 17,288 | 931 | 31 | 16 | 0.26 | 433 | 134 | 0.39 | 0.1 | 0.4 | 0 | 0.04 | 0.93 |
| 27 | BEIJING ENERGY INVEST HOLDING | China | 13 | 13,180 | 949 | 8 | 25 | 0.34 | 510 | 340 | 0.85 | 0.31 | 1 | 0 | 0.25 | 1.16 |
| 28 | TATA GROUP | India | 9 | 8,468 | 903 | 10 | 23 | 1 | 189 | 215 | 0.6 | 0.18 | 0.72 | 0.18 | 0 | 0.8 |
| 29 | CLP GROUP | Hong Kong | 8 | 10,118 | 959 | 22 | 24 | 0.51 | 412 | 418 | 0.38 | 0.24 | 0.42 | 0.15 | 0.06 | 0.57 |
| 30 | ADANI POWER LTD | India | 4 | 8,220 | 899 | 7 | 18 | 0.71 | 156 | 138 | 0.22 | 0 | 0.23 | 0.31 | 0 | 0.79 |
| 31 | RWE AG | Germany | 12 | 10,793 | 978 | 33 | 12 | 0.86 | 695 | 215 | 0.12 | 0 | 0.1 | 0.76 | 0 | 0.9 |
| 32 | VEDANTA RESOURCES PLC | India | 9 | 6,448 | 928 | 5 | 31 | 0.44 | 345 | 269 | 0.49 | 0.38 | 0.5 | 0.12 | 0.03 | 0.88 |
| 33 | J-POWER | Japan | 7 | 6,805 | 856 | 20 | 10 | 0.33 | 332 | 151 | 0.3 | 0.22 | 0.27 | 0 | 0 | 0.89 |
| 34 | HEBEI CONSTR & INVEST GROUP | China | 8 | 10,362 | 1063 | 14 | 67 | 0.36 | 1043 | 369 | 1 | 0.88 | 1 | 0 | 0.25 | 1.04 |
| 35 | SHANXI INTL ELEC GROUP CO LTD | China | 12 | 9,100 | 966 | 13 | 40 | 0.44 | 685 | 340 | 0.94 | 0.17 | 1 | 0 | 0.07 | 1.08 |
| 36 | DYNEGY HOLDINGS INC | USA | 14 | 14,541 | 981 | 43 | 8 | 0 | 213 | 59 | 0.26 | 0 | 0.38 | 0 | 0 | 1.17 |
| 37 | RELIANCE INFRASTRUCTURE LTD | India | 5 | 9,320 | 893 | 9 | 28 | 0.58 | 161 | 403 | 0.93 | 0.86 | 0.94 | 0 | 0 | 0.94 |
| 38 | STATE DEV INVESTMENT CORP | China | 8 | 12,325 | 933 | 13 | 41 | 0.69 | 601 | 548 | 0.39 | 0.07 | 0.44 | 0 | 0.32 | 1.01 |
| 39 | AES CORP | USA | 18 | 11,216 | 974 | 34 | 9 | 0.12 | 314 | 143 | 0.23 | 0.14 | 0.2 | 0 | 0 | 1 |
| 40 | PUBLIC POWER CORP (DEI) | Greece | 5 | 5,597 | 1073 | 29 | 10 | 0.21 | 168 | 310 | 0.59 | 0 | 0.77 | 1 | 0 | 1.07 |
| 41 | DTEK | Ukraine | 9 | 13,526 | 1039 | 41 | 10 | 0.17 | 265 | 86 | 0.39 | 0.34 | 0.44 | 0.03 | 0 | 1.21 |
| 42 | AGL ENERGY LTD | Australia | 3 | 5,238 | 1117 | 35 | 1 | 0 | 249 | 53 | 0.23 | 0 | 0.3 | 0.11 | 0 | 0.88 |
| 43 | PGE POLSKA GRUPA ENERGETYCZNA | Poland | 8 | 8,784 | 970 | 29 | 13 | 0.02 | 425 | 139 | 0.26 | 0 | 0.3 | 0.7 | 0 | 1.04 |
| 44 | ISRAEL ELECTRIC CORP | Israel | 2 | 6,185 | 898 | 19 | 13 | 0.43 | 269 | 144 | 1 | 1 | 1 | 0 | 0 | 0.96 |
| 45 | XCEL ENERGY INC | USA | 11 | 9,712 | 952 | 33 | 6 | 0 | 110 | 24 | 0.77 | 0.3 | 0.82 | 0 | 0 | 1.24 |
| 46 | STEAG GMBH | Germany | 14 | 7,984 | 930 | 32 | 12 | 0.68 | 610 | 169 | 0.18 | 0 | 0.22 | 0 | 0.05 | 0.92 |
| 47 | BERKSHIRE HATHAWAY ENERGY COMPANY | USA | 12 | 11,875 | 970 | 38 | 6 | 0 | 91 | 30 | 0.6 | 0.37 | 0.64 | 0 | 0 | 1.33 |
| 48 | DAMODAR VALLEY CORP (DVC) | India | 9 | 8,313 | 997 | 13 | 37 | 0.94 | 394 | 434 | 0.29 | 0 | 0.33 | 0 | 0 | 0.68 |
| 49 | MP POWER GENERATING CO LTD | India | 4 | 6,613 | 1022 | 13 | 23 | 1 | 116 | 96 | 0.45 | 0 | 0.48 | 0 | 0 | 0.91 |
| 50 | SHENERGY COMPANY LTD | China | 3 | 7,584 | 957 | 14 | 57 | 1 | 1256 | 3151 | 0.22 | 0 | 0.95 | 0 | 0 | 0.9 |
| 51 | JIANGSU GUOXIN INVEST GROUP | China | 11 | 16,665 | 1065 | 11 | 57 | 0.66 | 767 | 1027 | 0.66 | 0.36 | 0.79 | 0 | 0.26 | 0.92 |
| 52 | COMISION FEDERAL DE ELEC | Mexico | 3 | 4,700 | 1026 | 25 | 8 | 0 | 147 | 140 | 0.11 | 0 | 0.19 | 0 | 0 | 0.98 |
| 53 | CITIC PACIFIC LTD | China | 6 | 6,309 | 1003 | 15 | 66 | 0.94 | 1037 | 1250 | 0.36 | 0.34 | 0.4 | 0 | 0.63 | 0.94 |
| 54 | TRANSALTA CORP | Canada | 3 | 5,078 | 928 | 29 | 5 | 0 | 98 | 40 | 0.17 | 0 | 0.23 | 0 | 0 | 1.19 |
| 55 | FIRSTENERGY CORP | USA | 6 | 9,950 | 975 | 42 | 8 | 0 | 314 | 106 | 0.09 | 0 | 0.1 | 0 | 0.02 | 1.16 |
| 56 | GUJARAT STATE ELEC CORP LTD | India | 6 | 6,094 | 969 | 22 | 24 | 0.92 | 100 | 286 | 0.78 | 0.65 | 0.88 | 0.42 | 0.14 | 0.97 |
| 57 | PPL CORP | USA | 6 | 8,385 | 938 | 30 | 8 | 0 | 272 | 91 | 0.03 | 0 | 0.03 | 0 | 0.13 | 1.16 |

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*Table 64:* *(Table continued)*

| ## | PARENT OWNER | COUNTRY | NUM | CAP [MW] | UTI-1 CO2 | UTI-2 AGE | UTI-3 PM | PAT | NOX | HG | UTI-4 BWS | CWT | FWS | UTI-5 QUC | UTI-6 CCS | UTI-7 FHS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 | DOMINION | USA | 6 | 6,583 | 969 | 38 | 7 | 0 | 224 | 37 | 0.16 | 0 | 0.17 | 0 | 0 | 1 |
| 59 | ANDHRA PRADESH POWER GEN CORP | India | 5 | 6,980 | 904 | 8 | 17 | 0.53 | 202 | 97 | 0.67 | 0.23 | 0.74 | 0 | 0.57 | 0.74 |
| 60 | CHUBU ELECTRIC POWER CO INC | Japan | 1 | 4,100 | 760 | 19 | 9 | 0 | 499 | 126 | 0.53 | 0 | 0.53 | 0 | 0 | 0.84 |
| 61 | JINDAL STEEL & POWER LTD | India | 6 | 7,077 | 922 | 4 | 27 | 0.52 | 373 | 483 | 0.12 | 0 | 0.13 | 0 | 0 | 0.8 |
| 62 | TENAGA NASIONAL BERHAD (TNB) | Indonesia | 3 | 8,680 | 966 | 12 | 16 | 0.76 | 438 | 127 | 0.11 | 0 | 0.15 | 0 | 0 | 0.72 |
| 63 | OOO SIBERIAN GENERATING CO | Russia | 17 | 8,308 | 1198 | 37 | 7 | 0.3 | 95 | 50 | 0.1 | 0 | 0.11 | 0.32 | 0 | 1.43 |
| 64 | ENERGY FUTURE HOLDINGS CORP | USA | 5 | 8,496 | 959 | 30 | 5 | 0 | 121 | 88 | 0.14 | 0 | 0.17 | 1 | 0.2 | 1.02 |
| 65 | RIVERSTONE HOLDINGS | USA | 7 | 8,309 | 976 | 41 | 8 | 0 | 251 | 31 | 0.6 | 0.34 | 0.73 | 0 | 0 | 1.19 |
| 66 | CEZ AS | Czech | 12 | 6,235 | 1200 | 37 | 13 | 0.34 | 386 | 217 | 0.18 | 0 | 0.21 | 0.72 | 0 | 1.03 |
| 67 | NEYVELI LIGNITE CORP LTD | India | 5 | 4,615 | 945 | 18 | 20 | 0.89 | 211 | 253 | 0.9 | 1 | 1 | 1 | 0.27 | 0.76 |
| 68 | CHEUNG KONG INFRASTRUCTURE | Hong Kong | 5 | 6,306 | 939 | 21 | 19 | 0.97 | 434 | 303 | 0.3 | 0.05 | 0.17 | 0.1 | 0 | 0.77 |
| 69 | DTE ENERGY CO | USA | 5 | 7,909 | 981 | 45 | 8 | 0 | 357 | 77 | 0.23 | 0 | 0.25 | 0 | 0 | 1.25 |
| 70 | HARYANA POWER GEN CO (HPGC) | India | 4 | 6,145 | 1082 | 17 | 50 | 0.8 | 246 | 284 | 1 | 1 | 1 | 0.4 | 0 | 1.05 |
| 71 | ELECTRICITY OF VIETNAM (EVN) | Vietnam | 8 | 5,434 | 957 | 9 | 21 | 0.65 | 308 | 217 | 0.13 | 0 | 0.13 | 0 | 0 | 0.8 |
| 72 | GREAT PLAINS ENERGY INC | USA | 6 | 5,647 | 947 | 32 | 7 | 0 | 178 | 38 | 0.17 | 0 | 0.21 | 0 | 0 | 1.21 |
| 73 | WEST BENGAL POWER DEV CORP | India | 5 | 5,480 | 1038 | 20 | 37 | 1 | 331 | 381 | 0.23 | 0 | 0.25 | 0 | 0 | 0.66 |
| 74 | HENAN INVESTMENT GROUP CO LTD | China | 5 | 6,530 | 1023 | 9 | 75 | 0.71 | 809 | 757 | 0.94 | 0.71 | 1 | 0 | 0.18 | 1.01 |
| 75 | WISCONSIN ENERGY CORP | USA | 6 | 4,493 | 928 | 31 | 8 | 0 | 267 | 71 | 0.36 | 0 | 0.38 | 0 | 0 | 1.3 |
| 76 | INTER RAO UES | Russia | 6 | 8,030 | 952 | 37 | 9 | 0.35 | 191 | 21 | 0.16 | 0 | 0.25 | 0.54 | 0 | 1.04 |
| 77 | TAMIL NADU GEN & DIST CORP LTD | India | 3 | 4,320 | 933 | 17 | 18 | 1 | 182 | 211 | 0.75 | 0.42 | 0.79 | 0 | 0.42 | 0.67 |
| 78 | ZHEJIANG PROV ENERGY GROUP CO | China | 2 | 6,260 | 921 | 9 | 57 | 0.8 | 980 | 1991 | 0.77 | 0.8 | 0.87 | 0 | 0 | 0.9 |
| 79 | DATONG COAL MINE GROUP CO LTD | China | 6 | 6,670 | 912 | 5 | 32 | 0.96 | 485 | 409 | 0.79 | 0.61 | 0.88 | 0 | 0 | 1.13 |
| 80 | TOHOKU ELECTRIC POWER CO | Japan | 2 | 2,701 | 807 | 23 | 8 | 0 | 249 | 38 | 0.29 | 0 | 0.29 | 0 | 0 | 0.95 |
| 81 | AMEREN CORP | USA | 4 | 5,829 | 984 | 46 | 8 | 0 | 214 | 81 | 0.02 | 0 | 0.02 | 0 | 0 | 1.22 |
| 82 | RAJASTHAN RV UTPADAN NIGAM | India | 4 | 6,580 | 997 | 11 | 23 | 0.54 | 173 | 127 | 1 | 1 | 0.99 | 0.26 | 0 | 1.01 |
| 83 | SHENZHEN ENERGY GROUP CO LTD | China | 3 | 3,744 | 1098 | 16 | 29 | 1 | 535 | 942 | 0.33 | 0 | 0.32 | 0 | 0 | 0.82 |
| 84 | SUMITOMO CORP | Japan | 9 | 5,514 | 921 | 14 | 10 | 0.81 | 255 | 218 | 0.56 | 0 | 0.61 | 0 | 0.76 | 0.72 |
| 85 | MAHARASHTRA STATE POWER GEN CO | India | 4 | 5,550 | 907 | 11 | 25 | 1 | 134 | 99 | 0.42 | 0 | 0.6 | 0 | 0 | 0.88 |
| 86 | CHINA PETRO & CHEM (SINOPEC) | China | 16 | 4,074 | 1148 | 15 | 46 | 0.8 | 621 | 868 | 0.22 | 0.14 | 0.24 | 0.16 | 0.06 | 0.78 |
| 87 | ECU - ENERGY CO OF UKRAINE | Ukraine | 4 | 5,475 | 1005 | 45 | 10 | 0.33 | 237 | 44 | 0.23 | 0 | 0.31 | 0 | 0 | 1.21 |
| 88 | ENBW ENERGIE BADEN-WURTTEMBERG | Germany | 8 | 6,301 | 857 | 22 | 12 | 0.63 | 516 | 124 | 0.14 | 0 | 0.12 | 0 | 0 | 0.93 |
| 89 | TAURON POLSKA ENERGIA SA | Poland | 9 | 4,242 | 975 | 29 | 15 | 0.4 | 468 | 176 | 0.18 | 0 | 0.28 | 0 | 0 | 1.06 |
| 90 | ENTERGY CORP | USA | 3 | 4,997 | 965 | 37 | 7 | 0 | 123 | 25 | 0.17 | 0 | 0.18 | 0 | 0 | 1.03 |
| 91 | ALLIANT ENERGY CORP | USA | 10 | 3,950 | 986 | 42 | 9 | 0 | 136 | 30 | 0.31 | 0 | 0.32 | 0 | 0 | 1.32 |
| 92 | UTTAR PRADESH RAJYA VIDYUT | India | 3 | 3,490 | 910 | 19 | 31 | 1 | 254 | 458 | 0.35 | 0 | 0.38 | 0 | 0 | 0.94 |
| 93 | SCOTTISH AND SOUTHERN ENERGY | United Kingdom | 3 | 4,206 | 934 | 46 | 7 | 0 | 425 | 85 | 0.35 | 0 | 0.3 | 0 | 0 | 0.84 |
| 94 | BASIN ELECTRIC POWER COOP | USA | 4 | 3,688 | 960 | 32 | 5 | 0 | 97 | 64 | 0.66 | 0.46 | 0.68 | 0.42 | 0 | 1.29 |
| 95 | EUROSIBENERGO | Russia | 14 | 3,979 | 1303 | 45 | 4 | 0.28 | 56 | 47 | 0.03 | 0 | 0.03 | 0 | 0 | 1.34 |
| 96 | WENERGY-ANHUI PROV ENERGY | China | 4 | 4,345 | 868 | 13 | 59 | 0.78 | 615 | 819 | 0.33 | 0.3 | 0.34 | 0 | 0.29 | 0.95 |
| 97 | SANTEE COOPER | USA | 2 | 3,620 | 938 | 24 | 4 | 0 | 191 | 38 | 0.11 | 0 | 0.11 | 0 | 0 | 0.95 |
| 98 | SALT RIVER PROJECT (AZ) | USA | 2 | 3,231 | 970 | 40 | 4 | 0 | 83 | 51 | 0.11 | 0 | 0.2 | 0 | 0 | 1.23 |
| 99 | GAZPROM | Russia | 5 | 3,786 | 1301 | 29 | 7 | 0 | 77 | 37 | 0.04 | 0 | 0.04 | 0.65 | 0 | 1.42 |
| 100 | ELEKTROPRIVREDA SRBIJE (EPS) | Serbia | 3 | 446 | 1276 | 48 | 11 | 0.39 | 235 | 55 | 0.1 | 0 | 0.14 | 1 | 0 | 1.2 |

# Appendix B: Top Thermal Coal Mining Companies Tables

***Table 65:** Capital expenditure projection of top thermal coal miners with ≥30% revenue from thermal coal*

| Parent Owner | Country | % Rev Thermal Coal[1] | EBITDA LTM [US$mm] | Capital Expenditure Projection [CY US$mm] | | | |
|---|---|---|---|---|---|---|---|
| | | | | 2016 | 2017 | 2018 | 2019 |
| CHINA COAL ENERGY COMPANY | China | 52% | 1,049 | 2,505 | 1,722 | - | - |
| CHINA SHENHUA ENERGY CO | China | 35% | 10,877 | 4,869 | 4,883 | - | - |
| DATONG COAL INDUSTRY | China | 97% | 22 | 78 | 78 | - | - |
| INNER MONGOLIA YITAI COAL CO., LTD. | China | 85% | 515 | 1,561 | 1,348 | - | - |
| SHANXI LU'AN ENVIRONMENTAL ENERGY DEVELOPMENT | China | 90% | 179 | 288 | 291 | - | - |
| YANG QUAN COAL INDUSTRY (GROUP) CO., LTD. | China | 70% | 208 | 233 | 239 | - | - |
| YANZHOU COAL MINING COMPANY LIMITED | China | 31% | 481 | 761 | 685 | - | - |
| ALLIANCE RESROUCE PARTNERS | US | 100% | 817 | 222 | 228 | 250 | 250 |
| ALPHA NATURAL RESOURCES | US | 66% | 83 | 150 | 120 | - | - |
| ARCH COAL | US | 80% | 373 | 127 | 112 | - | - |
| CONSOL ENERGY INC | US | 46% | 987 | 647 | 684 | - | - |
| PEABODY ENERGY CORPORATION | US | 72% | 546 | 172 | 183 | 145 | - |
| INDO TAMBANGRAYA MEGAH TBK PT | Indonesia | 94% | 168 | 53 | 52 | 77 | 79 |
| PT ADARO ENERGY TBK | Indonesia | 91% | 717 | 161 | 175 | - | - |
| PT UNITED TRACTORS | Indonesia | 66% | 729 | 303 | 314 | 255 | 255 |
| ADANI ENTERPRISES LTD | India | 55% | 1,509 | 185 | 671 | - | - |
| COAL INDIA LTD | India | 89% | 2,747 | 1,016 | 1,187 | 1,420 | 1,482 |
| THE TATA POWER COMPANY | India | 31% | 1,184 | 275 | 256 | 144 | - |
| SASOL | South Africa | 58% | 4,992 | 5,603 | 4,019 | 3,105 | 2,324 |
| BANPU PUBLIC COMPANY LIMITED | Thailand | 85% | 336 | 245 | 222 | - | - |

[475] MSCI

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## **Table 66:** *Ownership of top thermal coal minters with ≥30% revenue from thermal coal*[476]

| Parent Owner | Country | Ticker | Ultimate Parent (if different) | Ownership* | Insiders | Institutions | Corporate | ESOP | State | Public/Other |
|---|---|---|---|---|---|---|---|---|---|---|
| **China Coal Energy Company Limited** | China | SEHK:1898 | China National Coal Group Corporation | PrC | 0 | 1.12 | 3.02 | - | - | 1.01 |
| **China Shenhua Energy Co. Ltd.** | China | SEHK:1088 | Shenhua Group Corporation Limited | PrC | - | 3.18 | 21.96 | - | - | 4.89 |
| **DaTong Coal Industry Co.,Ltd.** | China | SHSE:601001 | Datong Coal Mine Group Co., Ltd. | PrC | 0 | 0.06 | 0.88 | - | - | 0.51 |
| **Inner Mongolia Yitai Coal Co. Ltd.** | China | SHSE:900948 | - | PbC | - | 0.24 | 1.59 | 0.01 | - | 0.62 |
| **Shanxi Lu'an Environmental** Energy Development Co., Ltd. | China | SHSE:601699 | Shanxi Lu'an Mining Industry (Group) Company Ltd. | PrC | - | 0.13 | 1.9 | - | - | 0.96 |
| **Yang Quan Coal Industry (Group) Tiantai Investment Limited** | China | - | YANGQUAN COAL INDUSTRY(GROUP)CO.,LTD | PrC | - | - | - | - | - | - |
| **Yanzhou Coal Mining Co. Ltd**. | China | SEHK:1171 | Yankuang Group Co., Ltd. | PrC | 0 | 0.38 | 1.27 | - | - | 0.6 |
| **Alliance Resource Partners LP** | United States | NasdaqGS:ARLP | - | PbC | 0.01 | 0.22 | 0.41 | - | - | 0.28 |
| **Alpha Natural Resources, Inc.** | United States | OTCPK:ANRZ.Q | - | PbC | 0 | 0 | - | - | - | 0 |
| **Arch Coal Inc.** | United States | NYSE:ACI | - | PbC | 0 | 0.01 | - | - | - | 0.01 |
| **CONSOL Energy Inc.** | United States | NYSE:CNX | - | PbC | 0.01 | 1.55 | - | - | - | - |
| **Peabody Energy Corporation** | United States | NYSE:BTU | - | PbC | 0 | 0.07 | - | - | - | 0.07 |
| **PT Indo Tambangraya Megah Tbk** | Indonesia | JKSE:ITMG | Banpu Public Company Limited | PbC | 0 | 0.07 | 0.32 | - | 0 | 0.09 |
| **PT Adaro Energy Tbk** | Indonesia | JKSE:ADRO | - | PbC | 0.18 | 0.6 | - | - | - | 0.39 |
| **PT United Tractors Tbk** | Indonesia | JKSE:UNTR | Jardine Matheson Holdings Limited | PbC | 0 | 0.55 | 2.49 | - | - | 1.14 |
| **Adani Enterprises Limited** | India | BSE:512599 | S.B. Adani Family Trust | PrC | 0.12 | 0.23 | 0.88 | - | - | 0.09 |
| **Coal India Limited** | India | NSEI:COALINDIA | - | PbC | 0 | 4.23 | - | - | 23.97 | 1.89 |
| **The Tata Power Company Limited** | India | BSE:500400 | - | PbC | 0 | 1.05 | 0.86 | - | 0 | 0.72 |
| **Sasol Ltd.** | South Africa | JSE:SOL | - | PbC | 0 | 5.85 | - | - | 1.33 | 6.81 |
| **Banpu Public Company Limited** | Thailand | SET:BANPU | - | PbC | 0.16 | 0.21 | 0.14 | - | 0.02 | 0.69 |

*Gov: Government Institution; PrC: Private company; PrI: Private Investment Firm; PbC, Public company; PbI Public Investment Firm.

[476] Data from Standard & Poor's Capital IQ, November 2015.

***Table 67:*** *Debt positions of thermal coal miners with ≥30% revenue from thermal coal* [477]

| Parent owner | Country | Average Maturity | Perpetuities [US$mm] | Corporate Debentures [US$mm] | Total Debt/ EBITDA | Thermal Coal Rev [US$mm] |
|---|---|---|---|---|---|---|
| CHINA COAL ENERGY COMPANY | China | 2018 | 0 | 4709 | 17.1 | 5,966.30 |
| CHINA SHENHUA ENERGY CO | China | 0 | 0 | 0 | 1.5 | 14,006.39 |
| DATONG COAL INDUSTRY | China | 0 | 0 | 0 | 83 | 1,355.73 |
| INNER MONGOLIA YITAI COAL CO., LTD. | China | 2018 | 0 | 549 | 9 | 3,397.46 |
| SHANXI LU'AN ENVIRONMENTAL ENERGY DEVELOPMENT | China | 0 | 0 | 0 | 11.6 | 2,323.84 |
| YANG QUAN COAL INDUSTRY (GROUP) CO., LTD. | China | 2016 | 0 | 2170 | 5.4 | 2,336.67 |
| YANZHOU COAL MINING COMPANY LIMITED | China | 2019 | 300 | 3273 | 16.1 | 3,044.72 |
| ALLIANCE RESOURCE PARTNERS | US | 0 | 0 | 0 | 1.2 | 2,300.72 |
| ALPHA NATURAL RESOURCES | US | 2020 | 0 | 5724 | 45 | 2,836.85 |
| ARCH COAL | US | 2022 | 0 | 6853 | 13.8 | 2,349.70 |
| CONSOL ENERGY INC | US | 2021 | 0 | 11895 | 3.8 | 1,599.70 |
| PEABODY ENERGY CORPORATION | US | 2023 | 0 | 11023 | 11.5 | 4,890.38 |
| INDO TAMBANGRAYA MEGAH TBK PT | Indonesia | 0 | 0 | 0 | 0 | 1,740.86 |
| PT ADARO ENERGY TBK | Indonesia | 2019 | 0 | 800 | 2.3 | 2,908.70 |
| PT UNITED TRACTORS | Indonesia | 0 | 0 | 0 | 0.3 | 2,826.15 |
| ADANI ENTERPRISES LTD | India | 0 | 0 | 0 | 1.9 | 5,067.80 |
| COAL INDIA LTD | India | 0 | 0 | 0 | 0 | 10,250.88 |
| THE TATA POWER COMPANY | India | 2047 | 0 | 826 | 4.5 | 1,861.31 |
| SASOL | South Africa | 2022 | 0 | 1000 | 0.7 | 11,050.28 |
| BANPU PUBLIC COMPANY LIMITED | Thailand | 2020 | 0 | 320 | 9.6 | 2,637.96 |

[477] Data from Standard & Poor's Capital IQ, November 2015.

## *Table 68: Ratio analysis for thermal coal mining industry*

This table represents the median ratios across all firms available. For the thermal coal mining companies, we obtain data for 28 of the 30 coal companies listed in Table 21.

| Year | Count | (A) Net Profit Margin | (B) CAPEX to Assets | (C) Current Ratio | (D) Acid Test | (E) Total Debt to Equity | (F) Total Debt to Assets | (G) EBIT to interest expens | (H) EBITDA to interest expen | (I) (EBITDA-CAP to interest expe | (J) Total Debt to EBITDA | (K) Net Debt to EBITDA | (L) Total Debt to (EBITDA - CA | (M) Net Debt to (EBITDA - CA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 5 | 11.70% | 8.70% | 1.44x | 0.23x | 87.50% | 46.70% | 3.21x | 5.70x | 2.24x | 3.45x | 3.01x | 1.19x | 0.33x |
| 1996 | 6 | 10.40% | 6.10% | 1.67x | 0.45x | 74.40% | 42.40% | 4.41x | 5.79x | 3.98x | 1.70x | 1.68x | 1.81x | 1.11x |
| 1997 | 7 | 9.60% | 9.80% | 1.20x | 0.39x | 51.40% | 34.00% | 3.66x | 10.10x | 7.33x | 1.49x | 1.44x | 1.08x | 0.90x |
| 1998 | 8 | 2.80% | 7.00% | 1.02x | 0.25x | 48.70% | 56.90% | 2.62x | 4.78x | 2.98x | 1.36x | 1.07x | 2.77x | 1.79x |
| 1999 | 12 | 8.80% | 4.50% | 1.35x | 0.43x | 94.80% | 48.40% | 3.70x | 5.40x | 3.96x | 2.58x | 2.16x | 2.38x | 2.04x |
| 2000 | 13 | 3.60% | 5.00% | 1.31x | 0.34x | 87.40% | 46.60% | 1.94x | 3.93x | 1.62x | 3.23x | 2.60x | 4.67x | 4.22x |
| 2001 | 15 | 3.30% | 6.70% | 1.21x | 0.29x | 95.80% | 48.90% | 2.02x | 3.89x | 1.72x | 3.17x | 2.50x | 4.80x | 3.16x |
| 2002 | 17 | 5.50% | 7.60% | 0.87x | 0.24x | 96.70% | 49.20% | 2.65x | 3.99x | 1.95x | 2.33x | 1.93x | 3.42x | 3.02x |
| 2003 | 21 | 6.90% | 8.50% | 1.26x | 0.35x | 70.80% | 41.50% | 3.58x | 5.69x | 2.00x | 2.18x | 1.78x | 2.51x | 2.12x |
| 2004 | 23 | 10.70% | 11.30% | 1.36x | 0.40x | 82.60% | 45.20% | 6.23x | 9.41x | 3.86x | 1.65x | 1.19x | 3.05x | 1.81x |
| 2005 | 24 | 12.40% | 11.60% | 1.29x | 0.70x | 80.00% | 44.40% | 8.73x | 10.42x | 3.90x | 1.45x | 0.95x | 2.61x | 1.58x |
| 2006 | 25 | 11.50% | 10.90% | 1.31x | 0.54x | 84.70% | 45.80% | 6.82x | 9.21x | 4.33x | 1.66x | 1.04x | 2.56x | 1.59x |
| 2007 | 26 | 10.30% | 11.00% | 1.59x | 0.67x | 58.10% | 36.70% | 6.86x | 9.45x | 3.81x | 1.47x | 0.92x | 1.90x | 0.86x |
| 2008 | 26 | 14.20% | 12.20% | 1.56x | 0.62x | 71.80% | 41.80% | 12.05x | 15.00x | 5.46x | 1.13x | 0.42x | 2.34x | 0.84x |
| 2009 | 27 | 13.50% | 9.60% | 1.69x | 0.92x | 58.90% | 37.00% | 15.27x | 18.54x | 7.75x | 1.28x | 0.50x | 2.28x | 0.22x |
| 2010 | 28 | 11.70% | 9.30% | 1.78x | 1.16x | 58.80% | 37.00% | 13.28x | 17.42x | 7.05x | 1.28x | 0.61x | 1.77x | 0.40x |
| 2011 | 28 | 12.90% | 11.30% | 1.62x | 0.74x | 63.80% | 38.50% | 12.87x | 16.82x | 8.01x | 1.58x | 0.89x | 1.97x | -0.17x |
| 2012 | 28 | 10.20% | 10.60% | 1.45x | 0.65x | 75.20% | 42.80% | 6.50x | 10.03x | 4.26x | 1.48x | 1.19x | 1.32x | 0.01x |
| 2013 | 28 | 5.80% | 8.20% | 1.26x | 0.63x | 80.80% | 44.70% | 2.66x | 5.56x | 0.76x | 2.51x | 1.58x | 0.84x | 0.03x |
| 2014 | 28 | 4.40% | 5.80% | 1.35x | 0.61x | 104.20% | 50.90% | 2.28x | 4.00x | 0.91x | 4.06x | 3.20x | 1.56x | 0.22x |

### *Table 69: Thermal coal miners local risk hypotheses column labels*

| Label | Unit | Description |
|---|---|---|
| NUM | - | Total number of coal mines |
| PROD | [Mt (#)] | Total coal production capacity and number of data points available |
| PROT | - | Number of mines with protected areas within 40km |
| POP | [People/km$^2$] | Average local population density weighted by mine production |
| BWS | - | Baseline physical water stress indicator |
| FWS | - | Future physical water stress indicator |

### *Table 70: Thermal coal miners local risk hypotheses*

| GENERAL INFORMATION | | | | MIN-1 | | MIN-2 | |
|---|---|---|---|---|---|---|---|
| PARENT OWNER | COUNTRY | NUM | PROD | PROT | POP | BWS | FWS |
| CHINA COAL ENERGY COMPANY | China | 11 | 107 (6) | 73% | 125 | 100% | 100% |
| CHINA SHENHUA ENERGY CO | China | 23 | 305 (23) | 30% | 100 | 44% | 93% |
| DATONG COAL INDUSTRY | China | 4 | 15 (1) | 0% | 446 | 100% | 100% |
| INNER MONGOLIA YITAI COAL CO., LTD. | China | 13 | 51 (13) | 8% | 69 | 44% | 100% |
| SHANXI LU'AN ENVIRONMENTAL ENERGY DEVELOPMENT | China | 5 | 30 (5) | 100% | 451 | 100% | 100% |
| YANG QUAN COAL INDUSTRY (GROUP) CO., LTD. | China | 25 | 13 (4) | 68% | 202 | 100% | 100% |
| YANZHOU COAL MINING COMPANY LIMITED | China | 23 | 73 (19) | 22% | 163 | 68% | 45% |
| ALLIANCE RESROUCE PARTNERS | US | 13 | 41 (11) | 0% | 34 | 13% | 14% |
| ALPHA NATURAL RESOURCES | US | 3 | 84 (3) | 0% | 23 | 44% | 39% |
| ARCH COAL | US | 12 | 264 (11) | 0% | 25 | 38% | 40% |
| CONSOL ENERGY INC | US | 5 | 32 (5) | 0% | 48 | 17% | 17% |
| PEABODY ENERGY CORPORATION | US | 28 | 232 (28) | 0% | 45 | 30% | 32% |
| INDO TAMBANGRAYA MEGAH TBK PT | Indonesia | 6 | 29 (6) | 33% | 1,697 | 32% | 37% |
| PT ADARO ENERGY TBK | Indonesia | 4 | 56 (4) | 0% | 79 | 1% | 1% |
| PT UNITED TRACTORS | Indonesia | 1 | 6 (1) | 0% | 11 | 1% | 1% |
| ADANI ENTERPRISES LTD | India | 6 | 8 (2) | 0% | 238 | 16% | 22% |
| COAL INDIA LTD | India | 13 | 494 (8) | 38% | 1,912 | 15% | 18% |
| THE TATA POWER COMPANY | India | 3 | 27 (1) | 67% | 1,689 | 36% | 38% |
| SASOL | South Africa | 6 | 41 (6) | 0% | 55 | 17% | 21% |
| BANPU PUBLIC COMPANY LIMITED | Thailand | 10 | 39 (9) | 10% | 589 | 52% | 23% |

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# Appendix C: Top Coal-Processing Technology Companies Tables

## *Table 71: Ownership of coal processing technology plants*[478]

| Parent Owner | Country | Ticker | Ultimate Parent (if different) | Ownership* | Insiders | Institutions | Corporate | ESOP | State | Public/Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Anhui Huayi Chemical Co. Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| China National Offshore Oil Corporation | China | - | - | PrC | - | - | - | - | - | - |
| Chinacoal Group Shanxi Huayu Energy Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Datang International Power Generation Co., Ltd. | China | SEHK:991 | - | PbC | 0 | 0.26 | 2.49 | - | - | 0.97 |
| Guanghui Energy Co., Ltd. | China | SHSE:600256 | - | PbC | 0.11 | 0.4 | 2.39 | - | - | 2.44 |
| Harbin yilan coal gasification | China | - | | | | | | | | |
| Shandong Hualu-Hengsheng Chemical Co., Ltd. | China | SHSE:600426 | - | PbC | 0.03 | 0.37 | 0.74 | - | - | 0.99 |
| SES—GCL (Inner Mongolia) Coal Chemical Co., Ltd | United States | - | Synthesis Energy Systems, Inc. | PbC | - | - | - | - | - | - |
| Jiangsu Linggu Chemical Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Shangyu Jiehua Chemical Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Pucheng Clean Energy Chemical Co., Ltd | China | - | - | PrC | - | - | - | - | - | - |
| Inner Mongolia Qinghua Group Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Inner Mongolia Sanwei Resources Group Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Shenhua Group Corporation Limited | China | - | - | PrC | - | - | - | - | - | - |
| China Petroleum & Chemical Corp. | China | SEHK:386 | China Petrochemical Corporation | PrC | 0 | 7.2 | 51.46 | - | - | 13.49 |
| Tianjin Bohai Chemical Industry Group Corporation | China | - | - | PrC | - | - | - | - | - | - |
| Wison (Nanjing) Clean Energy Co. Ltd. | China | - | Beijing Qingkong Jinxin Investment ( | PrC | - | - | - | - | - | - |
| Zhejiang Xinhu Group Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Xinjiang Xin Lian Xin Chemical Energy Co., Ltd. | China | - | China XLX Fertiliser Ltd. | PbC | - | - | - | - | - | - |
| Yankuang Group Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Wanhua Chemical Group Co., Ltd. | China | SHSE:600309 | Wanhua Industrial Group Co., Ltd. | PrC | - | 0.9 | 3.12 | - | - | 2.05 |
| Inner Mongolia Yitai Group Co., Ltd. | China | - | - | PrC | - | - | - | - | - | - |
| Korea South-East Power Co., Ltd. | South Korea | - | Korea Electric Power Corp. | PbC | - | - | - | - | - | - |
| Korea Southern Power Co., Ltd. | South Korea | - | Korea Electric Power Corp. | PbC | - | - | - | - | - | - |
| POSCO | South Korea | KOSE:A005490 | - | PbC | 0 | 7.01 | 0.79 | 0.21 | 0.29 | 2.8 |
| Dakota Gasification Company Inc. | United States | - | Basin Electric Power Cooperative | PrC | - | - | - | - | - | - |
| EAST CHINA ENERGY | United States | - | | | | | | | | |
| Jindal Steel & Power Ltd. | India | NSEI:JINDALSTE | - | PbC | 0.02 | 0.42 | 0.59 | - | - | 0.24 |
| Tokyo Electric Power Company, Incorporated | Japan | TSE:9501 | - | PbC | 0 | 1.42 | 0.02 | 0.29 | 0.26 | 7.63 |
| Sasol Ltd. | South Africa | JSE:SOL | - | PbC | 0 | 5.85 | - | - | 1.33 | 6.81 |

*Gov: Government Institution; PrC: Private company; PrI: Private Investment Firm; PbC, Public company; PbI Public Investment Firm.

[478] Data from Standard & Poor's Capital IQ, November 2015.

## *Table 72:* *Debt positions of coal processing technology companies*[479]

| Owner | Country | Average Maturity | Perpetuities [US$mm] | Corporate Debentures [US$mm] | Total Debt/ EBITDA | Syngas capacity [kNm3/d] |
|---|---|---|---|---|---|---|
| ANHUI HUAYI CHEMICAL CO | China | 0 | 0 | 0 | none | 5,040 |
| CHINA NATIONAL OFFSHORE OIL CORPORATION (CNOOC) | China | 2025 | 180 | 30666 | 1.3 | 9,975 |
| CHINACOAL GROUP | China | 2016 | 0 | 141.3 | none | 24,231 |
| DATANG | China | 2022 | 0 | 622 | 6.9 | 48,550 |
| GUANGHUI ENERGY CO | China | 0 | 0 | 0 | 11.6 | 12,600 |
| HARBIN YILAN COAL GASIFICATION | China | none | none | none | none | 5,750 |
| HUALU HENGSHENG CHEMICALS | China | 0 | 0 | 0 | 1.8 | 6,890 |
| INNER MONGOLIA ZHUOZHENG COAL CHEMICAL CO | China | none | none | none | none | 9,040 |
| JIANGSU LINGGU CHEMICAL CO | China | 0 | 0 | 0 | none | 6,090 |
| JIEHUA CHEMICAL | China | 0 | 0 | 0 | none | 8,000 |
| PUCHENG CLEAN ENERGY CHEMICAL CO | China | none | none | none | none | 12,100 |
| QINGHUA GROUP | China | 0 | 0 | 0 | none | 13,860 |
| SANWEI RESOURCE GROUP | China | 0 | 0 | 0 | none | 9,744 |
| SHENHUA GROUP | China | 2018 | 0 | 19232 | 3.1 | 43,360 |
| SINOPEC | China | 2020 | 0 | 12072 | 1.7 | 32,036 |
| TIANJIN BOHAI CHEMICAL GROUP | China | 0 | 0 | 0 | none | 8,787 |
| WISON (NANJING) CLEAN ENERGY CO | China | 0 | 0 | 0 | none | 11,932 |
| XINHU GROUP | China | 2016 | 0 | 470 | none | 12,000 |
| XINJIANG XINLIANXIN FERTILIZER CO. LTD. | China | none | none | none | none | 5,040 |
| YANKUANG GROUP | China | 2019 | 300 | 3273 | none | 13,415 |
| YANTAI WANHUA | China | 0 | 0 | 0 | 5.1 | 5,040 |
| YITAI COAL OIL MANUFACTURING CO (INNER MONGOLIA YITAI GROUP | China | 2018 | 0 | 549 | 9 | 33,700 |
| KOREA SOUTH EAST POWER CO (KOSEP) | South Korea | 2019 | 0 | 1842 | 3.5 | 8,400 |
| KOREA SOUTHERN POWER CO (KOSPO) | South Korea | 2020 | 0 | 1541 | 6.2 | 8,400 |
| POSCO | South Korea | 2019 | 0 | 5635 | 4.6 | 6,934 |
| DAKOTA GASIFICATION CO | US | 0 | 0 | 0 | none | 13,900 |
| EAST CHINA ENERGY | US | none | none | none | none | 5,000 |
| JINDAL STEEL & POWER LTD | India | 0 | 0 | 0 | 8.1 | 8,025 |
| TOKYO ELECTRIC POWER COMPANY (TEPCO) | Japan | 2019 | 0 | 19142 | 6.7 | 11,566 |
| SASOL | South Africa | 2022 | 0 | 1000 | 0.7 | 90,260 |

[479] Data from Standard & Poor's Capital IQ, November 2015.

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## *Table 73: Ratio analysis for coal processing technology companies*

This table represents the median ratios across all firms available. For the coal-fired power utilities, data was available for 11 of the 30 companies listed in Table 72

| Year | Count | (A) Net Profit Margin | (B) CAPEX to Assets | (C) Current Ratio | (D) Acid Test | (E) Total Debt to Equity | (F) Total Debt to Assets | (G) EBIT to interest expense | (H) EBITDA to interest expense | (I) (EBITDA-CAPEX) to interest expense | (J) Total Debt to EBITDA | (K) Net Debt to EBITDA | (L) Total Debt to (EBITDA – CAPEX) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 3 | 11.00% | 12.30% | 1.25x | 0.45x | 91.20% | 47.70% | 3.27x | 5.51x | 1.07x | 1.31x | 0.74x | 1.19x |
| 1996 | 3 | 6.10% | 11.00% | 1.22x | 0.45x | 95.70% | 48.90% | 2.53x | 5.01x | 0.41x | 1.51x | 0.87x | 0.98x |
| 1997 | 3 | 6.30% | 10.40% | 1.17x | 0.31x | 137.50% | 57.90% | 2.50x | 4.32x | 1.21x | 1.91x | 1.37x | 0.80x |
| 1998 | 3 | 4.90% | 11.50% | 1.35x | 0.44x | 99.50% | 49.90% | 3.11x | 4.90x | 1.46x | 1.53x | 0.86x | 1.91x |
| 1999 | 5 | 12.20% | 9.50% | 1.32x | 0.41x | 54.20% | 35.10% | 8.16x | 9.37x | 0.00x | 1.19x | 0.69x | 0.70x |
| 2000 | 7 | 13.20% | 6.60% | 1.18x | 0.33x | 59.70% | 37.00% | 6.74x | 6.07x | 1.61x | 1.72x | 1.16x | 2.20x |
| 2001 | 7 | 11.80% | 7.50% | 1.37x | 0.31x | 56.90% | 36.20% | 4.89x | 5.57x | 0.58x | 2.16x | 1.70x | 0.43x |
| 2002 | 7 | 11.70% | 15.90% | 1.36x | 0.36x | 47.80% | 32.30% | 6.93x | 11.52x | 1.81x | 1.91x | 0.87x | 1.30x |
| 2003 | 7 | 12.10% | 17.20% | 1.43x | 0.72x | 78.70% | 43.40% | 9.39x | 11.51x | 1.48x | 2.76x | 1.24x | 1.62x |
| 2004 | 7 | 13.70% | 12.30% | 1.22x | 0.33x | 87.30% | 46.50% | 11.68x | 15.89x | 1.56x | 2.05x | 1.65x | 3.75x |
| 2005 | 7 | 14.50% | 14.60% | 1.45x | 0.59x | 90.40% | 47.20% | 13.27x | 15.76x | 2.75x | 1.82x | 1.67x | 1.44x |
| 2006 | 7 | 14.60% | 12.50% | 1.08x | 0.68x | 82.60% | 44.70% | 10.34x | 11.97x | 4.78x | 2.21x | 1.58x | 1.53x |
| 2007 | 7 | 18.20% | 8.40% | 1.38x | 0.64x | 67.90% | 40.00% | 10.49x | 13.32x | 7.37x | 2.08x | 1.31x | 1.14x |
| 2008 | 7 | 18.40% | 11.20% | 1.17x | 0.64x | 69.10% | 39.00% | 10.42x | 12.44x | 5.29x | 1.60x | 1.03x | 1.89x |
| 2009 | 7 | 13.50% | 15.60% | 1.17x | 0.83x | 92.40% | 48.00% | 8.20x | 11.66x | 1.12x | 1.83x | 1.30x | 17.38x |
| 2010 | 7 | 14.60% | 9.70% | 1.50x | 0.49x | 79.30% | 44.20% | 10.11x | 13.59x | 4.20x | 2.18x | 1.46x | 3.33x |
| 2011 | 7 | 13.70% | 14.20% | 1.20x | 0.68x | 95.70% | 48.90% | 9.87x | 12.26x | -0.78x | 2.79x | 2.33x | -1.70x |
| 2012 | 8 | 14.30% | 11.80% | 1.05x | 0.52x | 99.00% | 49.70% | 8.32x | 9.85x | 0.90x | 3.03x | 2.54x | 1.32x |
| 2013 | 8 | 14.20% | 11.90% | 1.14x | 0.43x | 105.30% | 51.20% | 3.88x | 6.10x | -1.33x | 3.66x | 3.41x | -12.70x |
| 2014 | 8 | 9.30% | 11.60% | 1.24x | 0.42x | 138.60% | 57.70% | 3.31x | 6.06x | 0.99x | 4.91x | 4.17x | -1.45x |

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***Table 74:*** *Coal processing technology company local risk hypotheses column labels*

| Label | Unit | Description |
|---|---|---|
| NUM | - | Total number of coal mines |
| PROD | [Mt (#)] | Total coal production capacity and number of data points available |
| PROT | - | Number of mines with protected areas within 40km |
| POP | [People/km$^2$] | Average local population density weighted by mine production |
| BWS | - | Baseline physical water stress indicator |
| FWS | - | Future physical water stress indicator |

***Table 75:*** *Coal processing technology company local risk hypotheses exposure*

| GENERAL INFO | | | | CPT-1 | CPT-2 | | CPT-3 |
|---|---|---|---|---|---|---|---|
| COMPANY | COUNTRY | CAP | NUM | AGE | BWS | FWS | CCS |
| ANHUI HUAYI CHEMICAL CO | China | 5,040 | 1 | 3 | 4.00% | 5.10% | 100% |
| CHINACOAL GROUP | China | 24,100 | 2 | 1 | 44.70% | 59.20% | 0% |
| CHINA NATIONAL OFFSHORE OIL CORPORATION (CNOOC) | China | 9,975 | 1 | 0 | 14.50% | 16.80% | 100% |
| DATANG | China | 48,550 | 4 | 3 | 95.80% | 96.00% | 92% |
| GUANGHUI ENERGY CO | China | 12,600 | 1 | 2 | 100.00% | 100.00% | 100% |
| HARBIN YILAN COAL GASIFICATION | China | 5,750 | 1 | 22 | 31.10% | 35.60% | 100% |
| HUALU HENGSHENG CHEMICALS | China | 6,890 | 3 | 4 | 100.00% | 100.00% | 29% |
| INNER MONGOLIA ZHUOZHENG COAL CHEMICAL CO | China | 9,040 | 1 | 2 | 38.50% | 100.00% | 0% |
| JIANGSU LINGGU CHEMICAL CO | China | 6,090 | 2 | 3 | 69.10% | 83.40% | 100% |
| JIEHUA CHEMICAL | China | 8,000 | 1 | 4 | 7.60% | 9.20% | 100% |
| PUCHENG CLEAN ENERGY CHEMICAL CO | China | 12,100 | 1 | 1 | 33.60% | 94.10% | 100% |
| QINGHUA GROUP | China | 13,860 | 1 | 2 | 100.00% | 100.00% | 100% |
| SANWEI RESOURCE GROUP | China | 9,744 | 2 | 4 | 76.10% | 100.00% | 86% |
| SHENHUA GROUP | China | 43,360 | 3 | 3 | 91.60% | 100.00% | 71% |
| SINOPEC | China | 29,481 | 10 | 4 | 32.30% | 33.80% | 79% |
| TIANJIN BOHAI CHEMICAL GROUP | China | 8,787 | 2 | 5 | 100.00% | 100.00% | 0% |
| WISON (NANJING) CLEAN ENERGY CO | China | 11,932 | 4 | 3 | 4.00% | 5.10% | 0% |
| XINHU GROUP | China | 12,000 | 1 | 1 | 38.50% | 100.00% | 0% |
| XINJIANG XINLIANXIN FERTILIZER CO. LTD. | China | 5,040 | 1 | 0 | 100.00% | 100.00% | 0% |
| YANKUANG GROUP | China | 13,415 | 5 | 6 | 66.70% | 68.30% | 100% |
| YANTAI WANHUA | China | 5,040 | 1 | 1 | 100.00% | 100.00% | 100% |
| YITAI COAL OIL MANUFACTURING CO (INNER MONGOLIA YITAI GROUP | China | 33,700 | 2 | 0 | 38.50% | 100.00% | 0% |
| JINDAL STEEL & POWER LTD | India | 8,025 | 2 | 2 | 14.80% | 18.80% | 100% |
| TOKYO ELECTRIC POWER COMPANY (TEPCO) | Japan | 11,566 | 2 | 0 | 15.20% | 15.30% | 100% |
| SASOL | South Africa | 90,260 | 4 | 36 | 6.60% | 10.50% | 100% |
| KOREA SOUTH EAST POWER CO (KOSEP) | South Korea | 8,400 | 1 | 0 | 100.00% | 100.00% | 100% |
| KOREA SOUTHERN POWER CO (KOSPO) | South Korea | 8,400 | 1 | 0 | 23.10% | 22.80% | 100% |
| POSCO | South Korea | 6,934 | 1 | 0 | 22.40% | 22.10% | 100% |
| DAKOTA GASIFICATION CO | US | 13,900 | 1 | 31 | 21.30% | 23.10% | 0% |
| EAST CHINA ENERGY | US | 5,000 | 1 | 2 | 23.70% | 26.40% | 0% |

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PERSPECTIVES

# Hedging Climate Risk

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*We present a simple dynamic investment strategy that allows long-term passive investors to hedge climate risk without sacrificing financial returns. We illustrate how the tracking error can be virtually eliminated even for a low-carbon index with 50% less carbon footprint than its benchmark. By investing in such a decarbonized index, investors in effect are holding a "free option on carbon." As long as climate change mitigation actions are pending, the low-carbon index obtains the same return as the benchmark index; but once carbon dioxide emissions are priced, or expected to be priced, the low-carbon index should start to outperform the benchmark.*

Whether or not one agrees with the scientific consensus on climate change, both climate risk and climate change mitigation policy risk are worth hedging. The evidence on rising global average temperatures has been the subject of recent debates, especially in light of the apparent slowdown in global warming over 1998–2014.[1] The perceived slowdown has confirmed the beliefs of climate change doubters and fueled a debate on climate science widely covered by the media. This ongoing debate is stimulated by three important considerations.

The first and most obvious consideration is that not all countries and industries are equally affected by climate change. As in other policy areas, the introduction of a new regulation naturally gives rise to policy debates between the losers, who exaggerate the costs, and the winners, who emphasize the urgency of the new policy. The second consideration is that climate mitigation has typically not been a "front burner" political issue. Politicians often tend to "kick the can down the road" rather than introduce policies that are costly in the short run and risk alienating their constituencies—all the more so if there is a perception that the climate change debate is not yet fully settled and that climate change mitigation may not require urgent attention. The third consideration is that although the scientific evidence on the link between carbon dioxide ($CO_2$) emissions and the greenhouse effect is overwhelming, there is considerable uncertainty regarding the rate of increase in average temperatures over the next 20 or 30 years and the effects on climate change. There is also considerable uncertainty regarding the "tipping point" beyond which catastrophic climate dynamics are set in motion.[2] As with financial crises, the observation of growing imbalances can alert analysts to the inevitability of a crash but still leave them in the dark as to when the crisis is likely to occur.

This uncertainty should be understood as an increasingly important risk factor for investors, particularly long-term investors. At a minimum, the climate science consensus tells us that the risks of a climate disaster are substantial and rising. Moreover, as further evidence of climate events linked to human-caused emissions of $CO_2$ accumulates and global temperatures keep rising, there is an increased likelihood of policy intervention to limit these emissions.[3] The prospect of such interventions has increased significantly following the Paris Climate Change Conference and the unanimous adoption of a new universal agreement on climate change.[4] Of course, other plausible scenarios can be envisioned whereby the Paris agreement is not followed by meaningful policies. From an investor's perspective, there is therefore a risk with respect to both climate change and the timing of climate mitigation policies. Still, overall, investors should—and some are beginning to—factor carbon risk into their investment policies. It is fair to say, however, that there is still little awareness of this risk factor among (institutional)

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*Editor's note:* The views expressed in this article are those of the authors and do not necessarily reflect the views of the Amundi Group, AP4, or MSCI.

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investors.[5] Few investors are aware of the carbon footprint and climate impact of the companies in their portfolios. Among investors holding oil and gas stocks, few are aware of the risks they face with respect to those companies' stranded assets.[6]

In this article, we revisit and analyze a simple, dynamic investment strategy that allows long-term passive investors—a huge institutional investor clientele that includes pension funds, insurance and re-insurance companies, central banks, and sovereign wealth funds—to significantly hedge climate risk while essentially sacrificing no financial returns. One of the main challenges for long-term investors is the uncertainty with respect to the timing of climate mitigation policies. To use another helpful analogy with financial crises, it is extremely risky for a fund manager to exit (or short) an asset class that is perceived to be overvalued and subject to a speculative bubble because the fund could be forced to close as a result of massive redemptions before the bubble has burst. Similarly, an asset manager looking to hedge climate risk by divesting from stocks with high carbon footprints bears the risk of underperforming his benchmark for as long as climate mitigation policies are postponed and market expectations about their introduction are low. Such a fund manager may well be wiped out long before serious limits on $CO_2$ emissions are introduced.

A number of "green" financial indexes have existed for many years. These indexes fall into two broad groups: (1) pure-play indexes that focus on renewable energy, clean technology, and/or environmental services and (2) "decarbonized" indexes (or "green beta" indexes), whose basic construction principle is to take a standard benchmark, such as the S&P 500 or NASDAQ 100, and remove or underweight the companies with relatively high carbon footprints.[7] The "first family" of green indexes offers no protection against the timing risk of climate change mitigation policies. But the "second family" of decarbonized indexes does: An investor holding such a decarbonized index is hedged against the timing risk of climate mitigation policies (which are expected to disproportionately hit high-carbon-footprint companies) because the decarbonized indexes are structured to maintain a low tracking error with respect to the benchmark indexes.

Thus far, the success of pure-play indexes has been limited. One important reason, highlighted in **Table 1**, is that since the onset of the financial crisis in 2007–2008, these index funds have significantly underperformed market benchmarks.

Besides the fact that clean tech has been overhyped,[8] one of the reasons why these indexes have underperformed is that some of the climate mitigation policies in place before the financial crisis have been scaled back (e.g., in Spain). In addition, financial markets may have rationally anticipated that one of the consequences of the financial crisis would be the likely postponement of the introduction of limits on $CO_2$ emissions. These changed expectations benefited the carbon-intensive utilities and energy companies more than other companies and may explain the relative underperformance of the green pure-play indexes. More importantly, the reach of the pure-play green funds is very limited because they concentrate investments in a couple of subsectors and, in any case, cannot serve as a basis for building a core equity portfolio for institutional investors.

The basic point underlying a climate risk–hedging strategy that uses decarbonized indexes is to go beyond a simple divestment policy or investments in only pure-play indexes and instead keep an aggregate risk exposure similar to that of standard market benchmarks. Indeed, divestment of high-carbon-footprint stocks is just the first step. The second key step is to optimize the composition and weighting of the decarbonized index in order to minimize the tracking error (TE) with the reference benchmark index. It turns out that TE can be virtually eliminated, with the overall carbon footprint of the decarbonized index remaining substantially lower than that of the reference index (close to 50% in terms of both carbon intensities and absolute carbon emissions). Decarbonized indexes have thus far essentially matched or even outperformed the benchmark index.[9] In other words, investors holding a decarbonized index have been able to significantly

**Table 1. Pure-Play Clean Energy Indexes vs. Global Indexes**

| | S&P 500 | NASDAQ 100 | PP 1 | PP 2 | PP 3 | PP 4 | PP 5 |
|---|---|---|---|---|---|---|---|
| Annualized return | 4.79% | 11.40% | 5.02% | –8.72% | 2.26% | –8.03% | –1.89% |
| Annualized volatility | 22.3 | 23.6 | 24.1 | 39.3 | 30.2 | 33.8 | 37.3 |

*Notes:* Table 1 gives the financial returns of several ETFs that track leading clean energy pure-play indexes. Pure Play 1 refers to Market Vectors Environmental Services ETF, Pure Play 2 to Market Vectors Global Alternative Energy ETF, Pure Play 3 to PowerShares Cleantech Portfolio, Pure Play 4 to PowerShares Global Clean Energy Portfolio, and Pure Play 5 to First Trust NASDAQ Clean Edge Green Energy Index Fund. Annualized return and volatility were calculated using daily data from 5 January 2007 to the liquidation of Pure Play 1 on 12 November 2014.
*Sources:* Amundi and Bloomberg (1 September 2015).

reduce their carbon footprint exposure without sacrificing any financial returns. In effect, these investors are holding a "free option on carbon": So long as the introduction of significant limits on $CO_2$ emissions is postponed, they can obtain the same returns as on a benchmark index. But from the day $CO_2$ emissions are priced meaningfully and consistently and limits on $CO_2$ emissions are introduced, the decarbonized index should outperform the benchmark.[10] A climate risk–hedging policy around decarbonized indexes is essentially an unlevered minimum risk arbitrage policy that takes advantage of a currently mispriced risk factor (carbon risk) in financial markets. Although larger arbitrage gains are obtainable by taking larger risks (and this climate risk–hedging strategy errs on the side of caution), the strategy is particularly well suited for long-term passive investors who seek to maximize long-term returns while limiting active stock trading over time.

## A Green Index without Relative Market Risk: The Basic Concept

Investor perceptions of lower financial returns from green index funds could explain why green indexes have thus far remained a niche market. Another reason might be the design of most green indexes, which lend themselves more to a bet on clean energy than a hedge against carbon risk. In contrast, the design we support allows passive long-term investors to hedge carbon risk. Thus, the goal is not just to minimize exposure to carbon risk by completely divesting from any company with a carbon footprint exceeding a given threshold, but also to minimize the tracking error of the decarbonized index with the benchmark index. We support this design because it implements a true dynamic hedging strategy for passive investors and can easily be scaled to significantly affect not only portfolios' footprints but also (eventually) the real economy.[11]

The basic idea behind index decarbonization is to construct a portfolio with fewer composite stocks than the benchmark index but with similar aggregate risk exposure to all priced risk factors. This approach is possible because, as Koch and Bassen (2013) showed, carbon risk is asymmetrically concentrated in a few firms.[12] Ideally, the only major difference in aggregate risk exposure between the two indexes would be with respect to the carbon risk factor, which would be significantly lower for the decarbonized index. So long as carbon risk remains unpriced by the market, the two indexes will generate similar returns (i.e., offer the same compensation for risk demanded by the representative investor), thus achieving no or minimal TE. But once carbon risk is priced or is expected to be priced by the market, the decarbonized index should start outperforming the benchmark.

The central underlying premise of this strategy is that financial markets currently underprice carbon risk. Moreover, our fundamental belief is that eventually, if not in the near future, financial markets will begin to price carbon risk. Our premise leads inevitably to the conclusion that a decarbonized index is bound to provide higher financial returns than the benchmark index. We believe that the evidence in support of our premise is overwhelming. Currently, virtually all financial analysts overlook carbon risk. Only in 2014 did a discussion about stranded assets make it into a report from a leading oil company for the first time, and the report mostly denied any concern that a fraction of proven reserves might ever become stranded assets.[13] Only a few specialized financial analysts[14] factor stranded assets into their valuation models of oil company stocks. Nor, apart from a few exceptions,[15] do financial analysts ever evoke carbon-pricing risk in their reports to investors. In sum, current analysts' forecasts assume by default that there is no carbon risk. Under these circumstances, it takes a stretch of the imagination to explain that financial markets somehow currently price carbon risk correctly. Even more implausible is the notion that financial markets currently price carbon risk excessively. Only in this latter scenario would investors in a decarbonized index face lower financial returns than in the benchmark index.

Some might object that our fundamental belief that financial markets will price carbon risk in the future is not particularly plausible. After all, the evidence from many climate talks' failures following Kyoto suggests, if anything, that global carbon pricing in the near future is extremely unlikely. If that should be the case, our investor in the decarbonized index would simply match the returns of the benchmark index—a worst-case scenario. Any concrete progress in international negotiations—and the implementation of nationally determined independent contributions agreed to in Paris—will change financial market expectations about carbon risk and likely result in higher financial returns on the low-TE index relative to the benchmark index.

**The Decarbonized Index Optimization Problem.** Given our basic premise and fundamental belief, the next question is how to go about constructing the green index. There are several possible formulations of the problem in practice. One formulation is to eliminate high-carbon-footprint composite stocks, with the objective of meeting a target carbon footprint reduction for the green index, and then to reweight the remaining stocks in order to minimize tracking error with the benchmark index. The dual formulation is to begin by imposing a constraint on maximum allowable tracking error with the benchmark index and then, subject to this constraint, exclude and reweight composite stocks in the benchmark index to maximize the green index's carbon footprint reduction. Although there is no compelling reason to choose one formulation over the other, we favor the second formulation, which seeks to minimize tracking error subject to meeting a carbon footprint reduction target.

Another relevant variation in the design of the constrained optimization problem is whether to (1) require at the outset the complete exclusion of composite stocks of the worst performers in terms of carbon footprint or (2) allow the green index to simply underweight high-carbon-footprint stocks without completely excluding them. Although the latter formulation is more flexible, it has drawbacks, which we discuss later in the article.

We confine our analysis to essentially two alternatives among the many possible formulations of the constrained optimization problem for the construction of a decarbonized index that trades off exposure to carbon, tracking error, and expected returns. We describe both formulations formally, under the simplifying assumption that only one sector is represented in the benchmark index.

The two portfolio optimization problems can be simply and easily represented. Suppose that there are $N$ constituent stocks in the benchmark index and that the weight of each stock in the index is given by $w_i^b = \left[\frac{\text{Mkt cap}(i)}{\text{Total mkt cap}}\right]$. Suppose next that each constituent company is ranked in decreasing order of carbon intensity, $q_l^i$, with company $l = 1$ having the highest carbon intensity and company $l = N$ the lowest (each company is thus identified by two numbers [$i$,$l$], with the first number referring to the company's identity and the second to its ranking in carbon intensity).

In the first problem, the green portfolio can be constructed by choosing new weights, $w_i^g$, for the constituent stocks to solve the following minimization problem:

$$\text{Min TE} = sd\left(R^g - R^b\right),$$

where

$$w_l^g = 0 \text{ for all } l = 1,\ldots k$$

$$0 \le w_l^g \text{ for all } l = k+1,\ldots N$$

$sd$ = standard deviation

That is, the decarbonized index is constructed by first excluding the $k$ worst performers in terms of carbon intensity and reweighting the remaining stocks in the green portfolio to minimize TE.[16] This decarbonization method follows transparent rules of exclusion, whatever the threshold $k$.

In the second problem formulation, the first set of constraints ($w_j^g = 0$ for all $j = 1,\ldots k$) is replaced by the constraint that the green portfolio's carbon intensity must be smaller than a given threshold: $\sum_{l=1\ldots N} q_l w_l^g \le Q$. In other words, the second problem is a design, which potentially does not exclude any constituent stocks from the benchmark index and seeks only to reduce the carbon intensity of the index by reweighting the stocks in the green portfolio. Although the second problem formulation (pure optimization) dominates the first (transparent rules) for the same target aggregate carbon intensity, $Q$, because it has fewer constraints, it has a significant drawback in terms of the methodology's opacity and the lack of a clear signal for which constituent stocks to exclude on the basis of their relatively high carbon intensity.

**Optimization Procedure.** For both problem formulations, the *ex ante* TE—given by the estimated standard deviation of returns of the decarbonized portfolio from the benchmark—is estimated by using a multifactor model of aggregate risk (see Appendix D for more detailed information). This multifactor model significantly reduces computations, and the decomposition of individual stock returns into a weighted sum of common factor returns and specific returns provides a good approximation of individual stocks' expected returns. More formally, under the multifactor model the TE minimization problem has the following structure:

$$\text{Min}\left[\sqrt{\left(W^p - W^b\right)'\left(\boldsymbol{\beta}\boldsymbol{\Omega}_f\boldsymbol{\beta}' + \boldsymbol{\Delta}^{AR}\right)\left(W^p - W^b\right)}\right],$$

where

$$w_l^g = 0 \text{ for all } l = 1,\ldots k$$

$$0 \le w_l^g \text{ for all } l = k+1,\ldots N$$

$\left(W^p - W^b\right)$ = the vector of the difference in portfolio weights of the decarbonized portfolio and the benchmark

$\boldsymbol{\Omega}_f$ = the variance–covariance matrix of factors

$\boldsymbol{\beta}$ = the matrix of factor exposures

$\boldsymbol{\Delta}^{AR}$ = the diagonal matrix of specific risk variances

**Risk Mitigation Benefits of Low Tracking Error.** To explore more systematically the potential benefits of achieving a bounded tracking error, we ran a number of simulations with the pure optimization methodology and determined a

TE–carbon efficiency frontier for a decarbonized index constructed from the MSCI Europe Index. As illustrated in **Figure 1**, achieving a nearly 100% reduction in the MSCI Europe carbon footprint would come at the price of a huge tracking error of more than 3.5%.[17]

Such a large TE would expose investors in the decarbonized index to significant financial risk relative to the benchmark—even in a good scenario whereby the decarbonized index is expected to outperform the benchmark as a result of climate mitigation policies. **Figure 2** depicts the risk that a large TE might expose investors to and how that risk can be mitigated by lowering the TE. We first posit a scenario whereby the expected yearly return of the green index is 2.5% higher than that of the benchmark[18] and show (with a confidence interval of two standard deviations) that a 3.5% TE could expose investors to losses relative to the benchmark in the negative scenario.

As Figure 2 illustrates, if we lower the TE of the decarbonized index from 3.5% to 1.2%, the decarbonized index generates returns at least as high as those of the benchmark *even in the worst-case scenario*.

**Illustrative Example.** A simple example can illustrate in greater detail how a low-carbon, low-TE index might be constructed and how its financial returns—relative to the benchmark—would vary with (expectations of) the introduction of carbon taxes. Let us consider a portfolio of four stocks (A, B, C, D), each priced at 100. The first two stocks (A, B) are, say, oil company stocks; stock C is outside the oil industry but its price is perfectly correlated with the oil industry stock price; and stock D is a company whose stock price is uncorrelated with the oil industry. The pre–carbon taxation returns on these stocks are 20%, 20%, 20%, and 30%, respectively. On the one hand, we assume that stocks A and B have a relatively high carbon footprint, which would expose them to relatively high implied carbon taxation—40% and 10% of earnings, respectively. On the other hand, we assume that stocks C and D have no carbon tax exposure. We then construct the low-carbon, low-TE index as follows: (1) We filter out entirely stocks A and B, (2) we treble the weighting of stock C to maintain the same overall exposure to the oil sector as the benchmark portfolio, and (3) we leave the weighting of stock D unchanged. If the introduction of carbon taxes is expected, the price of stock A will drop to 72 and the price of stock B will increase to 108, whereas the price of stock C will increase to 120 and the price of stock D will rise to 130. What are the implications for returns on the low-carbon, low-TE index relative to the benchmark? In this scenario, the low-TE index would outperform the benchmark by 14%.

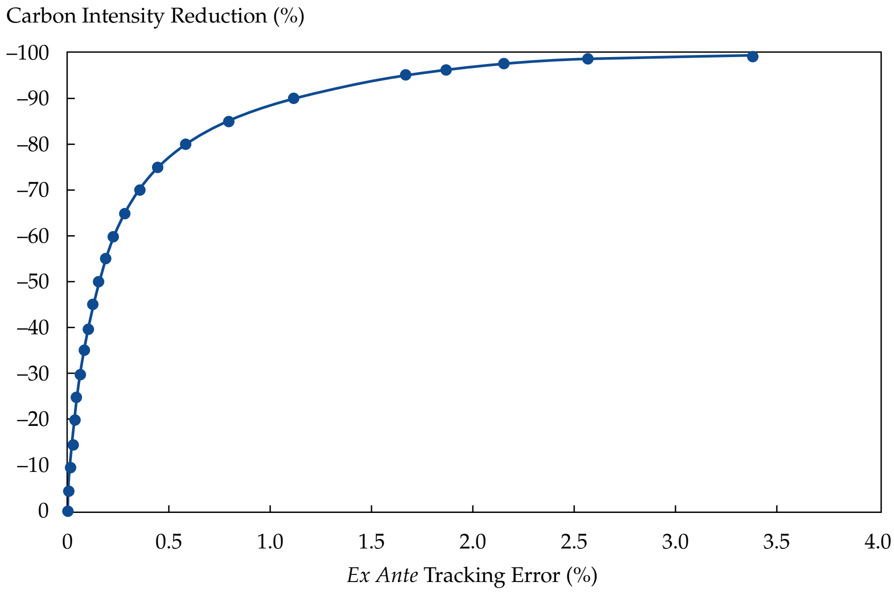
**Tracking Error Management and Carbon Risk Repricing.** Index managers seek to limit *ex ante* TE. However, some enhanced indexes, such as decarbonized indexes, also seek to increase returns relative to the benchmark. Although the two goals may seem in conflict, we note that the optimization procedure focuses on *ex ante* TE and excess returns are necessarily measured *ex post*. Therefore, if the risk model used to limit *ex ante* TE does not take into account carbon risk (or any factor responsible for a divergence of returns), a small *ex ante* TE can be compatible with active returns *ex post*. Two polar carbon-repricing scenarios can be considered: (1) a smooth repricing with moderate regulatory and technological changes that progressively impair the profitability of carbon-intensive companies and (2) a sharp repricing caused by unanticipated disruptive technologies or regulations. In the first scenario, investors could experience active positive returns with *ex post* TE in line with *ex ante* TE. In the second scenario, investors in a decarbonized index could experience a peak in *ex post* TE with active positive returns.

## Beyond Optimization: Methodological Considerations and Caveats

In this section, we consider other issues besides portfolio optimization, including the benefits of clear signaling via transparent rules, trade-offs involved in different designs of decarbonized indexes and different normalizations of carbon footprints, how to deal with anticipated changes in companies' carbon footprints, and a few caveats.

**Benefits of Clear Signaling through Transparent Rules.** As all issuers well understand, inclusion in or exclusion from an index matters and is a newsworthy event. We believe that inclusion in a decarbonized index ought to have similar value. Clearly communicating which constituent stocks are in the decarbonized index would not only reward the included companies for their efforts in reducing their carbon footprint but also help discipline the excluded companies. This pressure might induce excluded companies to take steps to reduce their carbon footprint and to reward their CEOs for any carbon footprint reductions.[19] Because companies' exclusion from the index would be reevaluated yearly, it would also induce healthy competition to perform well with respect to carbon footprints, with the goal of rejoining the index.[20] Finally, clear communications concerning exclusion criteria based on carbon footprints would inspire a debate on whether greenhouse gas (GHG) emissions are properly measured and would lead to improvements in the

**Figure 1. Carbon Frontier on the MSCI Europe Index**




*Source:* Amundi (30 June 2015).

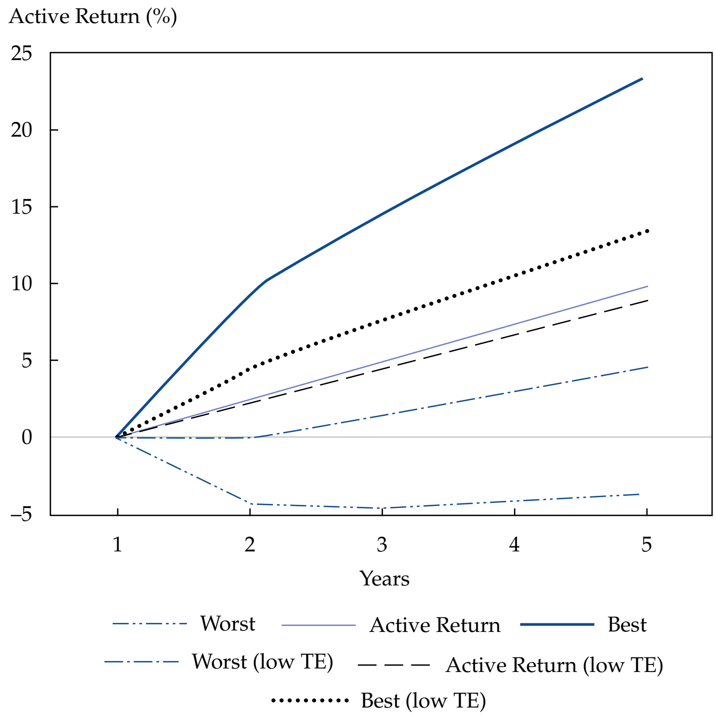
methodology for determining companies' carbon footprints.

**Design Trade-Offs.** A number of trade-offs are involved in the design of a decarbonized index. For example, an obvious question about balancing concerns the sector composition of the benchmark index. To what extent should the decarbonized index seek to preserve the sector balance of the benchmark? While seeking to preserve sector composition, should the filtering out of high-carbon-footprint stocks be performed sector by sector or across the entire benchmark index portfolio? Some believe that a sector-blind filtering out of companies by the size of their carbon footprint would result in an unbalanced decarbonized index that essentially excludes most of the fossil energy sector, electric utilities, and mining and materials companies. Obviously, such an unbalanced decarbonized index would have a very high tracking error and would be undesirable. Interestingly, however, a study of the world's 100 largest companies has shown that more than 90% of the world's GHG emissions are attributable to sectors other than oil and gas (see Climate Counts 2013). Hence, a sector-by-sector filtering approach could result in a significantly reduced carbon footprint while still maintaining a sector composition roughly similar to that of the benchmark. Later in the article, we show more concretely how much carbon footprint reduction can be achieved by decarbonizing the S&P 500 and MSCI Europe indexes.

One simple way to address this issue is to look at the decarbonized portfolio's TE for the different optimization problems and pick the procedure that yields the decarbonized index with the lowest TE. But there may be other relevant considerations besides TE minimization. For example, one advantage of a sector-by-sector filtering approach with transparent rules (subject to the constraint of maintaining roughly the same sector balance as that of the benchmark index) is that excluded companies can more easily determine their carbon footprint ranking in their industry and how much carbon footprint reduction it would take for their stock to be included in the decarbonized index. In other words, a sector-by-sector filtering approach would foster greater competition within each sector for companies to lower their carbon footprint. Another related benefit is that the exclusion of the worst GHG performers in the sector would also reduce exposure to companies that fare poorly on other material sustainability factors (given that carbon footprint reduction is a good proxy for investments in other material sustainability factors).[21]

**Normalization of the Carbon Footprint.** Because the largest companies in the benchmark index are likely to be the companies with the highest GHG emission levels, a filtering rule that excludes the stocks of companies with the highest absolute emission levels will tend to be biased against the largest companies, which could result in a high TE for the decarbonized index. Accordingly, some normalization of companies' carbon footprints is appropriate. Another reason to normalize the absolute carbon footprint measure is that a filter based on a normalized measure would be better at selecting the least wasteful companies in terms of GHG

**Figure 2. Returns and Risk with Low Tracking Error**




*Source:* Amundi.

emissions. That is, a normalized carbon footprint measure would better select companies on the basis of their energy efficiency. A simple and comprehensive, if somewhat rudimentary, normalization would be to divide each company's carbon footprint by sales. Normalizations adapted to each sector are preferable and could take the form of dividing $CO_2$ emissions by (1) tons of output in the oil and gas sector, (2) revenue from transporting one tonne over a certain distance in the transport sector, (3) total GWh (gigawatt-hour) electricity production in the electric utility sector, (4) square footage of floor space in the housing sector, or (5) total sales in the retail sector.

**Changes in Companies' Carbon Footprints.** Ideally, the green filter should take into account expected future carbon footprint reductions resulting from current investments in energy efficiency and reduced reliance on fossil fuels. Similarly, the green filter should penalize oil and gas companies that invest heavily in exploration with the goal of increasing their proven reserves, which raises the risk of stranded assets for such companies. This "threat" would provide an immediate incentive to any company with an exceptionally high carbon footprint to make investments to reduce it and would boost the financial returns of the decarbonized index relative to the benchmark.

**Caveats.** Whenever an investment strategy that is expected to outperform a market benchmark is pitched, a natural reaction is to ask, what's the catch? As explained earlier, the outperformance of the decarbonized index is premised on the fact that financial markets currently do not price carbon risk. Thus, an obvious potential flaw in our proposed climate risk–hedging strategy is the possibility that financial markets currently *overprice* carbon risk. While this overpricing is being corrected, the decarbonized index would underperform the benchmark index. We strongly believe this argument to be implausible because the current level of awareness of carbon risk remains very low outside a few circles of asset owners, a handful of brokers, and asset managers. Another highly implausible scenario is that somehow today's high-carbon-footprint sectors and companies will be tomorrow's low-carbon-footprint sectors and companies. One story to back such a scenario could be that the high-GHG emitters have the most to gain from carbon sequestration and will thus be the first to invest in that technology. Under this scenario, the decarbonized index would underperform the benchmark precisely when carbon taxes are introduced. This scenario is not in itself a crushing objection because the green filter can easily take into account investments in carbon sequestration as a criterion for inclusion in the index. In the end, this scenario simply suggests a reason for the carbon filter to take into account measures of companies' predicted carbon footprints.

A more valid concern is whether companies' carbon footprints are correctly measured and whether the filtering based on carbon intensity fits its purpose. Is there a built-in bias in the way carbon footprints are measured, or is the measure so noisy that investors could be exposed to many carbon measurement risks? A number of organizations—Trucost, CDP (formerly Carbon Disclosure Project), South Pole Group, and MSCI ESG Research—provide carbon footprint measures of the largest publicly traded companies, measures that can sometimes differ from one organization to another.[22] For example, it has been observed that GHG emissions associated with hydraulic fracturing for shale gas are significantly underestimated because the high methane emissions involved in the hydraulic fracturing process are not counted. Thus, what would appear to be—according to current carbon footprint measurements—a welcome reduction in carbon footprints following the shift from coal to shale gas could be just an illusion. Consequently, a green filter that relies on this biased carbon footprint measure risks exposing investors to more rather than less carbon risk.

As described in greater detail in Appendix C, GHG emissions are divided into three scopes: Scope 1, which measures direct GHG emissions; Scope 2, which concerns indirect emissions resulting from the company's purchases of energy; and Scope 3, which covers third-party emissions (suppliers and consumers) tied to the company's sales. Although Scope 3 emissions may represent the largest fraction of GHG emissions for some companies (e.g., consumer electronics companies and car manufacturers),[23] there is currently no systematic, standardized reporting of these emissions. This lack is clearly a major limitation and reduces the effectiveness of all existing decarbonization methodologies. For example, excluding the most-polluting companies in the automobile industry and the auto components industry on the basis of current emission measures would lead mostly to the exclusion of auto components companies. Automobile manufacturers would largely be preserved because most of the carbon emissions for a car maker are Scope 3 emissions. As reliance on decarbonized indexes grows in scale, however, more resources will likely be devoted to improving the quality of Scope 3 and the other categories of GHG emissions. The inclusion of Scope 3 emissions would also better account for green product innovations by materials companies that bolster the transition toward a low-carbon economy. For instance, aluminum producers might be excluded under the current GHG measures owing to their high carbon intensity even though aluminum will fare better than other materials in the transition to renewable energy.

There are three evident responses to these existing measurement limitations. First, drawing an analogy with credit markets, we know that a biased or noisy measure of credit risk by credit-rating agencies has never been a decisive reason for abolishing credit ratings altogether. Credit ratings have provided an essential reinforcement of credit markets for decades despite important imprecisions in their measurements of credit risk, which have been pointed out by researchers of credit markets over time. Second, as with credit ratings, methodologies for measuring carbon footprints will be improved, especially when the stakes involved in measuring carbon footprints correctly increase because of the role of these measures in any green filtering process. Third, the design of the decarbonized index itself offers protection against carbon footprint measurement risk; if there is virtually no tracking error with the benchmark, investors in the decarbonized index are partly hedged against this risk.

Finally, a somewhat more technical worry is that the stocks excluded from the decarbonized index could also be the most volatile stocks in the benchmark index because these stocks are the most sensitive to speculation about climate change and climate policy. If that is the case, tracking error cannot be eliminated entirely, but that should not be a reason for deciding not to invest in the decarbonized index. On the contrary, the decarbonized index will then have a higher Sharpe ratio than the benchmark, commensurate with a higher TE.[24]

To summarize, our proposed strategy for hedging climate risk is especially suitable for passive long-term investors. Rather than a risky bet on clean energy (at least in the short run), we have described a decarbonized index with minimal tracking error that offers passive investors a significantly reduced exposure to carbon risk, allowing them to "buy time" and limit their exposure with respect to the timing of the implementation of climate policy and a carbon tax. Thus, a key difference between this approach and existing green indexes is switching the focus from the inevitable transition to renewable energy to the timing risk with respect to climate policy. As we show later in the article, carbon exposure can be reduced significantly—with maximum insurance against the timing of climate policy—by minimizing tracking error with the benchmark index. We believe that this approach is essentially a win-win strategy for all passive asset owners and managers. Moreover, should this strategy be adopted by a large fraction of passive index investors—a market representing close to $11 trillion in assets, according to a recent study[25] (Boston Consulting Group 2015)—companies will feel the pressure to improve their performance on GHG emissions and debates about carbon emissions will surely be featured prominently in the financial press.[26] It constitutes, therefore, an easy entry point for a wide clientele of investors and could trigger the mobilization of a much broader ecosystem dedicated to the analysis and understanding of climate-related transition risks.

## Decarbonized Indexes in Practice: How Small Are Their Carbon Footprints?

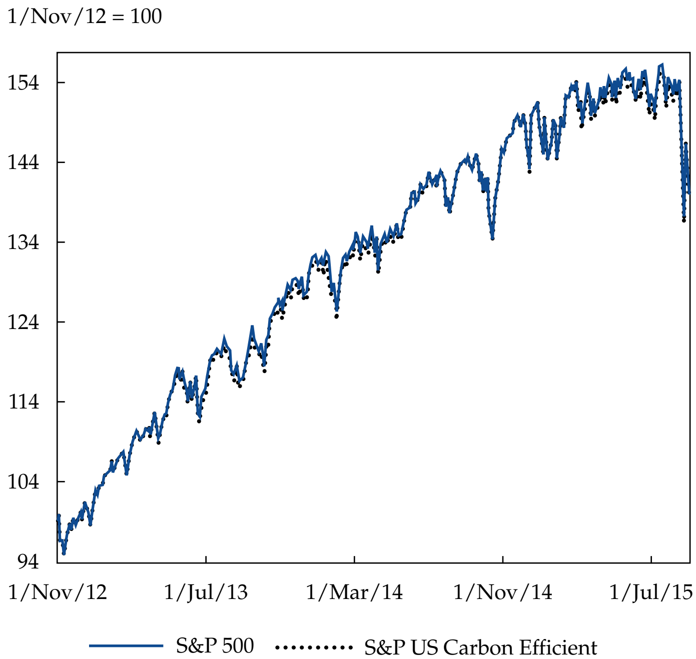
There are several examples of decarbonized indexes. AP4, the Fourth Swedish National Pension Fund (Fjärde AP-fonden), is, to our knowledge, the first institutional investor to adopt a systematic approach that uses some of these decarbonized indexes to significantly hedge the carbon exposure of its global equity portfolio. In 2012, AP4 decided to hedge the carbon exposure of its US equity holdings in the S&P 500 by switching to a decarbonized portfolio with a low TE relative to the S&P 500 through the replication of the S&P 500 Carbon Efficient Select Index. This index excludes the 20% worst performers in terms of carbon intensity ($CO_2$/Sales) as measured by Trucost, one of the leading companies specializing in the measurement of the environmental impacts of publicly traded companies. An initial design constraint on the decarbonized index is to ensure that stocks removed from the S&P 500 do not exceed a reduction in the Global Industry Classification Standard (GICS) sector weight of the S&P 500 by more than 50%. A second feature of the S&P 500 Carbon Efficient Select Index is the readjustment of the weighting of the remaining constituent stocks to minimize TE with the S&P 500. Remarkably, this decarbonized index reduces the overall carbon footprint of the S&P 500 by roughly 50%,[27] with a TE of no more than 0.5%. This first model of a decarbonized index strikingly illustrates that significant reductions in carbon exposure are possible without sacrificing much in the way of financial performance or TE. In fact, AP4's S&P 500 Carbon Efficient Select Index portfolio has outperformed the S&P 500 by about 24 bps annually since it first invested in the decarbonized index in November 2012, as **Figure 3** shows, which is in line with the 27 bp annual outperformance of the S&P 500 Carbon Efficient Select Index since January 2010.

AP4 has extended this approach to hedging climate risk to its equity holdings in emerging markets.[28] Relying on carbon footprint data from MSCI ESG Research, AP4 has sought to exclude from the MSCI EM Custom ESG Index not only the companies with the highest GHG emissions but also the worst companies in terms of stranded asset risk. Turning to its Pacific-ex-Japan stock holdings, AP4 has applied a similar methodology in constructing its decarbonized portfolio, excluding the companies with the largest reserves and highest carbon emissions intensity while maintaining both sector and country weights in line with its initial index holdings in the region.

More recently, AP4, FRR (Fonds de réserve pour les retraites, or the French pensions reserve fund), and Amundi have worked with MSCI to develop another family of decarbonized indexes, with a slightly different design. The result is the MSCI Global Low Carbon Leaders Index family—based on existing MSCI equity indexes (e.g., MSCI ACWI, MSCI World, and MSCI Europe)—which addresses two dimensions of carbon exposure. It excludes from the indexes the worst performers in terms of both carbon emissions intensity and fossil fuel reserves intensity while maintaining a maximum turnover constraint as well as minimum sector and country weights. The remaining constituent stocks are then rebalanced to minimize TE with the respective benchmarks.[29] **Table 2** compares the performance of the resulting decarbonized indexes, based on a backtest, with that of the MSCI Europe Index. As Table 2 shows, the Low Carbon Leaders Index delivers a remarkable 90 bp annualized outperformance over the MSCI Europe Index for November 2010–February 2016, with a similar volatility and a 0.7% tracking error.

At the end of January 2016, we conducted a performance attribution analysis, after the MSCI Europe Low Carbon Leaders Index was launched, for the period November 2014–January 2016,[30] when the outperformance was particularly strong (an overall 189 bps[31]). Our analysis shows how to distinguish which part of the performance is due to sector allocation (allocation effect[32]) and which part is due to stock selection within sectors (selection effect[33]). At the sector level (using the GICS[34] taxonomy), the allocation effect is responsible for 37 bps of outperformance, with the underweighting of the energy and materials sectors responsible for 40 bps and 20 bps, respectively. More importantly, the effect of screening out the worst GHG performers within a sector is greater than the allocation effect, with a 120 bp outperformance. Interestingly, the positive screening effect is concentrated in two sectors, Materials (127 bps) and Utilities (25 bps; see **Table E1** in Appendix E). The largest negative contributor, Consumer Staples, had an allocation effect of –37 bps and a selection effect of –8 bps.

**Figure 3. S&P 500 and S&P US Carbon Efficient Indexes**




*Sources:* Amundi and Bloomberg (31 August 2015).

We conducted a second-level analysis (industry level; see **Table E2** and **Table E3** in Appendix E) that focused on the largest contributor, the materials sector, and found that the index was strongly underweighted in the diversified metals and mining (DM&M) stocks, with a 68 bp allocation effect and a 36 bp selection effect. The reason behind this underweighting is that coal represents the major part of DM&M reserves. As for the utilities sector, the index was underweighted on multi-utilities because of their high emissions (an 11 bp selection effect and an 8 bp allocation effect). Stock performance for these two sectors was related to trends in the energy sector (mostly a fall in coal prices).

AP4, MSCI, FRR, and Amundi have further explored the robustness of these decarbonized indexes to other exclusion rules and to higher carbon footprint reductions. They found that there is not much to be gained by using more flexible criteria that permit less than 100% exclusion of high-carbon-footprint stocks. **Table 3** compares the performances of a fully "optimized" portfolio, with no strict exclusion of the worst performers, and a portfolio based on the "transparent exclusion rules" outlined earlier. Whether in terms of reduced exposure to carbon or overall tracking error, the two portfolios deliver similar results.

Interestingly, however, the two methods for constructing the decarbonized index yield substantial sector differences in TE contribution, which is concentrated in two sectors (Materials and Energy) for the fully optimized index. In contrast, the limit put on total sector exclusion in the Low Carbon Leaders Index (with transparent rules) spreads the effort across several sectors (see **Figure F1** in Appendix F for a detailed breakdown of the contributions to specific risks).

## Conclusion

Our decarbonized index investment strategy stands on its own as a simple and effective climate risk–hedging strategy for passive long-term institutional investors, but it is also an important complement to climate change mitigation policies. Governments have thus far focused mostly on introducing policies to control or tax GHG emissions and to build broad international agreements for the global implementation of such policies (for a discussion of the pros and cons of cap-and-trade mechanisms versus a GHG emissions tax, see Guesnerie and Stern 2012).[35] Governments have also provided subsidies to the solar and wind energy sectors, thereby boosting a small-business constituency that supports climate change mitigation policies. Similarly, index decarbonization can boost support for such policies from a large fraction of the investor community. In addition, as more and more funds are allocated to decarbonized indexes, stronger market incentives will materialize, inducing the

### Table 2. Financial Performance of Transparent Rules on MSCI Europe

| Key Metrics | MSCI Europe Index | MSCI Europe Low Carbon Leaders Index |
|---|---|---|
| Total return[a] | 7.8% | 8.7% |
| Total risk[a] | 13.2% | 13.2% |
| Return/risk | 0.59 | 0.65 |
| Sharpe ratio | 0.57 | 0.63 |
| Active return[a] | 0% | 0.9% |
| Tracking error[a] | 0% | 0.7% |
| Information ratio | NA | 1.16 |
| Historical beta | 1.00 | 1.16 |
| Turnover[b] | 1.8% | 9.9% |
| Securities excluded | NA | 93 |
| Market cap excluded | NA | 21.4% |
| Reduction in carbon emissions intensity ($tCO_2$/US$ millions) | NA | 52% |
| Reduction in carbon reserves intensity ($tCO_2$/US$ millions) | NA | 66% |

NA = not applicable.
*Notes:* The index of low-carbon leaders is reviewed and updated every six months (in May and November). This table was created after the November 2015 review of the list of index constituents.
[a]Gross returns were annualized in euros for 30 November 2010–29 February 2016.
[b]Annualized one-way index turnover for 30 November 2010–29 February 2016.
*Source:* MSCI (30 November 2010–29 February 2016).

### Table 3. Carbon and Financial Performances of Transparent Rules on MSCI Europe

| | Optimized Index (low-carbon target) | Transparent Rules (low-carbon leaders) |
|---|---|---|
| Reduction in carbon emissions intensity ($tCO_2$/US$ millions) | 82% | 62% |
| Reduction in carbon reserves intensity ($tCO_2$/US$ millions) | 90% | 81% |
| Tracking error[a] | 0.9% | 0.72% |

*Note:* Backtests were run over a four-year period, from 30 November 2010 to 30 June 2014.
[a]Gross returns were annualized in euros for 30 November 2010–31 July 2015.
*Source:* MSCI.

world's largest corporations—the publicly traded companies—to invest in reducing GHG emissions. Moreover, the encouragement of climate risk hedging can have real effects on reducing GHG emissions even before climate change mitigation policies are introduced. The mere expectation that such policies will be introduced will affect the stock prices of the highest-GHG emitters and reward those investors that have hedged climate risk by holding a decarbonized index. Finally, the anticipation of the introduction of climate change mitigation policies will create immediate incentives to initiate a transition to renewable energy.

A simple, costless policy in support of climate risk hedging that governments can adopt immediately is to mandate disclosure of the carbon footprint of their state-owned investment arms (public pension funds and sovereign wealth funds). Such a disclosure policy would have several benefits.

Given that climate change is a financial risk, disclosure provides investors (and citizens) with relevant information on the nature of the risks they are exposed to. Remarkably, some pension funds have already taken this step by disclosing their portfolios' carbon footprint—in particular, ERAFP and FRR in France; KPA Pension, the Church of Sweden, and the AP funds in Sweden; APG in the Netherlands; and the Government Employees Pension Fund (GEPF) in South Africa.

Given that citizens and pensioners will ultimately bear the costs of climate change mitigation, disclosure of their carbon exposure through their pension or sovereign wealth funds helps internalize the externalities of climate change. Indeed, investment by a public pension fund in polluting companies generates a cost borne by its government and trustees and thereby lowers the overall returns on investment. The China Investment Corporation

(CIC), China's sovereign wealth fund, has already made some statements in that direction.

Disclosure of the carbon footprint of a sovereign wealth fund's portfolio can be a way for sovereign wealth funds of oil- and gas-exporting countries to bolster risk diversification and hedging of commodity and carbon risk through their portfolio holdings. The basic concept underlying a sovereign wealth fund is to diversify the nature of the country's assets by extracting the oil and gas under the ground and thereby "transforming" these assets into "above-ground" diversifiable financial assets. Thus, it makes sense to follow up this policy by diversifying investments held by the sovereign wealth fund away from energy companies and other stock holdings that have a large carbon exposure. Interestingly, the French government recently approved a law on energy transition that requires French institutional investors to disclose their climate impact and carbon risk exposure.[36]

A more direct way to support investment in low-carbon, low-TE indexes is to push public asset owners and their managers to make such investments. Governments could thus play an important role as catalysts to accelerate the mainstream adoption of such investment policies. In this respect, it is worth mentioning the interesting precedent of the recent policy of the Shinzō Abe administration in Japan to support the development of the JPX-Nikkei Index 400. What is particularly noteworthy is that the Abe administration sees this index as an integral part of its "third arrow" plan to reform Japan's companies. GPIF—by far the largest Japanese public investor, with more than $1.4 trillion of assets under management—has adopted the new index. This example illustrates how the combination of a newly designed index with a policymaking objective and the adoption of that index by a public asset owner can be a catalyst for change.

In his book *Finance and the Good Society*, Robert J. Shiller (2012, p. 7) advances a welcome and refreshing perspective on financial economics:

> Finance is not about "making money" per se. It is a "functional" science in that it exists to support other goals—those of society. The better aligned society's financial institutions are with its goals and ideals, the stronger and more successful the society will be.

It is in this spirit that we have pursued our research on how investors can protect their savings from the momentous risks associated with GHG emissions and their long-term, potentially devastating effect on climate change. Climate change has mostly and appropriately been the bailiwick of scientists, climatologists, governments, and environmental activists. There has been relatively little engagement by finance with this important issue, but investors and financial markets cannot continue to ignore climate change. The effects of rising temperatures, the increasingly extreme weather events climate change generates, and the climate change mitigation policy responses it could provoke may have dramatic consequences for the economy and thus investment returns. Therefore, financial innovation should be explored so that the power of financial markets can be used to address one of the most challenging global threats faced by humankind.

Besides offering investors a hedging tool against the rising risks associated with climate change, a decarbonized index investment strategy can mobilize financial markets to support the common good. As a larger and larger fraction of the index-investing market is devoted to decarbonized indexes, a virtuous cycle will be activated and enhanced whereby the greater awareness of carbon footprints and GHG emissions will exert a disciplining pressure to reduce $CO_2$ emissions and will gradually build an investor constituency that supports climate change mitigation policies. Governments, businesses, technology innovators, and society will thus be encouraged to implement changes that accelerate the transition to a renewable energy economy.

Our basic premise/working assumption is that to foster the engagement of financial markets with climate change, it is advisable to appeal to investors' rationality and self-interest. Our argument is simply that even if some investors are climate change skeptics, the uncertainty surrounding climate change cannot be used to dismiss climate change and related mitigation policies as a zero probability risk. Any rational investor with a long-term perspective should be concerned about the absence of a market for carbon and the potential market failures that could result from this incompleteness. A dynamic decarbonized index investment strategy seeks to fill this void, offering an attractive hedging tool even for climate change skeptics.

Finally, the decarbonization approach we have described for equity indexes can also be applied to corporate debt indexes. Although the focus in fixed-income markets has been on green bonds, corporate debt indexes—decarbonized along the same lines as equity indexes (screening and exclusion based on carbon intensity and fossil fuel reserves while maintaining sector neutrality and a low TE)—could be a good complement to green bonds. Similarly, low-water-use indexes and other environmental leader indexes can be constructed in the same way as our decarbonized index.

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## Appendix A. Current Context of Climate Legislation

The United Nations Framework Convention on Climate Change (UNFCCC) coordinates global policy efforts toward the stabilization of GHG concentrations in the atmosphere, with a widely accepted policy target for the upcoming decades of limiting GHG emissions to keep average temperatures from rising more than 2°C by 2050. However, no concrete policies limiting GHG emissions have yet been agreed to that make this target a realistic prospect. To give an idea of what this target entails, scientists estimate that an overall limit on the concentration of $CO_2$ in the atmosphere between 350 parts per million (ppm) and 450 ppm should not be exceeded if we are to have a reasonable prospect of keeping temperatures from rising by more than 2°C (IPCC 2014). Maintaining $CO_2$ concentrations under that limit would require keeping global $CO_2$ emissions below roughly 35 billion tons a year, which is more or less the current rate of emissions; it was 34.5 gigatons (Gt) in 2012, according to the European Commission.

Although the process led by the UNFCCC stalled during many years following the adoption of the Kyoto Protocol, a number of countries have taken unilateral steps to limit GHG emissions in their jurisdictions. Thus, a very wide array of local regulations, as well as legislation focused on carbon emission limits and clean energy, has been introduced in the past decade—for example, 490 new regulations were put in place in 2012 as opposed to only 151 in 2004 and 46 in 1998 (UNEP FI 2013). Moreover, after promising signs of greater urgency concerning climate policies in both the United States[37] and China, the "Paris agreement" negotiated during the climate conference in Paris in December 2015 marked "an unprecedented political recognition of the risks of climate change."[38]

The Paris agreement, however, does not detail a course for action and entails many non-binding provisions with no penalties imposed on countries unwilling or unable to reach their targets. But if the prospect of a global market for $CO_2$ emission permits—or even a global carbon tax—also seems far off, the establishment of a national market for $CO_2$ emission permits in China in the next few years could be a game changer. Indeed, in the U.S.–China Joint Announcement on Climate Change and Clean Energy Cooperation, China has pledged to cap its $CO_2$ emissions around 2030 and to increase the non-fossil-fuel share of its energy consumption to around 20% by 2030.[39] Moreover, following the launch of seven pilot emissions-trading schemes (ETSs), which are currently in operation, China's National Development and Reform Commission (NDRC) stated that it aimed to establish a national ETS during its five-year plan (2016–2020).[40]

Yet, despite China's impressive stated climate policy goals and the Paris agreement, substantially more reductions in $CO_2$ emissions need to be implemented globally to have an impact on climate change. In particular, the global price of $CO_2$ emissions must be significantly higher to induce economic agents to reduce their reliance on fossil fuels or to make carbon capture and storage worthwhile (current estimates indicate that a minimum carbon price of $25–$30 per ton of carbon dioxide equivalent [$CO_2e$] is required to cover the cost of carbon capture).[41] Therefore, with the continued rise in global temperatures and the greater and greater urgency regarding strong climate mitigation policies in the coming years, policymakers may at last realize that they have little choice but to implement radical climate policies, resulting in a steep rise in the price of carbon. On top of national governments' mobilization and international agreements, major religious authorities have recently expressed their concerns about climate change, urging both governments and civil society to act.[42]

## Appendix B. Risk of Stranded Assets

The notion of stranded assets was introduced by the Carbon Tracker Initiative (2011, 2013)[43] and the Generation Foundation (2013). It refers to the possibility that not all known oil and gas reserves will be exploitable should the planet reach the peak of sustainable concentrations in the atmosphere before all oil and gas reserves have been exhausted. A plausible back-of-the-envelope calculation goes as follows: According to the Carbon Tracker Initiative (2011), Earth's proven fossil fuel reserves amount to approximately 2,800 Gt of $CO_2$ emissions. But to maintain the objective of no warming greater than 2°C by 2050 (with at least a 50% chance), the maximum amount of allowable emissions is roughly half, or 1,400 Gt of $CO_2$. In other words, oil companies' usable proven reserves are only about half of reported reserves. Responding to a shareholder resolution, ExxonMobil published in 2014, for the first time ever, a report describing how it assesses the risk of stranded assets.[44] Much of the report is an exercise in minimizing shareholders' and analysts' concerns about stranded asset risk by pointing to the International Energy Agency's projections on growing energy demand without competitive substitutes leading to higher fossil fuel prices. Nonetheless, it cannot be entirely ruled out that investors will see a growing fraction of proven reserves as unexploitable because they are simply too costly—whether because of the emergence of cheap, clean, and reliable substitutes in the form of competitive clean energy or because climate mitigation policies become an increasingly binding reality (or, most likely, both).

# Appendix C. Carbon Data

In this appendix, we offer further details on the available carbon emissions and carbon reserves data as well as the main providers of the carbon data we used.

## Nature of Carbon Emissions and Carbon Reserves Data

Carbon emissions and carbon reserves relate to a wide array of greenhouse gases (GHGs) and hydrocarbon reserves. The standard unit of measurement is the metric ton of carbon dioxide equivalent ($MtCO_2e$), usually shortened to tons of carbon. Regarding GHG emissions, the most widely used international carbon accounting tool for governments and businesses is the GHG protocol. This protocol serves as the foundation for almost every GHG standard in the world—notably, the International Organization for Standardization (ISO) and the Climate Registry. Corporate users include BP, Shell, General Motors, GE, AEG, Johnson & Johnson, Lafarge, and Tata Group. Non-corporate users include trading schemes (EU ETS, UK ETS, Chicago Climate Exchange); nongovernmental organizations (CDP, WWF, Global Reporting Initiative); and government agencies in China, the United States, US states, Canada, Australia, Mexico, and other jurisdictions.

According to the protocol, GHG emissions are divided into three scopes. Scope 1 relates to direct GHG emissions—that is, emissions that occur from sources owned or controlled by the company (e.g., emissions from fossil fuels burned on site or in leased vehicles). Scope 2 emissions are indirect GHG emissions resulting from the purchase of electricity, heating, cooling, or steam generated off-site but purchased by the entity. Scope 3 emissions encompass indirect emissions from sources not owned or directly controlled by the entity but related to its activities (e.g., employee travel and commuting, vendor supply chain). Obviously, Scope 3 emissions represent the largest GHG impact for many companies, whether in upstream activities (e.g., consumer electronics) or downstream activities (e.g., automotive industry). Scope 3 emissions reporting still lacks standardization, however, and the reporting level remains low; only 180 of the Fortune 500 companies reported on some portion of their supply chain in 2013.[45]

The estimation of the $CO_2$ equivalent of carbon reserves is a three-step process that involves the classification and estimation of hydrocarbon reserves that are then translated into $CO_2$ emissions. Most of the time, the data used for estimation of fossil fuel reserves and stranded assets concern proven reserves (a 90% probability that at least the actual reserves will exceed the estimated proven reserves). Those data are publicly available and must be disclosed in company reports. Once the proven reserves are estimated in volume or mass, two steps remain. First, the calorific value of total fossil fuel reserves must be estimated. Second, that calorific value must be translated into carbon reserves by using a carbon intensity table.

## Carbon Data Providers

At the two ends of the spectrum of carbon data providers, we found entities that simply aggregate data either provided directly by companies or publicly available as well as those that use only their internal models to estimate carbon emissions and reserves.

Corporations themselves are the primary providers of carbon data via two main channels: (1) CSR (corporate social responsibility) reports from 37% of the world's largest companies (with a market capitalization exceeding $2 billion), which completely disclose their GHG emission information; (2) CDP provides the largest global carbon-related database, in partnership with Bloomberg, MSCI ESG, Trucost, and others. Companies respond to CDP's annual information request forms for the collection of climate change–related information; the number of respondents has increased from 235 in 2003 to 2,132 in 2011. Financial data vendors, such as Bloomberg, generally provide datasets sourced from CDP, CSR reports, and other relevant reports. The heterogeneity of sources explains the discrepancies that can sometimes be found in carbon footprint measurements.

## Appendix D. TE Minimization with a Multifactor Risk Model

In this appendix, we describe the multifactor risk model that we used to determine the decarbonized portfolio with minimum tracking error. We reduce *ex ante* TE by first estimating factor returns, then estimating risk, and ultimately minimizing TE.

### *Ex Ante* and *Ex Post* Tracking Error

Index managers usually seek a very low tracking error, but some may also seek higher returns by optimizing index replication (e.g., tax optimization, management of changes in index composition, management of takeover bids). For index managers, there is a trade-off between the goals of minimizing tracking error and maximizing return. Portfolio managers use two different measures of tracking error: (1) *Ex post* TE is the measure of the volatility of the realized active return deviations from the benchmark, and (2) *ex ante* TE is an estimation (or prediction) based on an estimated multifactor model.

*Ex ante* TE is a function of portfolio weights, benchmark weights, the volatility of stocks, and correlations across assets. Thus, to estimate portfolio risk once portfolio weights and benchmark weights are given, we need the covariance matrix of security returns. One can estimate such a covariance matrix by using historical data of security returns, but that method is burdensome and prone to estimation error (spurious correlations).

An alternative method is to use a multifactor model. We rely on the widely used Barra multiple-factor model (MFM),[46] which decomposes the return of an individual stock into the weighted sum of common factor returns and an idiosyncratic return as follows:

$$r_i = \beta_{country\ i} f_{country\ i} + \beta_{sector\ i} f_{sector\ i} + \beta_{size\ i} f_{size\ i} + \cdots + u_i$$

$$r_i = \sum_{j=1}^{j} \beta_{ji} \tilde{f}_j + u_i$$

$$\begin{bmatrix} r_1 \\ \vdots \\ r_n \end{bmatrix} = \begin{bmatrix} \beta_{11} & \cdots & \beta_{1k} \\ \vdots & \ddots & \vdots \\ \beta_{nk} & \cdots & \beta_{nn} \end{bmatrix} \begin{bmatrix} f_1 \\ \vdots \\ f_j \end{bmatrix} + \begin{bmatrix} u_1 \\ \vdots \\ u_n \end{bmatrix}$$

$$r = \beta f + u,$$

where

$\beta_{ji}$ = the factor loading for security $i$ on common factor $j$

$f_j$ = the common factor return

$u_i$ = the part of the return that cannot be explained by common factors

### Estimating Factor Returns

Common factors used by Barra include industries, styles (size, value, momentum, and volatility), and currencies; 68 factors are used for the multiple-horizon US equity model.

Common factor returns are estimated using monthly stock returns. The time series of factor returns are then used to generate factor variances and covariances in the covariance matrix:

$$\begin{bmatrix} \mathrm{Var}(f_1) & \cdots & \mathrm{Cov}(f_1, f_k) \\ \vdots & \ddots & \vdots \\ \mathrm{Cov}(f_k, f_1) & \cdots & \mathrm{Var}(f_k) \end{bmatrix}.$$

To capture variance and covariance dynamics and improve the predictive power of the model, Barra uses an exponential weighting scheme that gives more weight to recent data, and so, on average, the last two to three years of data represent 50% of the available information ("half life").

### From Factor Returns to Risk Estimation

Similar to components of returns, components of risks can be divided into common factor sources and security-specific risks:

$$\mathrm{Var}(\text{total risk}) = \mathrm{Var}(\text{common factor risk}) + \mathrm{Var}(\text{active specific risk}),$$

and the multifactor equation becomes

$$\mathrm{Var}(r) = \mathrm{Var}(\boldsymbol{\beta} f + u)$$

$$\mathrm{Var}(r) = \boldsymbol{\beta}\boldsymbol{\Omega}_f\boldsymbol{\beta}' + \boldsymbol{\Delta},$$

where

$\boldsymbol{\beta}$ = the matrix of factor exposures

$\boldsymbol{\beta}'$ = the transposed matrix

$\boldsymbol{\Omega}$ = the variance–covariance matrix for the $k$ factors

$\boldsymbol{\Delta}$ = the diagonal matrix of specific risk variances

The volatility, $\sigma_p$, of any portfolio $p$, represented by a vector of portfolio weights $\mathbf{W}_p$, is thus

$$\sigma_p = \sqrt{\mathbf{W}_p\left(\boldsymbol{\beta}\boldsymbol{\Omega}_f\boldsymbol{\beta}' + \boldsymbol{\Delta}\right)\mathbf{W}_p'}.$$

### TE Minimization

In the case of tracking error minimization, the objective function is the *ex ante* tracking error; constraints can range from turnover limits to reweighting rules with or without active weight constraints, among others.

Let us consider an example of a low-carbon, low-TE, multi-utilities fund. First, we have a reference universe of 10 constituents: the multi-utilities industry group in the utilities sector in a large economic zone. We assign to each constituent an index weight equal to $\left[\text{Mkt cap}(i)/\text{Total mkt cap}\right]$ in order to obtain a market cap–weighted index, and we let $\left(w_1^b,\cdots,w_{10}^b\right)$ be the constituent stocks' weights. We rank the constituents according to their carbon intensity (e.g., $CO_2e$/GWh) and then adopt the following constraint (rule):

$$\begin{pmatrix} w_1^b \\ w_2^b \\ \vdots \\ w_{10}^b \end{pmatrix} => \begin{pmatrix} 0 \\ w_2 \\ \vdots \\ w_{10} \end{pmatrix}.$$

In other words, the optimal portfolio $(0, w_2, \cdots, w_{10})$ will be the result of the minimization of the following objective function:

$$\text{Min}\left[\sqrt{\left(W^p - W^b\right)'\left(\boldsymbol{\beta}\boldsymbol{\Omega}_f\boldsymbol{\beta}' + \boldsymbol{\Delta}\right)\left(W^p - W^b\right)}\right],$$

where

$$\forall i = 1,\cdots,10;\ 0 \le w_i$$
$$i = 1;\ w_1 = 0,$$

and

$\left(W^p - W^b\right)$ = the active weights of the portfolio with regard to the benchmark

$\boldsymbol{\Omega}_f$ = the variance–covariance matrix of factors

$\boldsymbol{\beta}$ = the matrix of factor exposures

$\boldsymbol{\Delta}$ = the diagonal matrix of specific risk variances

Barra uses an optimization algorithm to minimize TE under the new constraint of excluding stock 1. It selects active weights depending on the factor loading of each security and the covariance between each factor in order to create a new portfolio that closely tracks the reference portfolio.

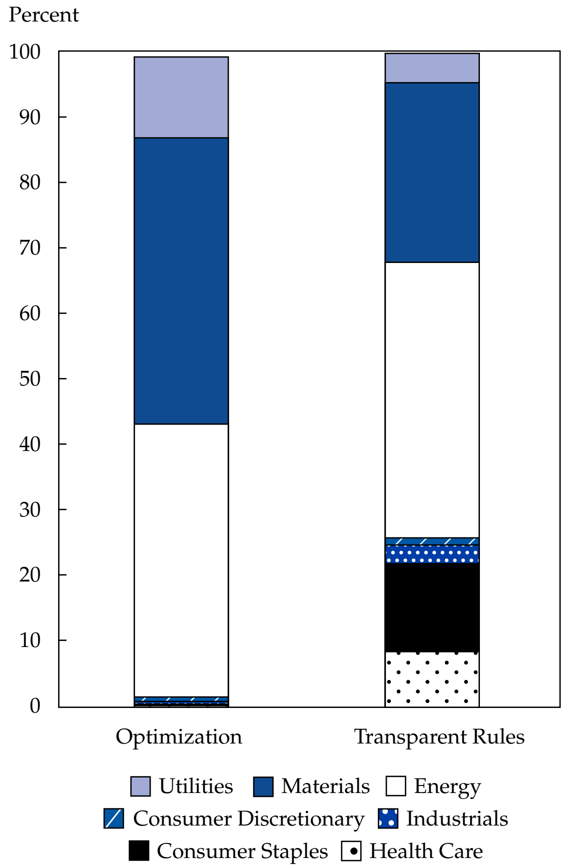
## Appendix E. Performance Attribution in the MSCI Europe Low Carbon Leaders Index vs. the MSCI Europe Index

In this appendix, **Table E1**, **Table E2**, and **Table E3** give several measures of performance attribution for various sectors in the MSCI Europe Low Carbon Leaders Index versus the MSCI Europe Index.

## Appendix F. Percentage Contributions to Specific Risks by Sector

In this appendix, **Figure F1** depicts the breakdown of the percentage contributions to specific risks by sector.

**Figure F1. Percentage Contributions to Specific Risks by Sector**



### Table E1. MSCI Europe Low Carbon Leaders vs. MSCI Europe, 7 November 2014–31 January 2016

| | MSCI Europe Low Carbon Leaders Index | | | MSCI Europe Index | | | Attribution Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| Sector | Weight | Total Return | Contribution to Return | Weight | Total Return | Contribution to Return | Allocation Effect | Selection Effect | Total Effect |
| *Total* | 100.00 | 6.06 | 6.06 | 100.00 | 4.17 | 4.17 | 0.37 | 1.52 | 1.89 |
| Materials | 6.18 | 2.65 | 0.20 | 7.23 | –17.72 | –1.10 | 0.20 | 1.27 | 1.47 |
| Utilities | 3.87 | 7.55 | 0.30 | 4.00 | 0.83 | 0.04 | 0.02 | 0.25 | 0.27 |
| Health care | 13.48 | 11.16 | 1.29 | 13.84 | 9.28 | 1.12 | 0.00 | 0.21 | 0.21 |
| Consumer discretionary | 12.57 | 12.58 | 1.41 | 11.45 | 12.18 | 1.23 | 0.09 | 0.05 | 0.15 |
| Industrials | 12.93 | 7.74 | 0.98 | 11.04 | 7.11 | 0.74 | 0.06 | 0.07 | 0.14 |
| Telecommunication services | 5.61 | 17.44 | 0.89 | 4.95 | 16.58 | 0.70 | 0.08 | 0.05 | 0.13 |
| Information technology | 3.69 | 25.97 | 0.93 | 3.56 | 21.92 | 0.69 | 0.02 | 0.11 | 0.13 |
| Financials | 24.64 | –4.18 | –1.18 | 22.75 | –4.55 | –1.26 | –0.15 | 0.11 | –0.04 |
| Energy | 5.15 | –26.05 | –1.33 | 7.13 | –16.82 | –1.10 | 0.40 | –0.52 | –0.12 |
| Consumer Staples | 11.90 | 22.71 | 2.56 | 14.07 | 24.19 | 3.12 | –0.37 | –0.08 | –0.45 |

*Sources:* Amundi; MSCI; FactSet.

### Table E2. MSCI Europe Low Carbon Leaders vs. MSCI Europe—Materials Sector, 7 November 2014–31 January 2016

| | MSCI Europe Low Carbon Leaders Index | | | MSCI Europe Index | | | Attribution Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| Sector | Weight | Total Return | Contribution to Return | Weight | Total Return | Contribution to Return | Allocation Effect | Selection Effect | Total Effect |
| *Materials* | 6.18 | 2.65 | 0.20 | 7.23 | –17.72 | –1.10 | 0.20 | 1.27 | 1.47 |
| Diversified metals and mining | 0.75 | –23.73 | –0.36 | 1.84 | –55.54 | –1.15 | 0.68 | 0.36 | 1.04 |
| Construction materials | 0.47 | 28.56 | 0.10 | 0.75 | –0.75 | –0.01 | 0.01 | 0.11 | 0.12 |
| Specialty chemicals | 1.69 | 14.25 | 0.32 | 1.16 | 12.26 | 0.12 | 0.04 | 0.03 | 0.06 |
| Steel | 0.34 | –23.61 | –0.06 | 0.27 | –43.40 | –0.11 | –0.04 | 0.09 | 0.06 |
| Diversified chemicals | 1.27 | –7.61 | –0.06 | 1.16 | –9.39 | –0.06 | –0.02 | 0.02 | 0.00 |

*Sources:* Amundi; MSCI; FactSet.

### Table E3. MSCI Europe Low Carbon Leaders vs. MSCI Europe—Utilities Sector, 7 November 2014–31 January 2016

| | MSCI Europe Low Carbon Leaders Index | | | MSCI Europe Index | | | Attribution Effect | | |
|---|---|---|---|---|---|---|---|---|---|
| Sector | Weight | Total Return | Contribution to Return | Weight | Total Return | Contribution to Return | Allocation Effect | Selection Effect | Total Effect |
| *Utilities* | 3.87 | 7.55 | 0.30 | 4.00 | 0.83 | 0.04 | 0.02 | 0.25 | 0.27 |
| Multi-utilities | 1.43 | –0.20 | –0.01 | 1.82 | –8.02 | –0.13 | 0.08 | 0.11 | 0.19 |
| Water utilities | 0.38 | 21.29 | 0.09 | 0.21 | 21.24 | 0.04 | 0.03 | 0.00 | 0.03 |
| Electric utilities | 1.45 | 12.10 | 0.18 | 1.63 | 7.66 | 0.10 | –0.03 | 0.05 | 0.03 |
| Gas utilities | 0.50 | 10.96 | 0.05 | 0.30 | 10.84 | 0.03 | 0.01 | 0.00 | 0.01 |
| Renewable electricity | 0.11 | –3.12 | 0.00 | 0.04 | –3.12 | 0.00 | 0.00 | 0.00 | 0.00 |

*Sources:* Amundi; MSCI; FactSet.

## Notes

1. A recent study by a team from the National Oceanic and Atmospheric Administration found that this perceived slowdown was entirely the result of measurement errors in recorded ocean temperatures (Karl, Arguez, Huang, Lawrimore, McMahon, Menne, Peterson, Vose, and Zhang 2015).
2. For an analysis of the consequences of this deep uncertainty for the economics of carbon pricing, see Litterman (2012).
3. For a widely quoted speech on climate change and the "tragedy of horizon" and related "transition risks," see Carney (2015).
4. The United Nations Framework Convention on Climate Change (UNFCCC) coordinates global policy efforts toward the stabilization of greenhouse gas (GHG) concentrations in the atmosphere, with a widely accepted policy target for the coming decades of limiting GHG emissions to keep average temperatures from rising more than 2°C by 2050. However, no concrete policies limiting GHG emissions have yet been accepted that make this target a realistic prospect. Although the process led by the UNFCCC stalled following the adoption of the Kyoto Protocol, a number of countries have taken unilateral steps to limit GHG emissions in their own jurisdictions. The 21st Conference of the Parties to the UNFCCC, which was held in Paris in December 2015 (http://www.un.org/sustainabledevelopment/cop21/), is seen by many observers as a crucial milestone in the fight against climate change. For further details, see Appendix A.
5. A handful of organizations contribute to raising awareness of carbon risk among institutional investors. For example, the Portfolio Decarbonization Coalition (PDC)—co-founded by AP4, CDP, Amundi, and UNEP FI in September 2014—enables pioneers in the decarbonization of portfolios to share their knowledge and best practices. When it was founded, PDC set a target of $100 billion in institutional investment decarbonization to be reached by the time of the Paris conference in December 2015. It was able to significantly surpass this target, with its 25 members claiming $600 billion of decarbonized investments out of $3.2 trillion of assets under management. For more information, see http://unepfi.org/pdc/ and Top1000Funds (2015). Another example is the "Aiming for A" coalition—a group representing institutional investors—which engages carbon-intensive companies to "measure and manage their carbon emissions and move to a low-carbon economy."
6. For more information on stranded assets, see Appendix B.
7. The carbon footprint of a company refers to its annualized GHG emissions relative to a financial metric (e.g., revenue or sales) or a relevant activity metric (e.g., units produced). For further details, see the pertinent discussion later in the article as well as Appendix C.
8. See Gartner, Inc. (2016).
9. Later in the article, we report the performance results of the "decarbonized" S&P 500 and MSCI Europe indexes.
10. The mechanics that affect the relationship of carbon legislation, technological changes, and financial returns are obviously complex and not straightforward. But the purpose of decarbonized indexes is to circumvent these difficulties by focusing on an area with somewhat less uncertainty: the companies most exposed to carbon risk. Later in the article, we delve into further details.
11. To explore the links between portfolio decarbonization and the incentives it gives to companies to rechannel their investments and lower their carbon footprint, see http://unepfi.org/pdc/wp-content/.
12. Koch and Bassen (2013) estimated an "equity value at risk from carbon" for European electric utilities, which is driven by their fossil fuel mix, and showed that a filter on companies with a high carbon-specific risk reduces the exposure to global carbon risk without otherwise affecting the risk–return performance of an equity portfolio.
13. See "Energy and Carbon—Managing the Risks," ExxonMobil report (March 2014).
14. These are mostly environmental, social, and governance (ESG) analysts, who until recently were largely segregated from mainstream equity analyst teams and whose audience consists predominantly of ethical investors.
15. HSBC is a notable exception, with its early integrated analysis of the materiality of carbon risk in the oil and gas as well as coal industries (HSBC 2008). Since then, the Carbon Tracker Initiative has been instrumental in raising awareness of stranded asset issues, and energy-focused analysts are increasingly and consistently integrating carbon-related risk into their analyses (see, e.g., HSBC 2012; Lewis 2014).
16. A multisector generalization of this optimization problem can break down the first set of constraints into companies that are excluded on the basis of their poor ranking in carbon intensity across all sectors, as well as companies that are excluded within each sector on the basis of either their poor carbon intensity score or high stranded assets relative to other companies in their sector.
17. Unless noted otherwise, tracking error is calculated *ex ante*.
18. This level of outperformance over such a time frame is hypothetical and for illustrative purposes only. Although we hope that a scenario of radical climate risk mitigation policy measures is possible in the near future, global climate policy implementation and its potential impact on equity valuation understandably remain a very speculative exercise.
19. In this respect, it is worth mentioning that Veolia and Danone now include carbon footprint improvement targets in their executive compensation contracts.
20. An interesting example of such a mechanism is the JPX-Nikkei Index 400, a new index based on both standard quantitative criteria (e.g., return on equity, operating profit, and market value) and more innovative qualitative criteria (e.g., a governance requirement of at least two independent outside directors). Launched with the support of the giant Japanese pension fund GPIF (Government Pension Investment Fund) to foster better corporate performance, the JPX-Nikkei 400 was quickly dubbed the "shame index." It is now carefully scrutinized by analysts, and companies are taking inclusion in the index more and more seriously.
21. For a discussion of the relationship between sustainability investments and shareholder value creation, see Khan, Serafeim, and Yoon (2015).
22. For an attempt at comparing different providers' results within a given universe, see http://www.iigcc.org/events/event/50-shades-of-green-carbon-foot-print-workshop. The differences that emerged came from different estimation models. But professionals agree that the measures are globally converging toward a much-improved harmonization.
23. For 60% of the companies in the MSCI World Index, at least 75% of emissions are from supply chains (Trucost 2013).
24. Moreover, most modern optimization techniques use factor exposures and correlations to reduce tracking error risk from such known systematic factors as volatility, small cap, and beta; they would therefore increase the weights on high-volatility/low-carbon stocks to replace high-volatility/high-carbon stocks.
25. Index and ETF investments represent a growing share of total investment products, amounting to almost 14% of total assets under management, with a year-over-year growth rate of 10% from 2013 to 2014.
26. Beyond the $11 trillion in index funds, asset owners that are members of CDP represent an asset base as high as $95 trillion (see CDP.net).
27. When AP4 started investing in 2012, a 48% reduction in carbon footprint was achieved.

28. For an early analysis of carbon-efficient indexes in emerging markets, see Banerjee (2010).
29. The criteria for excluding a stock from the index are straightforward: First, companies with the highest emissions intensity (as measured by GHG emissions/sales) are excluded, with a limit on cumulative sector weight exclusion of no more than 30%. Second, the largest owners of carbon reserves per dollar of market capitalization are excluded until the carbon reserves intensity of the index is reduced by at least 50%.
30. Our performance attribution analysis was for the MSCI Europe Low Carbon Leaders Index from 7 November 2014 to 29 January 2016.
31. During the same period, the MSCI North America Low Carbon Leaders Index outperformed the MSCI North America Index by 121 bps.
32. The allocation effect measures whether the choice of sector allocation led to a positive or negative contribution. All else being equal, overweighting outperforming sectors leads to a positive allocation effect.
33. The selection effect measures within each sector whether the portfolio manager selected the outperforming or underperforming stocks.
34. The Global Industry Classification Standard is an industry taxonomy consisting of 10 sectors, 24 industry groups, 67 industries, and 156 sub-industries.
35. Notable exceptions include the French government, which took a lead role ahead of the Paris conference in mobilizing the financial sector by requiring institutional investors to report on their climate risk exposure. A handful of central banks have also been instrumental in raising awareness of the possible hazards of climate change regulations and the potential mobilization of financial institutions. Significant contributions include the People's Bank of China and UNEP Inquiry (2015) report "Establishing China's Green Financial System" and the Bank of England's ongoing prudential review of climate-related risks to the financial sector.
36. See Article 173 of *Projet de loi relative à la transition énergétique pour la croissance verte*: "La prise en compte de l'exposition aux risques climatiques, notamment la mesure des émissions de gaz à effet de serre associées aux actifs détenus, ainsi que la contribution au respect de l'objectif international de limitation du réchauffement climatique et à l'atteinte des objectifs de la transition énergétique et écologique, figurent parmi les informations relevant de la prise en compte d'objectifs environnementaux." // "The information relative to the consideration of environmental objectives includes: the exposure to climate-related risks, including the GHG emissions associated with assets owned, and the contribution to the international goal of limiting global warming and to the achievement of the objectives of the energy and ecological transition."
37. Prominent voices in the business community have expressed their concern that the debate over climate policy has become too politicized. Also, in June 2014, the US Environmental Protection Agency unveiled an ambitious program calling for deep cuts in carbon emissions from existing power plants, with a 30% national target by 2030—which is equivalent to 730 million tons of carbon emission reductions, or about two-thirds of the nation's passenger vehicle annual emissions.
38. See "The Paris Agreement Marks an Unprecedented Political Recognition of the Risks of Climate Change," *Economist* (12 December 2015).
39. See https://www.whitehouse.gov/the-press-office/2014/11/11/fact-sheet-us-china-joint-announcement-climate-change-and-clean-energy-c.
40. The interregional ETS covering the Beijing, Tianjin, and Hebei Provinces was under discussion in February 2016, at the time of writing. In addition, the National Development and Reform Committee issued a paper in February 2016 that set up an agenda to ensure the establishment of a national ETS in 2017. We note that following China's lead, a movement is underway to move away from existing oil and gas subsidies. According to a recent IMF study by Coady, Parry, Sears, and Shang (2015), global subsidies for fossil fuels were estimated to be $333 billion in 2015.
41. The current price level is far below $30, with average carbon prices ranging from the lowest at RMB9.00/$tCO_2e$ in Shanghai to the highest at RMB44.4/$tCO_2e$ in Shenzhen, with others traded at RMB35 in Beijing, RMB23 in Tianjin, RMB22 in Hubei, RMB13 in Chongqing, and RMB14 in Guangdong (as of 4 March 2016); around EUR4.96/$CO_2e$ (as of 7 March 2016) in Europe; and $7.5/$CO_2e$ under the Regional Greenhouse Gas Initiative in the United States (as of 2 February 2016).
42. Pope Francis's *Laudato Si'* encyclical (published in May 2015), Muslim scholars' *Islamic Declaration on Global Climate Change* (published in August 2015), and US rabbis' *Rabbinic Letter on the Climate Crisis* (released in May 2015) show that climate change has become a shared concern among religious authorities.
43. For a recent study on the risk of stranded assets, see Lewis (2014).
44. See ExxonMobil (2014); Shell followed with its "Open Letter on Stranded-Asset Risk" in May 2014.
45. See https://www.greenbiz.com/blog/2013/08/12/hybrid-lcas-help-companies-size-scope-3-emissions.
46. For a thorough review of Barra equity risk modeling, see MSCI Barra (2007).

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# Climate Risks and Market Efficiency*

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**Abstract**

We investigate whether stock markets efficiently price risks brought on or exacerbated by climate change. We focus on drought, the most damaging natural disaster for crops and food-company cash flows. We show that prolonged drought in a country, measured by the Palmer Drought Severity Index (PDSI) from climate studies, forecasts both declines in profitability ratios and poor stock returns for food companies in that country. A portfolio short food stocks of countries in drought and long those of countries not in drought generates a 9.2% annualized return from 1985 to 2015. This excess predictability is larger in countries having little history of droughts prior to the 1980s. Our findings support regulatory concerns of markets inexperienced with climate change underreacting to such risks and calls for disclosing corporate exposures.

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# 1 Introduction

Regulators are increasingly worried about the extent to which stock markets efficiently price climate change risks. Most notably, Mark Carney, the head of the Bank of England, recently linked these risks to financial stability (Carney (2015)). Such risks include energy corporations' exposure to carbon assets, which might be affected by future carbon prices or taxes. This so-called "stranded asset issue" has attracted the most discussion in regulatory and market circles at this point.[1] But climate change risks need not be so narrowly confined to carbon exposures. Vulnerability of corporations' production processes to natural disasters such as prolonged drought, which is likely to be amplified by climate change and the focus of our paper, is also important and can impose significant damage to corporate profits (see, e.g., Trenberth, Dai, van der Schrier, Jones, Barichivich, Briffa, and Sheffield (2014)).[2] In particular, regulators are concerned that markets have had little experience in dealing with such risks and might not pay enough attention and underreact to them as a result. Various regulatory bodies are promoting both voluntary and mandatory disclosures of corporations' climate risk exposures to address this issue.[3] However, there is little systematic research on the topic of climate risks and market efficiency up to this point.

We tackle this important question by focusing on the efficiency with which the stock prices of food companies respond to information about drought. Our focus on drought has a few different motivations. First, among the natural disasters that might be amplified by climate change, including drought, heat waves, floods, and cold spells, drought is considered one of the most devastating for economic production. A recent study (Lesk, Rowhani, and Ramankutty (2016)) looks at 2,800 weather disasters along with data on 16 different cereals grown in over 100 countries. They found that droughts cut a country's crop production by ten percent, heat waves

[1] See, e.g., "The elephant in the atmosphere," *Economist* July 19th, 2014.

[2] Another recent study by Williams, Seager, Abatzoglou, Cook, Smerdon, and Cook (2015) argues that global warming caused by human emissions has most likely intensified the drought in California by 15 to 20 percent.

[3] Examples of the more prominent voluntary disclosure initiatives include the Carbon Standards Disclosure Board, Integrated Reporting, the Carbon Disclosure Project, and the UN Principles for Responsible Investment.

by nine percent, but floods and cold spells had no effects on agricultural production levels.[4]

Second, a number of water engineering studies find that the food industry is the most reliant on water and hence the most sensitive to drought risk (Blackhurst, Hendrickson, and Vidal (2010)).[5] Indeed, there are an increasing number of reports of dramatic short-falls in earnings and compressed profitability ratios or margins due to drought for agribusinesses such as Cargill, Tyson Foods, and Campbell Soup.[6] For instance, Tyson Foods, a large multinational food processor, suffered steep profit drops due to the 2012 droughts in the main US agricultural states.[7]

Third, drought is easy to quantify by using the Palmer Drought Severity Index (PDSI), a widely used monthly metric in climate studies (Palmer (1965)). PDSI combines information such as temperature and the amount of moisture in the soil to create an index that does an accurate job of measuring drought intensity. Less positive values of PDSI are associated with more drought-like conditions. While not perfect, it is by far the most widely used in climate studies and the most readily available (Alley (1984)). Globally, it is available at the country level and goes back to the 1870s. This data is available in the US by state going back to the 1890s.

We study the relationship between climate risks and stock markets in an international sample of countries. The time series of stock markets for most countries are much shorter than that of the US. The earliest start date is 1975 and much of our sample only begins in the early 1990s.[8] We consider a sample of around 30 countries (including the US) with at least 10 food

[4]This is distinct from whether a warming climate is good or bad for crop yields (Mendelsohn, Nordhaus, and Shaw (1994)).

[5]The other major industry perhaps comparable to food companies in terms of water use is the power industry, but utilities are regulated and their profitability is largely unaffected by drought. The only other industry that also consumes a significant amount of water in its production process is the automative industry but its reliance on water is much less than that of the food industry.

[6]See "Feeding Ourselves Thirsty: How the Food Sector is Managing Global Water Risks", *A Ceres Report*, May 2015.

[7]See, e.g., "Meat Stocks Fall Tyson 8% As Drought Hits Earnings", *Investor's Business Daily* August 6, 2012. Grain price is the main input cost for raising livestocks. The higher grain prices squeezed profit margins. Additionally, extreme reductions in output can also hurt food businesses relying on turnover as well as margins.

[8]However, the data for international markets includes 2015 in contrast to the US data which is only available

companies during the entire period. In other words, our sample of countries are those with significant agricultural sectors. In robustness checks, we also separately analyze the US time series going back to 1927.

Our dependent variable of interests are the change in profitability ratios and the returns of the FOOD industry of each country.[9] FOOD combines food processing and agricultural companies. We focus on this aggregated industry portfolio as opposed to the finer industry classifications, which separate FOOD into smaller components. The reason is that drought is likely to have a direct impact on the profits of both food processing and agricultural companies.[10]

First, we show that from roughly 1900 to now, when global temperatures exhibit a prominent increasing trend (see Figure 4), there is an increasing trend toward droughts across the countries in our sample. Climate studies typically focus on all places in the world, while we focus on just the countries that have large enough food industries. While not the focus of our paper, we provide evidence consistent with previous climate studies that suggest an association between global warming and droughts. It supports the premise behind our paper that drought is a channel through which a warming climate might impact the global economies and stock markets.

Second, we then show that droughts are problematic for food industry profitability, consistent with the anecdotes described earlier. Droughts are considered economically worrisome should the PDSI be elevated for a prolonged period. For short durations, drought has a negligible effect as production can adjust. It might even be helpful depending on when it occurs (before or after a harvest). But long periods of drought, running into years have negative consequences. Our main predictor variable will be a moving average of these PDSI series, averaged over horizons of anywhere from 12 months to 36 months (PDSI12m to PDSI36m). As our baseline, we focus on a 36-month moving average (PDSI36m). We pool together all the countries to run our

up to 2014.

[9]We use Datastream industry classifications for the international sample excluding the US. For the US, we use the Fama and French (1997) 17-industry classification.

[10]Drought also creates water shortages which impact agricultural companies. While some of these cost increases can be temporarily passed onto consumers, prolonged drought ultimately also severely impacts agriculture as well.

regressions and control for country fixed effects. We find that this moving average of the PDSI index strongly predicts changes in FOOD industry profitability ratios, as measured by industry net income over assets: low or negative values of PDSI for the previous 36 months are correlated with low or negative changes in food industry profitability ratios over the next 12 months.

Third, we then examine the relationship between this moving-average PDSI and food industry expected returns. Under the efficient market null hypothesis, we expect the coefficient on our independent variable of interest, the moving-average PDSI, to be zero (assuming there is no risk premium for drought) or negative (if there is a risk premium for drought).[11] Yet to the extent that the market is underreacting to drought risk, as hypothesized by regulators, we expect the coefficient on the moving-average PDSI to be positive.

To see which is the case, we can construct a portfolio strategy that conditions on the PDSI information and consider the returns associated with this strategy. A strategy that longs the food industry portfolios of countries with high PDSI and shorts those with low PDSI in any given month and holds for one year generates an excess return of 0.77% per month with a $t$-statistic of 2.74. The Sharpe Ratio is 0.50.[12] The results are similar whether we adjust the return spread using the global Sharpe (1964) CAPM, Fama and French (1993) three factor or Carhart (1997) four factor model as our long/short portfolio has little exposure to these common factors. These results support that there is underreaction in international markets since markets with drought do worst in the future than markets without drought. This underreaction is also symmetric with respect to negative and positive values of PDSI across countries.[13]

Another way to get at this same result is to use excess return predictability regressions. The portfolio results make clear that the predictability concerns food industry specific profitability and returns. As such, we extract the food industry specific returns in two ways. The first is that

[11] A lower PDSI level is associated with more uncertainty regarding future cash flows and hence should compensate investors with higher expected returns.

[12] Our portfolio analysis in contrast to our international sample regressions includes the US food stocks for purposes of investability.

[13] Our study assumes that even if the PDSI metric is not widely used until the 1970s producers and investors have always had access to temperature and other related information to form expectations of drought severity.

we control in our predictive regressions, where the dependent variable is the FOOD portfolio return net of the risk-free rate, for a host of variables that are known to predict aggregate market returns. The second is that we can calculate the market portfolio net of FOOD stocks and then subtract from the FOOD returns the returns of the market portfolio purged of the FOOD sector. International cross-country regressions with country fixed effects yield a similar conclusion as our cross-country portfolio strategy.

Fourth, we can exploit exogenous variation in historical PDSI across countries to get at the experience mechanism behind regulatory concerns about market underreaction to climate change risks. Some countries in our sample have low PDSI scores in the past, while others have very high PDSI scores and little history with droughts. The main reason why regulators are worried that markets might be underreacting to climate change risks is that climate change represents a new phenomenon that markets do not have experience with. This scenario corresponds to the countries in our sample with high past PDSI scores. We find that the degree of underreaction for this subset of countries is more than twice that of other countries, consistent with regulatory concerns. Moreover, this underreaction is particularly strong for droughts or dry climate among these high past PDSI score countries.

We also conduct a series of robustness exercises, including separately analyzing the US sample where we have a long time series from 1927 to 2014 and where we have more detailed data on droughts. We can construct a measure of drought for the US by aggregating state-level drought measures for the top agricultural producing states. We find similar results as when we use a coarser measure of PDSI for the US, providing comfort that our international results are sensible. We also consider a number of extensions and robustness checks of our baseline specification, including (1) looking at short-horizon return predictability (1-month, 3-month and 6-month), and (2) seeing if our $t$-statistics are inflated due to persistent predictor variables since our PDSI measure is highly persistent (close to a random walk) by implementing the Campbell and Yogo (2006) test. We also show that our results are specific to the FOOD industry and this excess predictability is not apparent across other industries in the US.

Our findings are similar in spirit to the recent literature on attention and return predictability (see, e.g., Hong, Torous, and Valkanov (2007), DellaVigna and Pollet (2007), Cohen and Frazzini (2008)), whereby the market underreacts to many types of value relevant information such as industry news, demographic shifts, and upstream-downstream relationships. Even for these types of obviously relevant news, the market can be inattentive. Our analysis points to a similar underreaction to information on climate risks. In such a world, disclosures properly constructed can improve market efficiency (Hirshleifer and Teoh (2003)), supporting recent proposals by central banks and regulators on this issue.

Climate risk variables can be quantified and have been used successfully in the pricing of weather derivatives.[14] However, the broader question of the extent to which information on such risks is appropriately discounted in stock markets has not received much attention to date. Our study of climate risks and market efficiency helps characterize the nature of the potential inefficiencies, which might inform regulatory responses and be useful for practitioners interested in the construction of quantitative risk-management models (Shiller (1994)).

There is a large literature on the economic analysis of how to design government policies to deal with climate change (see, e.g., Stern (2007), Nordhaus (1994)), be it through emissions trading (Montgomery (1972)) or taxes (Golosov, Hassler, Krusell, and Tsyvinski (2014)). In contrast, our analysis highlights the role of markets in potentially mitigating the risks brought on or exacerbated by climate change. Understanding the role of financial markets in pricing climate risks is a natural one, though work is limited at this point with some notable exceptions. Bansal, Kiku, and Ochoa (2014) argue that long-run climate risks as captured by temperature are priced into the market. Daniel, Litterman, and Wagner (2015) and Giglio, Maggiori, Stroebel, and Weber (2015) show how stock and real estate markets might help guide government policies assuming markets efficiently incorporate such climate risks. Our analysis suggests that such

[14] See, e.g., Roll (1984), Campbell and Diebold (2005).

climate risk information, at least when it comes to natural disasters, is not efficiently priced.

# 2 Data, Variables and Summary Statistics

## 2.1 International Drought Measures

Our data for the global (excluding the US) Palmer Drought Severity index comes from Dai, Trenberth, and Qian (2004). The index is a measurement of drought intensity based on a supply-and-demand model of soil moisture developed by Palmer (1965). The index takes into account not only temperature and the amount of moisture in the soil, but also hard-to-calibrate factors such as evapotranspiration and recharge rates. It is a widely used metric in climate studies. The index grades drought and moisture conditions in the following scale: -4 and below is extreme drought, -3.9 to -3 is severe drought, -2.9 to -2 is moderate drought, -1.9 to 1.9 is mid-range (normal), 2 to 2.9 is moderately moist, 3 to 3.9 is very moist, 4 and above is extremely moist. The extreme values for PDSI are -10 and 10.

The data consists of the monthly PDSI over global land areas computed using observed or model monthly surface air temperature and precipitation. The global PDSI dataset is structured in terms of longitude and latitude coordinates and we extract each country's PDSI based on that country's geographic coordinates. The sample period of global PDSI is from January 1870 to December 2014.

We present the evolution of droughts in a number of countries from our international sample. Figure 1 plots the time series of monthly PDSI values for several countries, including Australia, India, Russia, Japan and Israel. The sample starts from 1927 and ends in 2014. We also identify some of the most severe drought episodes in the history, which correspond closely to very negative values of PDSI in the data. For example, the Millennium drought in Australia started from 1997 and continued for more than 10 years, which is recognized as the worst on record since settlement in Australia.

Since droughts that last for a few months are unlikely to do any harm to the food industry (and under certain circumstances might even be helpful depending on whether it occurs before or after a harvest), we consider a moving average of these monthly drought measures, where the average is over years. As we discussed in the Introduction, prolonged droughts that last years are likely to substantially impair food industry cashflows and hence their stock prices. The idea is that by shortening or lengthening the window over which we do the average, we pick up more prolonged periods of drought. We will focus on the baseline 36 months moving average of PDSI (PDSI36m) for our countries. In robustness checks, we also consider shorter horizon moving averages, ranging from 12 months to 30 months.

To see why smoothing over long periods makes sense, consider that the monthly Palmer Drought Severity Index (PDSI) in month $t$ is computed based on the following equation:

$$\mathrm{PDSI}_t = 0.897\,\mathrm{PDSI}_{t-1} + \frac{1}{3}Z_t, \tag{2.1}$$

where $\mathrm{PDSI}_t$ is the current PDSI in month $t$, $\mathrm{PDSI}_{t-1}$ is the PDSI in the previous month $t-1$, and $Z_t$ is called the "moisture anomaly index", which can be thought of as the moisture "shock" in month $t$.[15] The initial monthly PDSI value at $(t = 0)$ in a spell of dry or wet weather is

$$\mathrm{PDSI}_0 = \frac{1}{3}Z_0. \tag{2.2}$$

Hence the PDSI in a month depends on both the current-month moisture anomaly $Z_t$ and the previous-month PDSI value ($\mathrm{PDSI}_{t-1}$). The value of $\mathrm{PDSI}_t$ in equation (2.1) is not a weighted average of $\mathrm{PDSI}_{t-1}$ and $Z_t$, since the sum of the weights 0.897 and 1/3 is strictly greater than 1.[16] This means the weight (1/3) on the current moisture anomaly is too large, so that the monthly PDSI values respond too rapidly to monthly moisture shocks. This is one reason for

[15] See, e.g., Alley (1984) and Karl (1986).

[16] If the weight on $Z_t$ were $1 - 0.897 = 0.103$, then (2.1) would have been an exponentially weighted moving average model.

why there are such large monthly fluctuations in PDSI in the graphs we showed before. As a result, practitioners often advocate smoothing by averaging over longer periods to get a more sensible result for a prolonged drought, which is what we do in the paper.[17]

Panel B of Table 2 shows the summary statistics for various drought measures in our international sample. Our main drought measure PDSI36m has a mean of -0.22 and a standard deviation of 1.13. The mean of PDSI measured over various horizons are quite similar and as expected, the standard deviation is smaller when PDSI is averaged over longer horizons.

## 2.2 International Stock Market Data

We obtain firm-level stock returns and accounting variables for a broad cross section of countries (except for the U.S.) from Datastream and Worldscope, respectively. The sample includes live as well as dead stocks, ensuring that the data are free of survivorship bias. We compute the stock returns in local currency using the return index (which includes dividends) supplied by Datastream and convert them to U.S. dollar returns using the conversion function built into Datastream. In some of our tests, we also use price-to-book ratio which is directly available from Worldscope database. Inflation rate for international countries is from the World Bank database.

We apply the following sequence of filters that are derived from the extensive data investigations by Ince and Porter (2006), Griffin, Kelly, and Nardari (2010) and Hou, Karolyi, and Kho (2011) as follows. First, we require that firms selected for each country are domestically incorporated based on their home country information (GEOGC). A single exchange with the largest number of listed stocks is chosen for most countries, whereas multiple exchanges are used for China (Shanghai and Shenzhen) and Japan (Tokyo and Osaka). We eliminate non-

[17]Another reason for smoothing is that the PDSI is not a real time measure but potentially delayed by a month or two so depending on whether climate models can accurately verify that a drought has ended or began. In practice, there is little difference between different versions of PDSI (which is available for the US and called PDMI).

common stocks such as preferred stocks, warrants, REITs, and ADRs. A cross-listed stock is included only in its home country sample. If a stock has multiple share classes, only the primary class is included. For example, we include only A-shares in the Chinese stock market and only bearer-shares in the Swiss stock market.

To filter out suspicious stock returns, we set returns to missing for stocks that rises by 300% or more within a month and drops by 50% or more in the following month (or falls and subsequently rises). We also treat returns as missing for stocks that rise by more than 1,000% within a month. Finally, in each month for each country, we winsorize returns at the 1st and the 99th percentiles, to reduce the impact of outliers on our results (McLean, Pontiff, and Watanabe (2009)). Datastream classifies industries according to Industrial Classification Benchmark (ICB). The food portfolio includes stocks in the food & beverage supersector.[18] Food portfolio returns are individual stock returns weighted by lagged market capitalization. In addition, to meaningfully identify the drought impact in our international sample, we further exclude countries with less than 10 stocks in the food portfolio in its entire time series. The final sample includes 30 countries, among which 15 are developed countries and 15 are developing countries.

Table 1 Panel A reports the summary statistics of our international sample. The average number of stocks in the food industry varies considerably across countries, from 7 in Finland to 108 in India. We also report the median firm market capitalization in the food industry within each country as of the end of 2013 in millions of U.S. dollars, as well as the mean and standard deviation of the monthly PDSI values for each country.

As we can also see from Panel A, the time series of stock returns for international countries are much shorter than for the US. As a result, we cannot conduct an individual time series exercise for each country. Instead, we will pool together all the international monthly observations and

[18]ICB Supersector Level classifies industries as follows: Oil & Gas, Chemicals, Basic Resources, Construction & Materials, Industrial Goods & Services, Automobiles & Parts, Food & Beverage, Personal & Household Goods, Health Care, Retail, Media, Travel & Leisure, Telecommunications, Utilities, Banks, Insurance, Real Estate, Financial Services, Equity/Non-Equity Investment Instruments, and Technology.

run a pooled regression. We control for country fixed effects to isolate the time series return predictability of lagged PDSI from the cross-country effect.

Panel B of Table 1 reports the summary statistics for the control variables. The market predictor variables we have for the international sample include the lagged 12-month returns of the market (MRET12), the lagged inflation rate of the country (INF12), the dividend-to-price ratio of the country market index (DP12) and the market volatility (MVOL12). Food industry-specific controls include the price-to-book ratio of the food industry stocks (FOODPB12) and the 12-month food industry return (FOODRET12m). The mean annual market return is 7.98% with a standard deviation of 30.03%. The mean annual inflation rate is 7.32%, annual dividend-to-price ratio is 2.98% and the mean annual market volatility is 23.12%. The mean price-to-book ratio for the food stocks is 2.56.

Finally, we report the summary statistics for the international FOOD industry portfolios return in Panel C of Table 1. The mean 12-month food industry return is 12.86% with a standard deviation of 41.30%. We also report the change in the food industry profitability ratio in Panel C. The change in the food industry profitability ratio in year $t$ is defined as $CP_t = NI_t/A_t - NI_{t-1}/A_{t-1}$, where $NI$ is the food industry net income and $A$ is the food industry total asset. The food industry net income and total asset are obtained respectively by aggregating the net income and the total asset of individual firms within the food industry. The cashflow variable CP has a median of -.01% and a standard deviation of 3.34%.

## 2.3 US Drought Measures

Our PDSI data for the US comes from the National Centers for Environmental Information (NCEI) of the US National Oceanic and Atmospheric Administration (NOAA). The PDSI is updated monthly on the NOAA's website, and the index value extends back to January 1895. We obtain the monthly PDSI data of all 48 contiguous states in the US (excluding Alaska and Hawaii because there is no data) from January 1927 to December 2014 as well as the aggregated

US drought measure produced by US NOAA (PDSIUSA). PDSIUSA is essentially a land-area weighted average of the PDSI values from all climate divisions in the US.

Figure 2 illustrates the historical evolution of this drought measure from January 1927 to December 2014, with its value shown on the vertical axis. The PDSIUSA measure identifies some of the most recognizable droughts in the US history. For example, we can see the infamous "Dust Bowl" period of prolonged droughts in the 1930s, and an extended period of severe droughts in the 1950s, with the PDSI value falling frequently below -2 and even breaking -8. From the 1960s to the 1980s, the US experienced several spells of relatively shorter yet significant droughts. Since the turn of the 21st century, the US has been bombarded by various droughts that include the current ongoing drought in California. This might suggest that the climate risk due to global warming has intensified, as the droughts in the 1930s and 1950s could be (at least) partly attributed to bad soil management and exploitative farming techniques.

Because not every state in the US has significant croplands or an agricultural sector, we construct our own aggregated measures of drought for the US. The first one, PDSIWA, is the weighted average of the PDSI values from the top 10 food-producing states (in terms of gross cash income of the state's farm sector), using cropland area as weight. Data for both the cropland area and the gross cash income of the farm sector in each state are obtainable from the US Department of Agriculture. The top 10 food-producing states are (in alphabetic order): California, Illinois, Indiana, Iowa, Kansas, Minnesota, North Carolina, Nebraska, Texas, Wisconsin. This is our main drought measure in our robustness checks section.

Our second aggregate measure (PDSIASWA) is the weighted average of the PDSI values from all 48 contiguous states based on cropland area. We focus on the top 10 food producing states but a number of states have some croplands, and so we also consider this measure. Our third aggregate measure is PDSIASCAWA, which is simply the weighted average PDSI of the 48 states using gross cash income of the farm sector as weights.

For our main baseline measure PDSIWA, using the top 10 states, we consider moving averages from 12 months to 36 months (e.g. PDSIWA12m to PDSIWA36m). For our other three drought measures, we will just consider a 36-month moving average. In theory, we could average over much longer periods of time. The trade-off is that we then lose time series variation in our drought measure. As such, we consider 36-month (a 3 year drought) as a reasonable length to focus on and assess the sensitivity of our findings to differing lengths.

Panel A of Table 2 shows the summary statistics for our various drought measures. Our main drought measure PDSIWA36m has a mean of 0.17 and a standard deviation of 1.26. Moreover, the four drought measures are all positively correlated, as demonstrated in Panel D of Table 2. The PDSIUSA36m measure is less correlated not surprisingly with our other three measures since it weighs by land mass as opposed to cropland. Nonetheless, the correlation of PDSIUSA36m with PDSIWA36m is 0.88. As such we expect our baseline measure to be a better predictor of food stock returns than the PDSIUSA36m measure but this standard NOAA measure ought to still have information about food stock returns.

## 2.4 US Stock Market Data

Our second set of data comes from Kenneth French's website.[19] It contains the monthly value-weighted returns for the Fama-French 17 industry portfolios from January 1927 to December 2014.[20] Our interest is in the FOOD industry, which includes agriculture firms, food products and food processing firms, candy and soda-producing firms, beer and liquor-producing firms, as well as related wholesale firms.

We take the raw continuously compounded monthly industry returns and net them off the one-month T-bill return to obtain the monthly excess returns for all industries. We denote

[19] http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

[20] The 17 industries are: (1) Food, (2) Mining and Minerals, (3) Oil and Petroleum Products, (4) Textiles, Apparel and Footware, (5) Consumer Durables, (6) Chemicals, (7) Drugs, Soap, Perfumes, Tobacco, (8) Construction and Construction Materials, (9) Steel Works, (10) Fabricated Products, (11) Machinery and Business Equipment, (12) Automobiles, (13) Transportation, (14) Utilities, (15) Retail Stores, (16) Banks, Insurance Companies and Other Financials, (17) Other.

the food industry excess return by FOODRET. We then take the FOODRET at 1-month, 3-month, 6-month, and 12-month frequencies. Panel B of Table 2 shows the summary statistics for FOODRET. Our baseline dependent variable of interest, FOODRET12m, has a mean of 7.16% and a standard deviation of 17.45%.

In addition to FOODRET12m, we create a FOOD industry return that nets the market portfolio. The problem is that the FOOD industry is also a big part of the market. As such, we create a market portfolio excluding the food stocks and then subtract the returns of this alternate market portfolio from the FOOD industry returns. We call this variable FOODXMRET12m. It has a mean of 1% and a standard deviation of 11.75%. The cashflow variable CP has a mean of -0.03% and a standard deviation of 0.77%.

Our second data set also has the value-weighted average book-to-market ratio for each of the industries observed at annual frequency. We take the log value for all the industry book-to-market ratios, and we denote this value for the food industry by FOODBM. Moreover, it has the monthly market excess returns (the CRSP value-weighted market portfolio excess return over the Treasury-bill), and we denote this variable by MRET.

Our third set of data comes from Amit Goyal's website.[21] It contains the monthly data for all other market predictor variables that we will use. It includes the following variables: the inflation rate (INF), the log value of the dividend-price ratio of the S&P 500 index (DP), the volatility of the S&P 500 index (MVOL), the net equity expansion of the NYSE stocks (NTIS), the difference between BAA and AAA-rated corporate bond yields (DSPR), and the difference between the long term yield on government bonds and the Treasury-bill (TSPR). Panel C of Table 2 provides the summary statistics for all of our predictor variables (annualized and hence the appending of 12 (denoting 12-month) to the variable names) as well MRET12 and FOODBM12. We can see that the summary statistics of our variables are consistent with those in the literature. For instance, our market excess return MRET12 has a mean of 6%

[21] `http://www.hec.unil.ch/agoyal/docs/PredictorData2014.xlsx`

and a standard deviation of 20% (see, e.g., Fama and French (2015)). Moreover, our annual inflation is 2.94% that is in line with the long-run inflation rate in the US. Panel D reports the correlation matrix for these variables.

In Figure 3, we plot the time series of our independent variable of interest (PDSIWA36m) along with one of our dependent variable of interest (the future 12-month return of the food industry net of the market return, i.e. FOODXMRET12m). To the extent that the market is not efficiently pricing in the information about prolonged droughts, we expect a positive correlation between these two time series. This is indeed what we see. We have marked some of the main droughts in US history. Prolonged drought episodes are typically periods when future returns to the food portfolio is low. Similarly, periods when there is plentiful water (i.e. positive values of PDSI) are associated with higher than average returns to the food industry portfolio. As we will show in various ways below, the relationship between these two time series is positive and statistically significant.

## 2.5 Climate Change and Droughts

While not the focus of our paper, we briefly show here that for our sample of large FOOD producing countries, a warming climate since 1900 (see Figure 4) is associated with an increasing trend toward droughts. Let the PDSI variable in question be $PDSIvar$. The PDSI variable can be the monthly median PDSI value of the international countries (including the US), the lower quartile (20th percentile) value, or the upper quartile (75th percentile) value. We can estimate the trend in drought, along with allowing for potential changes in this trend during the latter part of our sample, by estimating the following regression:

$$PDSIvar_t = \alpha_0 + \beta_0 t + \beta_1 (t - \tau) D(t \geq \tau) + \varepsilon_t, \tag{2.3}$$

where $D(t \geq \tau)$ is a dummy variable that equals 1 if time $t$ is greater than or equal to January 1980 (198001), the break point. We choose 1980 as a natural breakpoint in trend because the global annual temperature anomaly measures (from Figure 4) typically take the 1950-1980 as the thirty-year average against which the anomaly in other time periods is measured. The coefficient $\beta_1$ captures the effect from the structural break in the time trend, i.e. the PDSI variable is trending at the speed of $\beta_0$ before 1980 but the speed rises to $\beta_0 + \beta_1$ after 1980.[22] We estimate this equation by allowing the error term $\varepsilon$ to be serially correlated and heteroskedastic, and in doing so we adjust the standard errors of the estimates by using Newey-West (1992) HAC standard errors.

The estimation results are reported in Table 3. In Panel A, we first estimate the trend without allowing for a break. We can see that the coefficient $\beta_0$ is negative for all three measures of PDSI. It is statistically significant for the 25th and 50th percentile PDSI. Panel B of Figure 5 plots the series of the 50th percentile PDSI and the fitted trend line. We can see a prominent downward trend in the median PDSI. In Panel B, we allow for a break in trend. We can see that the coefficient $\beta_1$, the effect from the structural break in the time trend, is negative for all of the PDSI variables but only statistically significant for the 25th percentile PDSI. To visualize this structural break in trend for the 25th percentile PDSI after 1980, we plot in Panel A of Figure 5 the time-series of monthly lower quartile of PDSI value of the international countries and the the fitted trend line that allows for a break after 1980. Overall, we provide evidence consistent

[22] However, we need to be careful before carrying out this structural break test for the deterministic time trend in $PDSIvar$ because potentially, $PDSIvar$ could be a unit root process. In other words, $PDSIvar$ could be a random walk with drift

$$PDSIvar_t = \theta + PDSIvar_{t-1} + \epsilon_t \quad \text{(difference stationary)}, \tag{2.4}$$

instead of the trend stationary process that we specified above. If this is the case, then our structural break test for the time trend would be invalid. Therefore, we need to rule out the possibility that $PDSIvar$ is a unit root process. To this end, we invoke the unit-root test of Zivot and Andrews (1992) that allows for a potential structural break in the intercept (constant) and/or the trend. This test is more appropriate than the traditional augmented Dicky-Fuller test (Dickey and Fuller (1979)) for unit root since potentially there can be a structural break, which would invalidate the augmented Dick-Fuller test. The null hypothesis of a unit root is rejected for all the PDSI variables at the 1% significance level. These results are available from the authors. Thus we can proceed with our time-trend structural break test.

with earlier climate studies that droughts have become worst over time, especially after 1980.

## 3 Droughts and Food Industry Profitability

We show how our drought measures impact the future profitability of the FOOD industry following the methodology set out in Fama and French (2000). The dependent variable is the future 1-year change in the food industry profitability ratio (CP) in each country. The key explanatory variable is the 36-month moving average of country-level PDSI values (PDSI36m).

We specify this PDSI-food return relation for a given country $i$ as the linear regression

$$\mathrm{CP}_{i,t} = \alpha_i + \beta_i \mathrm{PDSI36m}_{i,t-1} + \gamma_i' X_{i,t-1} + e_{i,t}, \tag{3.1}$$

where $\mathrm{CP}_{i,t}$ is the future change in the food industry profitability over the next 12 months for country $i$, $\mathrm{PDSI36m}_{i,t-1}$ is the moving average of PDSI over the previous 36 months and $X_{i,t-1}$ is a set of lagged predictors from the country's stock market.

To increase the power of our inferences in equation (3.1), we pool all countries together and estimate a panel regression that imposes the restriction

$$\beta_1 = \beta_2 = ... = \beta \tag{3.2}$$

$$\gamma_1 = \gamma_2 = ... = \gamma \tag{3.3}$$

across all countries, so that $\beta$ reflects only the contribution of within-country time variation in PDSI36m. The $\alpha_i$ in equation (3.1) corresponds to country fixed effects when the restrictions in (3.2) and (3.3) are imposed across all countries. When we combine equation (3.1), (3.2) and (3.3), the regression is a panel regression with country fixed effects

$$\mathrm{CP}_{i,t} = \alpha_i + \beta \mathrm{PDSI36m}_{i,t-1} + \gamma' X_{i,t-1} + e_{i,t}. \tag{3.4}$$

Given country fixed effects, the OLS estimate $\hat{\beta}$ from this panel regression reflects only time-series variations in PDSI36m and food sector change in profitatbility. $\hat{\beta}$ is a weighted-average of the slope estimates from pure time-series regressions (Pastor, Stambaugh, and Taylor (2014)). This weighting scheme places larger weights on the time-series slopes of countries with more observations as well as countries whose PDSI fluctuates more over time. Following Petersen (2009), we cluster the standard errors at both the country and month dimensions.

Our hypothesis is that low PDSI would predict low future change in profitability within each country, so it is essentially a time-series relation between lagged PDSI and future food industry profitability. The result is reported in Table 4. In column (1), we report the coefficients for the market control variables, including MRET12, DP12, INF12, and MVOL12. MVOL12 comes in with a statistically significant coefficient. In column (2), we also add as control variables the lagged CP measure, FOODRET12m, and FOODPB12. These are industry specific controls from the literature. In column (2), we find that high lagged CP measure forecasts decreasing food industry profitability over the next year.

The coefficient of interest is in column (3) where we find that PDSI36m attracts a coefficient of 0.14 with a $t$-statistic of 1.8. Drought is associated with a decline in the food industry profitability over the next year. A one standard deviation move in our drought measure results in a 0.16% fall in CP (the standard deviation of PDSI36m is 1.13). This is 5% of the standard deviation of CP, which is a substantial decrease.

In Figure 6, we show the scatterplot of the residual of CP generated from the predictive regression in column (2) and our drought measure. The univariate regression through the scatterplot has a coefficient of 0.08 with a $t$-statistic of 1.7. In sum, our global markets result provides additional evidence that climate risks, such as prolonged droughts, could negatively impact the profitability of the food and agricultural sector.

# 4 Cross-Country Portfolio Strategy Based on PDSI

In this section, we conduct a portfolio strategy test of market efficiency. We want to see if global markets are efficiently responding to drought information. To this end, we construct a trading strategy that is long the food portfolio in countries with high PDSI and short the food portfolio in countries with low PDSI in any given month. We expect this strategy to generate abnormal returns if markets indeed underreact to drought contained in the PDSI.

Our trading strategy is constructed as follows. To make the level of PDSI36m comparable across countries, we first standardize the PDSI36m by subtracting its mean and dividing by its standard deviation. We use the past 70 years of PDSI data to calculate a rolling mean and standard deviation of PDSI36m. This standardization uses only lagged drought information since we have long time series of drought for all countries. Every month, we sort the food-industry portfolios across all countries into quintiles based on the standardized PDSI36m (denoted as PDSI36m*) at the previous month. We then hold each portfolio for $K$ months (where $K$ can range anywhere from 1 month to 12 months) and returns are equally-weighted within each quintile portfolio. We follow Jegadeesh and Titman (1993) to construct the overlapping portfolios. For each quintile portfolio at month $t$, we have $K$ portfolios formed from month $t-1$ to $t-K$. Returns on the $K$ portfolios are then equally-weighted to get the average return for each quintile portfolio at month $t$. The quintile portfolios are rebalanced monthly as we replace $1/K$ fraction of the portfolio that have reached the end of its holding horizons. In addition to the mean portfolio returns, we also report portfolio alphas adjusted using global factor models.[23] Our sample starts from January 1985 when we have at least 10 countries to do the sorting exercise. The result is reported in Table 5.

In Panel A, we report the monthly mean excess returns and factor-adjusted alphas for quintile portfolios with a holding horizon of $K = 12$ months. The middle three portfolios are grouped

[23] The global market, size, book-to-market and momentum factors are the weighted average of the respective country-specific factors, where the weight is the lagged total market capitalization in that country.

together by equal weighting their respective returns. In the first column, we report the mean standardized PDSI36m for each quintile portfolio. By construction, mean PDSI36m* increases monotonically from low to high PDSI36m* countries. Interestingly, we see from column (2) that portfolio returns also increase from low to high PDSI36m* countries. The mean excess return for countries in the bottom quintile of PDSI36m* is 0.38% per month, and for countries in the top quintile, the number is 1.15%. The return spread for the long/short strategy is 0.77% per month and significant at 1% level (t=2.74). The row "Middle - Low" shows that the bottom portfolio underperform the middle portfolio by 0.33%, while the row "High - Middle" shows that the top quintile portfolio outperforms the middle by 0.44%. The difference between these two numbers is not significant (t=0.1). In the last column, we also report the portfolio alphas adjusted using a global Carhart (1997) four factor model. Our results are not affected as the long/short strategy generates a monthly alpha of 0.83% (t=2.87). In untabulated tables, we show that a value-weighted long/short portfolio using the lagged total market capitalization of the food sector in that country as weight generates a monthly excess return of 0.72% (t=1.95) and a four-factor alpha of 0.68% (t=1.82).[24]

In Panel B, we report the return spread as well as factor-adjusted alphas on this long/short portfolio with holding horizons varying from $K = 1$ month to $K = 12$ months. The mean excess returns are positive and significant across all holding horizons. Consistent with our time-series return predictability result, the return spread becomes more pronounced when we increase the holding horizon, indicating that it takes time for market to fully incorporate the information about drought into stock prices. For example, the mean monthly excess return on this long/short strategy for the 12-month holding horizon is 0.77%, with an annualized Sharpe ratio of 0.50. The return decreases to 0.74% when we only hold the portfolio for three months, and further decreases to 0.57% when the holding horizon is 1 month. The results are similar whether we adjust the return spread using a global Sharpe (1964) CAPM, Fama and French

[24]Such a value-weighted portfolio is dominated by the food sector from the US since the total market capitalization of the food industry is much larger in the US than in other countries.

(1993) three factor or Carhart (1997) four factor model as our long/short portfolio has little exposure to these common factors.

# 5 Droughts and Food Industry Excess Return Predictability

We now conduct an excess return predictability regression analog of our portfolio strategy above. We examine whether droughts forecast food stock returns in international markets.[25] In Table 6, we consider how PDSI averaged over 36 months predict future food industry returns. To increase the power of our test, we pool all countries together, and run a panel regression by including a country fixed effect. We specify this PDSI-food return relation for a given country $i$ as the linear regression

$$\text{FOODRET12m}_{i,t} = \alpha_i + \beta \text{PDSI36m}_{i,t-1} + \gamma' X_{i,t-1} + e_{i,t}. \tag{5.1}$$

Given country fixed effects, the OLS estimate $\hat{\beta}$ from this panel regression again reflects only time-series variations in PDSI36m and food sector returns. $\hat{\beta}$ is a weighted-average of the slope estimates from pure time-series regressions.

In column (1), the coefficient on MRET12 is statistically insignificant. The coefficient on INF12 is positive. A higher dividend-price ratio forecasts lower returns. Over this sample period, this variable is highly statistically significant. Lagged market volatility attracts a positive sign. The $R^2$ of this time series regression is 16.7%. As such, we believe that this expected return model for the market does an adequate job of explaining the systematic component of FOOD industry returns.

[25]For the international return predictability regressions, we include the US in the international sample. We will also do the return predictability for the US separately as we have a much longer US time-series sample of the return starting from 1927. But removing the US from the international sample does not change the main conclusion at all. This result is available from the authors.

In column (2), we add in two FOOD industry specific variables in the form of the lagged past 12-month FOOD industry returns (FOODRET12m) and the book-to-market ratio of the FOOD industry portfolio (FOOBM12). These FOOD industry specific return predictors are motivated by momentum or positive serial correlation in industry portfolios (Moskowitz and Grinblatt (1999), Hong, Torous, and Valkanov (2007)) and the potential conditioning information in the cost of equity by industries (Fama and French (1997)). Both variables come in with the expected signs. They increase the $R^2$ from 16.7% in column (1) to 19.5% in column (2).

In column (3), we then add in our variable of interest PDSI36m and find that it has significant incremental forecasting power for the future returns of the food portfolio. The coefficient estimate of PDSI36m is 3.48 with a $t$-statistic of 2.26, which is significant at the 5% statistical significance level. It increases the $R^2$ from 19.5% in column (2) to 21.3% in column (3). Moreover, notice that the coefficients in front of the previous market and industry predictor variables from columns (1) and (2) are largely unchanged. This is to be expected from our discussion regarding the contemporaneous correlations of the PDSI36m with the standard market and industry predictor variables. Our variable of interest is not significantly correlated with these predictors. As a result, adding our variable of interest has little effect on the coefficients in columns (1) and (2). Hence we can be assured that our drought variable is not picking up the traditional market predictors nor is it priced into the book-to-market ratio of the FOOD industry. If the information in drought were priced in, we might expect it to be captured by the FOOD past returns and book-to-market ratio in column (2).

To the extent markets are efficient, we would expect zero excess return forecastability on the moving average of PDSI36m for the food portfolio. However, our baseline result of strong forecastability suggests that markets are under-reacting to climate risks from droughts. Moreover, the sign on the coefficient of interest suggests that this is not a risk premium mechanism at work. If it were risk, we would expect that more intense drought results in higher as opposed to lower expected returns. Moreover, we might expect that if markets were efficient in pricing drought, the information in drought would be captured by the FOOD industry book-to-market ratio introduced in column (2).

The implied economic significance of our PDSI variable is large. The mean return of this portfolio is 12.86%. Hence the decrease in returns associated with a one standard deviation increase in drought is roughly 31% of the mean. The economic magnitude from our international sample is large. Another way to gauge the economic significance of our drought variable is to compare it to the predictive power of the traditional market predictors. In column (3), the two most powerful predictors are the FOODPB12 and DP12. Our drought effect is about 60% of that of the FOODPB12 and 40% of that of the DP12.

To visualize the regression results in Table 6, we produce a scatterplot in Figure 7 of the FOOD returns residualized from the predictive model given in column (2) against our PDSI36m measure. That is, we are plotting the FOOD returns in excess of the expected returns as captured by the traditional market predictor and industry predictor variables with our drought measure. We then run a simple univariate regression on these residuals. The coefficient is 2.16 with a $t$-statistic of 3.69. The coefficient is not identical to column (3) since there are non-zero covariances between PDSI36m and the other variables. But since these covariances are not too large, the coefficients are similar in magnitude. Furthermore, the appealing aspect of this scatterplot analysis is that we can see that our drought effect is coming from both negative values of PDSI as well as positive values of PDSI. That is, since PDSI measures the combined moisture in soil and temperature, we expect that when there is less drought (i.e. more moist conditions), we also get higher returns or more profits for the FOOD industry. This difference in the mean FOOD industry returns across drought conditions is visible in the scatterplot.

Our focus on 12-month horizon returns for FOOD brings up the usual worries of long-horizon excess return predictability (Valkanov (2003)). These worries are alleviated somewhat in our setting since our $t$-statistic is around 2 and the scatterplot analysis points to a pronounced decline in expected returns with drought. Nonetheless, to fully address such concerns, we repeat our analysis (column (3) of the previous table) but now using short (1 month) to intermediate horizon returns (3 and 6 months).

In Table 7, we examine the excess return predictability at shorter horizons from 1 month to 6 months. In column (1), we consider the 1-month return results. Our FOODPB12, MRET12 and MVOL12 are economically and statistically significant. Our coefficient of interest is 0.175 with a $t$-statistic of 2.0. A one standard deviation increase in PDSI36m (1.13) leads to a higher expected return of .20% next month. The mean 1-month return is 1.04%. This is nearly 19% of the mean.

In columns (2) and (3), we consider intermediate horizon returns of 3 months and 6 months. In column (2), the coefficient of interest is .597 with a $t$-statistic of 2.38. A one standard deviation decrease in PDSI36m leads to a decline of .67% in next quarter returns, which is around 21% of the mean FOOD return. Among the traditional predictors, only FOODPB12 are more significant than our variable.

In column (3), the coefficient of interest is 1.30 with a $t$-statistic of 2.12. The implied economic effect for drought as a fraction of the mean return of FOOD is similar but as a fraction of the standard deviation of FOOD returns, it is smaller than the 12-month case (at around 6%). Overall, we conclude that the economic significance of our drought variable is there at short, intermediate and long horizons.

In Table 8, we use a FOOD industry portfolio return that is net of the market portfolio of that country. The market portfolio for each country is calculated, as in the case of the US, by excluding food industry stocks. In column (1), we show the monthly return results. The coefficient is 0.136 with a $t$-statistic of 1.83. All the specifications as we go further out in horizon are economically significant. The columns that are not statistically significant are the 3- and 6-month horizon results. The coefficients are sizeable but only attracts a $t$-statistic of 1.44 and 1.43, respectively.

In Appendix Table 1, we explore the extent to which different horizons of our baseline PDSI (from 12-month moving average to 30-month moving average) forecast food portfolio returns over the next 12 months. We always use the specification with the full list of control variables from column (3) of Table 6.

In columns (1) and (2), we use a moving average of 12 months and 18 months. We can think of this short-horizon moving average as capturing shorter episodes of drought. The coefficients are positive but marginally insignificant. It is in column (3), at the 24-month moving average horizon, that we see a statistically significant result. The coefficient of interest is 2.58 with a $t$-statistic of 1.74. Similarly, in column (4), the coefficient is even larger and significant at the 5% level of significance. Overall, the predictability of FOOD returns by drought information increases the more prolonged the drought is.

# 6 How Excess Predictability Varies Across Countries Depending on Experience with Droughts

Up to now, our goal has been to establish that stock markets underreact to the implications of drought for future food industry profitability. In this section, we want to address more directly regulatory concerns. The main reason why regulators are worried that markets might be underreacting to climate risks is that climate change represents a new phenomenon that markets do not have experience with. There is a literature in behavioral economics and finance which supports a related idea, namely that investors might pay limited or not enough attention to information that is not salient (see, e.g., Klibanoff, Lamont, and Wizman (1998)).

To this end, we exploit exogenous variation in PDSI across countries. The key for us is that some countries in our sample have very high PDSI scores in the past, while others have very low PDSI scores. As such, we expect that investors in countries with previously temperate climates would underreact more to drought information in the 1975 onward sample than investors in countries with previous experience with drought. This would be a way of testing the regulatory hypothesis that markets are underreacting to climate change risks that they do not have experience with.

We take our sample of international countries with PDSI monthly values going back to the 1900s. We can see from Panel A of Table 9 that there is significant dispersion in PDSI (mean PDSI36m values) measured up to 1975 across countries. In Panel B of Table 9, we then re-calculate our results from Table 6 but now split the countries into three groups: high, medium and low past PDSI terciles (based on the past mean PDSI36m values). Recall that our excess predictability regressions are ran from 1975 onwards. We drop the middle group from our analysis and focus on a comparison of the high and low tercile countries. In the first column, for the low PDSI tercile sub-sample, we see that the coefficient of PDSI36m is 2.83 and the $t$-statistic is 1.48. In the second column, for the high PDSI tercile sub-sample, we find that the coefficient is 5.90 and the $t$-statistic is 2.54. Therefore, our findings from Table 6 on underreaction in international markets are coming from the sub-sample of countries with previously temperate climates and little history with droughts.

In the final column, we conduct a formal statistical test of this difference by introducing an additional covariate PDSI36m*HighPDSI, which is an interaction term involving PDSI36m and a dummy variable HighPDSI that equals one if a country is in the highest tercile of PDSI. The coefficient on the interaction term is 3.82 and statistically significant. In short, we find that the degree of under-reaction for this subset of high PDSI countries is more than twice that of other countries.

To further examine whether markets underreact more to drought in countries with previous temperate climates, we create two dummies dry and wet when the PDSI value is below or above certain threshold. We first demean PDSI36m by subtracting its sample mean estimated using past 70 years of data. Dry is a dummy equals one when the demeaned PDSI36m is less than -1, and wet is a dummy equals one when the demeaned PDSI36m is greater than +1. In Panel C of Table 9, we show the return predictability results using the dry and wet dummy instead of PDSI36m for low and high past PDSI countries separately. As we can see, the coefficient on Dry and Wet are larger in magnitude and more significant for countries with high past PDSI score. So there is more underreaction in general (to both Dry and Wet conditions) in previously temperate countries. But the coefficient is particularly large for Dry conditions. The results strongly support the idea that the degree of under-reaction to drought is related to the countries' previous drought history.

In Figure 8, we show a scatterplot of the relationship between residualized future 12-month FOOD returns and PDSI for the two sub-samples: the blue dots represent the observations for the countries in the highest PDSI tercile and the red dots represent the observations for the countries in the lowest tercile. We also draw the fitted line for these two subsamples respectively, with the standard errors of the coefficient estimates clustered at the country level. We can see that there is a more pronounced upward slope for the blue dots of the highest PDSI tercile sub-sample. The coefficients are not identical to columns (1) and (2) of Panel B in Table 9 because we do not include country fixed effects for purposes of showing the fitted lines.

# 7 Robustness: US Time Series

In this section, we show that these conclusions from the international sample hold when we just consider the long US time series going back to 1927. For this long US sample, we focus on the 36-month moving average of the PDSIWA using the top 10 food producing US states (PDSIWA36m) as our baseline drought measure.[26] This stands in contrast to coarser measures which we used in the international sample. But the results are very similar in the US regardless of the measure we use, which is reassuring.

[26] All of the predictive regressions for FOOD returns and cash flows using the US sample have been repeated with the alternative Modified Palmer Drought Severity Index (PMDI) as the drought measure instead of the PDSI, i.e. we use PMDIWA36m, the 36-month moving average of weighted PMDI values (PMDIWA), as the main explanatory variable in the predictive regressions. The corresponding results are shown in Appendix Table 9, which are similar to the results using PDSIWA36m.

## 7.1 Excess Return Predicatbility

In Appendix Table 2, we use this variable to forecast FOODRET12m, the excess returns of the FOOD industry portfolio (net of the risk-free rate) FOODRET over the next 12 months. Our sample period is from 1927 to 2014. The empirical specification is

$$\text{FOODRET12m}_t = \alpha + \beta \text{PDSIWA36m}_{t-1} + \gamma' X_{t-1} + \varepsilon_t, \tag{7.1}$$

where $\text{FOODRET12m}_t$ denotes the future non-overlapping FOOD return over the next 12 months, $\text{PDSIWA36m}_{t-1}$ is the moving average of PDSIWA over the previous 36 months, and $X_{t-1}$ includes market and food industry specific controls. [27]

In column (3), we add in our variable of interest PDSIWA36m and find that it has significant incremental forecasting power for the future returns of the food portfolio. The coefficient estimate of PDSIWA36m is 2 with a $t$-statistic of 2.5, which is significant at the 5% statistical significance level. It increases the $R^2$ from 24% in column (2) to 26% in column (3).

The implied economic significance of our PDSI variable is large. It means that if the average weighted PDSI value of the top 10 food-producing states over the previous 36 months falls by 1 standard deviation (about 1.26 from Table 2), the average excess return of the food industry portfolio over the risk-free rate in the next 12 months (FOODRET12m) will decrease by about 2.5%. From Table 2, the mean FOODRET12m is 7.16% with a standard deviation of 17.45%. Thus the implied economic effect is about 35% of the mean of the food portfolio return and about 15% of the standard deviation of FOODRET12m, which are both economically significant results.

[27] We use the traditional market predictor variables, including the lagged 12-month aggregate market return MRET (see, e.g., Poterba and Summers (1988)), the inflation rate INF (see, e.g., Fama and Schwert (1977)), the log value of the dividend-price ratio of the aggregate market DP (see, e.g.,Campbell and Shiller (1988)), the volatility of the aggregate market MVOL (see, e.g., French, Schwert, and Stambaugh (1987)), the net equity expansion of the aggregate market NTIS (see, e.g., Baker and Wurgler (2000)), a corporate bond spread (DSPR), and a treasury yield spread TSPR (Fama and French (1989)).All of these market predictor variables have a suffix of 12 to denote they are annualized values over the past 12 months.

To visualize the regression results in Appendix Table 2, we produce a scatterplot in Appendix Figure 1 of the FOOD returns residualized from the predictive model given in column (2) against our PDSIWA36m measure. That is, we are plotting the FOOD returns in excess of the expected returns as captured by the traditional market predictor and industry predictor variables with our drought measure. We then run a simple univariate regression on these residuals. The coefficient is 1.61 with a $t$-statistic of 2.

One important concern is that the $t$-statistics of our predictability regressions are inflated due to persistent predictor variables since our PDSIWA36m is highly persistent (close to a random walk). To deal with this concern, we implement the Campbell and Yogo (2006) test. For this test in our baseline case, we do the following. First, we carry out the following two regressions:

$$\text{FOODRET12m}_t = \alpha + \beta \text{PDSIWA36m}_{t-1} + e_t, \tag{7.2}$$

$$\text{PDSIWA36m}_t = \gamma + \rho \text{PDSIWA36m}_{t-1} + u_t, \tag{7.3}$$

where $\text{FOODRET12m}_t$ denotes the future non-overlapping FOOD return over the next 12 months, $\text{PDSIWA36m}_{t-1}$ is the moving average of PDSIWA over the previous 36 months, and $\text{PDSIWA36m}_t$ is the one-step ahead value of $\text{PDSIWA36m}_{t-1}$ (i.e. the contemporaneous value of PDSIWA36m corresponding to $\text{FOODRET12m}_t$). We obtain the residuals from regressions (7.2) and (7.3), and denote them as $e_t$ and $u_t$ respectively. Then we calculate the correlation between the residuals $e_t$ and $u_t$. The correlation turns out to be merely $-0.001$. As shown in Campbell and Yogo (2006), the bias in $t$-statistics would be a concern if the residuals $e_t$ and $u_t$ are highly negatively correlated. This is not the case in our sample. Furthermore, as demonstrated in their Table 4 and 5 in Campbell and Yogo (2006), when the correlation is very close to zero as opposed to being close to $-1$, the confidence intervals for the standard $t$-test are almost unaffected. Therefore, based on the (extremely) low correlation we find in our sample, we are on safe ground in proceeding with the standard $t$-test in our analysis and not adjusting the $t$-statistics values.

### 7.2 Short and Intermediate Horizon Predictability

Our focus on 12-month horizon returns for FOOD brings up the usual worries of long-horizon excess return predictability (Valkanov (2003)). These worries are alleviated somewhat in our setting since our $t$-statistic is around 2.5 and the scatterplot analysis points to a pronounced decline in expected returns with drought. Nonetheless, to fully address such concerns, we repeat our analysis (column (3) of Appendix Table 2) in Appendix Table 3 but now using short (1 month) to intermediate horizon returns (3 and 6 months). Our results are qualitatively similar to the 12 month results.

### 7.3 Different Horizon Drought Measures

In Appendix Table 4, we explore the extent to which different horizons of our baseline PDSIWA (from 12-month moving average to 30-month moving average) forecast food portfolio returns over the next 12 months. We always use the specification with the full list of control variables from column (3) of Appendix Table 2.

In columns (1) and (2), we use a moving average of 12 months and 18 months. We can think of this short-horizon moving average as capturing shorter episodes of drought. The coefficients are positive as before but are not statistically significant. Take the 0.673 coefficient in column (1). A standard deviation of PDSIWA12m is 1.6, which is as expected larger than the standard deviation of 1.26 for our baseline PDSIWA36m measure. Thus a one standard deviation increase in this short-horizon drought measure translates to around a 1% increase in FOOD returns. This economic magnitude is about 40% of that of our 36-month moving average measure. The economic effect is smaller, as we hypothesized, since short duration droughts should have less of an effect on the FOOD industry, all else equal. Indeed, if we took the view that information about a prolonged 36-month drought is much more salient than a 12-month drought and ought to be more readily priced in by the market, then the difference in the predictability generated by the long versus the short-horizon drought measures are even more pronounced.

It is in column (3), at the 24-month moving average horizon, that we see a statistically significant result. The coefficient of interest is 1.264 with a $t$-statistic of 2.25. Similarly, in column (4), the coefficient is even larger and significant at the 1% level of significance. The implied economic magnitudes are nonetheless smaller than our 36-month moving average baseline measure. Overall, the predictability of FOOD returns by drought information increases the more prolonged the drought is.

### 7.4 PDSI at Different Levels of Granularity

In Appendix Table 5, we use 36-month moving averages of alternative PDSI measures as the predictor in our baseline regression specification to forecast 12-month FOOD returns. In column (1), the alternative measure is the PDSI using the 48 contiguous US states weighted by cropland area. The coefficient of interest is 2.5 with a $t$-statistic of 2.4. In column (2), the measure is the PDSI aggregated across the US but weighted by the food cash receipts produced by that state. The coefficient of interest is 2.5 with a $t$-statistic of 1.9. In column (3), we use the PDSI measure produced by NOAA. The coefficient is 1.26 with a $t$-statistic of 1.77.

All of the alternative drought measures carry comparable statistically significant forecasting power on food portfolio returns. The implied economic effects are also comparable to our top 10 agricultural producing states measure. It is comforting that we can find predictability results even using a coarse PDSIUSA measure since for our international analysis below we only have access to such a coarse measure.

## 7.5 Food Returns Net of the Market

We now use our second approach to calculate FOOD returns in excess of the market. In Appendix Table 6, we do just this. From column (3), our estimate in front of our coefficient of interest is 1.23 with a $t$-statistic of 3.01. A one standard deviation increase in PDSIWA36m leads to a 1.55% higher return over the next 12 months for FOODXMRET. The mean of FOODXMRET12m is 1% with a standard deviation of 11.75%. The economic significance is comparable to our first method. The corresponding plot of this regression is in Figure 3.

## 7.6 US Cashflows

In Appendix Table 7, we perform the following regression of forecasting the future 1-year change in CP:

$$CP_{t+1} = \alpha + \beta \text{PDSIWA36m}_t + \gamma' X_t + \varepsilon_{t+1}, \tag{7.4}$$

where $X$ denotes the control variables apart from PDSIWA36m. This specification is similar to the one used in Fama and French (2000). The one modification of our control variables is that we include in columns (2) and (3) of Appendix Table 7 the previous 1-year change in the food industry profitability (i.e. $CP_t$). Otherwise, the control variables are the same as before, which include all of the controls as specified in column (3) of Appendix Table 2.

The coefficient of interest is in column (3) where we find that PDSIWA36m attracts a coefficient of 0.10 with a $t$-statistic of 2.41. Drought is associated with a decline in the food industry profitability over the next year. The standard deviation of CP is 0.77%. Hence, a one standard deviation move in our drought measure results in a 0.12% fall in CP (the standard deviation of PDSIWA36m in our regression (7.4) is 1.2). This is nearly 16% of the standard deviation of CP, which is a substantial decrease.

In Appendix Figure 2, we show the scatterplot of the residual of CP generated from the predictive regression in column (2) and our drought measure. The univariate regression through the scatterplot has a coefficient of 0.08 with a $t$-statistic of 2.47. In short, we confirm that our interpretation of the excess FOOD return predictability regressions is due to the market underreacting to the implications of drought for FOOD industry cash flow-related news.

## 7.7 Other Industries

We have focused on the returns of the food industry since it is the most directly linked to crops, agricultural production and drought. Our prior is that drought should not significantly predict returns of other industries. To see if this is the case, we run the same predictive regression for each industry in the Fama-French 17-industry categories. Appendix Table 8 reports the coefficient estimates and $t$-statistics of PDSIWA36m for the Fama-French 17 industries and the ranking is based on the magnitude of the $t$-statistics. As we can see, the Food industry is ranked 1st among all 17 industries for return horizons over future 1 to 12 months. For convenience, we report the coefficients and $t$-statistics for FOOD, which are the same as those presented earlier. Notice for the 1-month horizon returns, no other industry is significant besides FOOD. The same is true for the 3-month horizon returns and the 6-month horizon returns. At 12 months, Steel is significant besides FOOD but attracts a negative sign. In short, drought only significantly predicts FOOD, consistent with our priors.

Having said this, we are working with very aggregate portfolios. It is possible that perhaps when we consider disaggregated industry portfolios, such as the Fama-French 48 industries categorization, we might see different results. Drought might predict some sub-industries with a positive sign (i.e. they are hurt by drought) and others with a negative sign (i.e. they benefit from drought).

# 8 Conclusion

We show that stock markets are inefficient with respect to information about prolonged drought, one of the most important climate risks that are brought on or exacerbated by climate change. Using a global dataset of the widely-used Palmer Drought Severity Index (PDSI) from climate studies, we show that prolonged drought spells in a country, as measured by a 3-year moving average of PDSI, forecast poor returns for a portfolio comprised of food stocks in that country. This predictability is stronger in countries with previously temperate climates and little history of droughts.

Our findings have a number of implications for policymakers and practitioners. First, our findings confirm regulatory worries about markets underreacting to climate risks and support the need for disclosure of corporate exposures. The question becomes what the best way is to disclose such risks. Second, our findings show that PDSI might be a very useful metric of drought to form portfolios and manage risks. We leave these topics for future research.

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Table 1: Summary Statistics of the International Sample

This table reports summary statistics of the sample of 30 international countries, including 15 developed countries and 15 developing countries. We report the average number of stocks in the food industry, the median firm market captitalization in US dollars, the mean and standard deviation of the PDSI value and the starting date for each country. Countries with missing variables and less than 10 stocks in the food industry in the whole sample are excluded. The overall sample runs from 1975 to 2015. Stock return data and accounting information for international countries are taken from Datastream and Worldscope, respectively.

| Panel A | | | | | |
|---|---|---|---|---|---|
| Country<br>**Developed Countries** | Average #<br>of Stocks | Median Firm Size<br>(Million USD) | Palmer Drought Severity Index<br>Mean | <br>Std. | Start<br>date |
| Australia | 25 | 37.65 | -0.98 | 2.16 | 197501 |
| Belgium | 12 | 49.06 | 0.16 | 2.27 | 198601 |
| Canada | 16 | 266.58 | -0.40 | 1.75 | 197501 |
| Switzerland | 12 | 163.44 | -0.64 | 2.25 | 197501 |
| Germany | 15 | 125.31 | -0.66 | 1.84 | 198410 |
| Denmark | 9 | 94.01 | 0.58 | 2.41 | 198804 |
| Finland | 7 | 154.74 | 0.87 | 2.07 | 199008 |
| France | 26 | 71.13 | -0.58 | 2.15 | 197501 |
| United Kingdom | 56 | 23.70 | -0.05 | 2.27 | 197501 |
| Greece | 24 | 33.32 | -0.53 | 2.45 | 198801 |
| Israel | 23 | 22.93 | 0.00 | 1.78 | 198601 |
| Japan | 90 | 158.62 | -0.35 | 2.40 | 197501 |
| Netherlands | 12 | 261.64 | 0.26 | 2.40 | 197501 |
| New Zealand | 10 | 29.25 | -0.94 | 2.03 | 198801 |
| Portugal | 9 | 10.32 | -0.60 | 2.45 | 198801 |
| **Developing Countries** | | | | | |
| Brazil | 14 | 160.94 | -1.05 | 1.78 | 199001 |
| Chile | 20 | 75.68 | -0.46 | 2.06 | 198907 |
| China | 54 | 306.79 | -3.08 | 2.18 | 199311 |
| Indonesia | 22 | 56.50 | -0.41 | 1.35 | 199006 |
| India | 108 | 2.86 | 0.94 | 2.88 | 199001 |
| South Korea | 39 | 58.96 | -0.24 | 2.24 | 198407 |
| Mexico | 9 | 128.17 | 0.21 | 1.85 | 199107 |
| Malaysia | 50 | 49.64 | 1.17 | 2.55 | 198601 |
| Peru | 19 | 19.67 | -1.34 | 2.18 | 199112 |
| Philippines | 11 | 39.99 | 0.29 | 2.84 | 199308 |
| Poland | 22 | 35.22 | -0.58 | 1.68 | 199410 |
| Russian Federation | 10 | 101.14 | 1.27 | 1.84 | 200601 |
| Thailand | 32 | 31.10 | -1.23 | 2.10 | 198701 |
| Turkey | 17 | 24.74 | 2.21 | 3.04 | 199011 |
| South Africa | 15 | 162.98 | -0.34 | 3.05 | 198703 |

Summary Statistics of the International Sample, Continued

This table continues with the summary statistics for the variables in our international sample with all countries pooled together. Panel B shows the summary statistics of our main drought measure and other control variables. PDSI12m to PDSI36m are the 12-month to 36-month moving average of the PDSI for international countries. MRET12, INF12, FOODPB12, DP12 and MVOL12 denote respectively the market excess return, the inflation rate, the price-to-book ratio of the food portfolio, the dividend-to-price ratio and the market volatility over 12 months. Panel C shows the summary statistics of non-overlapping returns of the food portfolio over different horizons. CP is the annual change in the food industry profitability ratio. FOODRET to FOODRET12m denote, respectively, the non-overlapping return over 1 month, 3 months, 6 months and 12 months. FOODXMRET12m is the food portfolio return net of the return of the market excluding food portfolio over 12 months.

Panel B: Drought measure and other controls

| | Mean | S.D. | Median | Min | Max |
|---|---|---|---|---|---|
| PDSI12m | -0.20 | 1.71 | -0.26 | -3.75 | 3.83 |
| PDSI18m | -0.20 | 1.53 | -0.26 | -3.27 | 3.41 |
| PDSI24m | -0.20 | 1.37 | -0.27 | -2.95 | 3.01 |
| PDSI30m | -0.21 | 1.24 | -0.27 | -2.72 | 2.62 |
| PDSI36m | -0.22 | 1.13 | -0.26 | -2.52 | 2.27 |
| MRET12 (%) | 7.98 | 30.03 | 9.14 | -70.31 | 83.83 |
| INF12 (%) | 7.32 | 6.57 | 5.13 | 1.08 | 26.19 |
| FOODPB12 | 2.56 | 1.29 | 2.28 | 0.84 | 5.82 |
| DP12 (%) | 2.98 | 2.21 | 2.35 | 0.73 | 9.84 |
| MVOL12 (%) | 23.12 | 13.74 | 19.74 | 6.47 | 82.27 |

Panel C: Food Portfolio Non-overlapping Returns

| | Mean | S.D. | Median | Min | Max |
|---|---|---|---|---|---|
| CP (%) | 0.00 | 3.34 | -0.01 | -14.71 | 15.49 |
| FOODRET (%) | 1.04 | 8.74 | 0.88 | -105.17 | 143.33 |
| FOODRET3m (%) | 3.22 | 16.93 | 2.80 | -87.83 | 237.11 |
| FOODRET6m (%) | 6.42 | 26.16 | 5.86 | -108.33 | 420.44 |
| FOODRET12m (%) | 12.86 | 41.30 | 11.91 | -132.06 | 528.09 |
| FOODXMRET12m (%) | 2.93 | 24.04 | 2.02 | -65.53 | 99.91 |

# Table 2: Summary Statistics of the US Sample

This table reports the summary statistics for the variables in our sample. The sample is from January 1927 to December 2014 and comprises monthly observations of all variables except FOODBM which is observed annually. Panel A shows PDSIUSA, the Palmer Drought Severity Index (PDSI) of USA produced directly by the US National Oceanic and Atmospheric Administration. PDSIUSA36m is the the 36-month moving average of the PDSIUSA. The alternative drought measure PDSIWA is the weighted average PDSI values for the top 10 food-producing states (in terms of cash value) in the US. PDSIWA12m to PDSIWA36m denote, respectively, the moving average of the PDSIWA values over 12 months, 18 months, 24 months, 30 months and 36 months. It also shows the 36-month moving average of 2 other alternative drought measures: PDSIASWA is the weighted average (based on cropland areas) of the PDSI values of all 48 contiguous US states (excluding Alaska, Hawaii, and Washington D.C. because of no data), and PDSIASCA is the weighted average PDSI of all 48 states with the gross cash income of the farm sector in each state as weight. Panel B shows the Fama-French 17-industry food industry portfolio non-overlapping excess returns over various horizons. FOODRET is the monthly excess return (net of the 1-month T-bill rate), FOODRET3m to FOODRET12m denote the excess returns over 3 months, 6 months and 12 months respectively, and FOODXMRET12m is the food portfolio return net of the return of the market excluding food (MXF) portfolio over 12 months. CP is the annual change in the food industry profitability ratio. Panel C shows the non-overlapping values for other control variables over 12 months. FOODBM is the log value of the value-weighted average of the book-to-market ratios of the firms in the food industry portfolio. MRET is the CRSP value-weighted market portfolio excess return. INF is the CPI inflation rate. DP is the log value of the dividend-price ratio of the S&P 500 index. MVOL is the market volatility (volatility of the S&P 500 index). NTIS is the net equity expansion of the NYSE stocks. DSPR is the default yield spread, the difference between BAA and AAA-rated corporate bond yields. TSPR is the term spread, the difference between the long term yield on government bonds and the Treasury-bill. Panel D gives the correlations among the variables of interest in Panel (A) to (C).

Panel A: Palmer Drought Severity Index (PDSI) Values

| | Mean | S.D. | Median | Min | Max |
|---|---|---|---|---|---|
| PDSIUSA36m | 0.17 | 1.96 | 0.33 | -4.44 | 4.11 |
| PDSIWA12m | 0.17 | 1.60 | 0.54 | -4.25 | 4.10 |
| PDSIWA18m | 0.16 | 1.55 | 0.51 | -3.79 | 3.64 |
| PDSIWA24m | 0.17 | 1.41 | 0.42 | -3.40 | 2.99 |
| PDSIWA30m | 0.16 | 1.36 | 0.29 | -3.24 | 2.83 |
| PDSIWA36m | 0.17 | 1.26 | 0.29 | -3.12 | 2.53 |
| PDSIASWA36m | 0.15 | 1.06 | 0.22 | -2.35 | 2.07 |
| PDSIASCAWA36m | 0.07 | 0.89 | 0.19 | -1.95 | 1.77 |

Panel B: Fama-French 17-Industry Food Portfolio Non-overlapping Returns and Cashflow Measure

| | Mean | S.D. | Median | Min | Max |
|---|---|---|---|---|---|
| FOODRET (%) | 0.60 | 4.80 | 0.87 | -33.35 | 28.61 |
| FOODRET3m (%) | 1.79 | 9.37 | 2.51 | -42.59 | 52.88 |
| FOODRET6m (%) | 3.58 | 12.78 | 4.51 | -42.48 | 54.73 |
| FOODRET12m (%) | 7.16 | 17.45 | 8.68 | -43.63 | 39.81 |
| FOODXMRET12m (%) | 1.01 | 11.75 | 1.37 | -37.19 | 30.87 |
| CP (%) | -0.03 | 0.77 | 0.07 | -2.26 | 2.24 |

Panel C: Other Control Variables, Non-overlapping

| | Mean | S.D. | Median | Min | Max |
|---|---|---|---|---|---|
| FOODBM12 | -0.67 | 0.46 | -0.64 | -1.77 | 0.26 |
| MRET12 (%) | 6.02 | 20.07 | 9.87 | -59.11 | 45.04 |
| INF12 (%) | 2.94 | 3.96 | 2.77 | -10.93 | 16.44 |
| DP12 | -3.36 | 0.47 | -3.34 | -4.48 | -2.29 |
| MVOL12 (%) | 13.91 | 8.78 | 10.94 | 5.54 | 50.43 |
| NTIS12 (%) | 1.85 | 2.63 | 1.76 | -4.19 | 16.35 |
| DSPR12 (%) | 1.20 | 0.79 | 0.96 | 0.34 | 5.10 |
| TSPR12 (%) | 1.61 | 1.42 | 1.64 | -3.50 | 4.53 |

Summary Statistics, Continued

| Panel D: Correlations | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| (1) PDSIWA36m | 1 | | | | | | | | | | | | | |
| (2) PDSIASWA36m | 0.97 | 1 | | | | | | | | | | | | |
| (3) PDSIASCAWA36m | 0.94 | 0.98 | 1 | | | | | | | | | | | |
| (4) PDSIUSA36m | 0.88 | 0.94 | 0.96 | 1 | | | | | | | | | | |
| (5) FOODRET12m | 0.00 | 0.01 | 0.02 | 0.03 | 1 | | | | | | | | | |
| (6) FOODXMRET12m | 0.06 | 0.00 | -0.02 | -0.04 | 0.08 | 1 | | | | | | | | |
| (7) FOODBM12 | -0.29 | -0.30 | -0.22 | -0.15 | 0.18 | -0.03 | 1 | | | | | | | |
| (8) MRET12 | -0.04 | 0.00 | 0.02 | 0.05 | 0.82 | -0.49 | 0.18 | 1 | | | | | | |
| (9) INF12 | 0.25 | 0.27 | 0.32 | 0.31 | -0.03 | -0.12 | 0.04 | 0.04 | 1 | | | | | |
| (10) DP12 | -0.21 | -0.22 | -0.15 | -0.06 | -0.22 | 0.10 | 0.81 | -0.25 | 0.02 | 1 | | | | |
| (11) MVOL12 | -0.06 | -0.08 | -0.12 | -0.14 | -0.44 | 0.30 | -0.04 | -0.55 | -0.27 | 0.24 | 1 | | | |
| (12) NTIS12 | 0.05 | 0.11 | 0.12 | 0.14 | -0.20 | -0.18 | 0.03 | -0.08 | -0.04 | 0.18 | 0.05 | 1 | | |
| (13) DSPR12 | -0.21 | -0.27 | -0.26 | -0.25 | -0.28 | 0.32 | 0.25 | -0.42 | -0.36 | 0.40 | 0.73 | -0.18 | 1 | |
| (14) TSPR12 | 0.05 | -0.02 | -0.06 | -0.06 | 0.16 | 0.13 | -0.18 | 0.07 | -0.29 | -0.14 | 0.12 | -0.14 | 0.25 | 1 |

# Table 3: Trend in Global PDSI Variables

This table shows the results for estimating a time trend in several global PDSI variables. The dependent variables, PDSI25%ile, PDSI50%ile, and PDSI75%ile denote the monthly 25th percentile (lower quartile) PDSI value of all international countries (including the US), the 50th percentile (median) value, and the 75th percentile (upper quartile) value respectively. Panel A estimates the trend model $PDSIvar_t = \alpha_0 + \beta_0 t + \varepsilon_t$ where $PDSIvar$ is PDSI25%ile, PDSI50%ile, or PDSI75%ile. Panel B estimates the model $PDSIvar_t = \alpha_0 + \beta_0 t + \beta_1 (t - \tau) D(t \geq \tau) + \varepsilon_t$ where we allow for a structural break in trend at time $\tau$. The explanatory variable $t$ denotes the time trend. $D(t \geq \tau)$ is a dummy variable that equals to 1 if time $t$ is greater than or equal to the break point $\tau$. The break point $\tau$ is January 1980 (198001). $\alpha_0$ is the constant term. The parameter in brackets after the corresponding explanatory variable denotes the coefficient in front of that variable. $t$-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 12 months for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample is from 190001 (January 1900) to 201412 (December 2014).

Panel A: Estimating a Time Trend in Global PDSI Variables

| | (1) | (2) | (3) |
|---|---|---|---|
| | Dependent Variable | | |
| | PDSI25%ile | PDSI50%ile | PDSI75%ile |
| $t$ $(\beta_0)$ | -0.0004*** | -0.0003*** | -0.0001 |
| | (-3.816) | (-2.744) | (-0.941) |
| $\alpha_0$ | -1.3086*** | 0.0816 | 1.5709*** |
| | (-14.773) | (0.788) | (18.281) |
| $R^2$ | 0.07 | 0.03 | 0.01 |
| $N$ | 1380 | 1380 | 1380 |

Panel B: Allowing for a Structural Break in Trend at Jan 1980

| | (1) | (2) | (3) |
|---|---|---|---|
| | Dependent Variable | | |
| | PDSI25%ile | PDSI50%ile | PDSI75%ile |
| $t$ $(\beta_0)$ | -0.0000 | -0.0002 | -0.0000 |
| | (-0.089) | (-1.040) | (-0.248) |
| $(t - \tau) \times D(t \geq \tau)$ $(\beta_1)$ | -0.0004*** | -0.0001 | -0.0001 |
| | (-2.806) | (-0.787) | (-0.437) |
| $\alpha_0$ | -1.4544*** | 0.0348 | 1.5459*** |
| | (-14.202) | (0.289) | (16.499) |
| $R^2$ | 0.10 | 0.04 | 0.01 |
| $N$ | 1380 | 1380 | 1380 |

Table 4: International Evidence: Predicting 1-year Food Industry Change in Profitability (CP) with 36-month Moving Average of PDSI

This table presents the results from forecasting the future 1-year CP, the change in profitability of the food industry over the next year, using the 36-month moving average of the PDSI values (PDSI36m). The dependent variable (forecast) is the CP, the future change in the food industry profitability, over the next year. The key explanatory (forecasting) variable, PDSI36m, is the moving average of the PDSI values over the previous 3 years (36 months). Other control variables, CP1y, FOODRET12m, FOODPB12, MRET12, INF12, DP12 and MVOL12 denote, respectively, the change in the food industry profitability, the food industry portfolio return (FOODRET), the log of the food industry price-to-book ratio (FOODPB), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP) and the market volatility (MVOL). We control for country fixed effects in the regression and standard errors are double clustered along the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is 1975 to 2015.

| | Dependent Variable: Future 1-year Change in Food Industry Profitability | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| PDSI36m | | | 0.141* |
| | | | (1.812) |
| CP1y | | -0.458*** | -0.453*** |
| | | (-13.645) | (-10.661) |
| FOODRET12m | | 0.005 | 0.002 |
| | | (0.646) | (0.309) |
| FOODPB12 | | -0.099 | -0.091 |
| | | (-0.475) | (-0.517) |
| MRET12 | -0.002 | -0.001 | 0.001 |
| | (-0.404) | (-0.137) | (0.256) |
| DP12 | -0.014 | -0.018 | -0.020 |
| | (-1.303) | (-0.844) | (-0.878) |
| INF12 | -0.000 | -0.001 | -0.001 |
| | (-1.526) | (-0.819) | (-0.572) |
| MVOL12 | 0.073*** | 0.039 | 0.042* |
| | (4.548) | (1.618) | (1.808) |
| Ave. R-sq | 0.019 | 0.209 | 0.204 |
| N. of Obs. | 717 | 704 | 670 |

Table 5: Return to Portfolio Strategies Sorted on Standardized PDSI36m

This table presents the returns and alphas (in percentage) to country food portfolios sorted on lagged PDSI36m. PDSI36m is first standardized by substracting its mean and dividing by its standard deviation. We estimate the rolling mean and standard deviation of PDSI36m with past 70 years of data. Each month all country food-industry portfolios are sorted into quintiles based on their standardized PDSI36m (denoted as PDSI36m*) from the previous month end and held for various horizons from 1 month to 12 months. In panel A, we report the mean PDSI36m*, excess returns and Carhart (1997) four factor alphas for quintile portfolios with a holding period of 12 months. We group the middle three portfolios together by equal weighting their respective returns. Row "Middle - Low" shows the return difference between middle portfolio and lowest PDSI36m* portfolio. "High - Middle" and "High - Low" follows the similar definition. Row "DiD" shows the difference between "High - Middle" and "Middle - Low". In panel B, we report the long/short return spread and factor-adjusted alphas from 1 month to 12 months. The alphas are adjusted using global Sharpe (1964) CAPM, Fama and French (1993) three factors and Carhart (1997) four factors model following the methodology of constructing local factors. The sample period is from January 1985 to December 2015.

Panel A: Quintile Portfolios sorted on standardized PDSI36m

| Portfolio | PDSI36m* | Excess Return | t-stat | 4-factor alpha | t-stat |
|---|---|---|---|---|---|
| Low PDSI | -1.60 | 0.38 | 1.31 | 0.27 | 1.04 |
| Middle PDSI | 0.25 | 0.71 | 3.03 | 0.59 | 3.14 |
| High PDSI | 1.37 | 1.15 | 3.87 | 1.10 | 4.28 |
| Middle - Low | 1.32 | 0.33 | 1.82 | 0.33 | 1.85 |
| High - Middle | 1.61 | 0.44 | 2.14 | 0.51 | 2.41 |
| DiD | 0.30 | 0.10 | 0.35 | 0.18 | 0.58 |
| High - Low | 2.97 | 0.77 | 2.74 | 0.83 | 2.87 |

## Table 5 Continued

Panel B: L/S Portfolios sorted on standardized PDSI36m for various holding horizons

| | 12-month Holding Period | | | |
|---|---|---|---|---|
| | Excess Return | CAPM alpha | Three-factor alpha | Four-factor alpha |
| Mean | 0.77 | 0.76 | 0.80 | 0.83 |
| t-stat | 2.74 | 2.69 | 2.78 | 2.87 |
| Std.Dev | 5.34 | | | |
| Sharpe Ratio | 0.50 | | | |
| No.of obs. | 360 | | | |

| | 6-month Holding Period | | | |
|---|---|---|---|---|
| | Excess Return | CAPM alpha | Three-factor alpha | Four-factor alpha |
| Mean | 0.74 | 0.73 | 0.75 | 0.81 |
| t-stat | 2.49 | 2.45 | 2.46 | 2.63 |
| Std.Dev | 5.68 | | | |
| Sharpe Ratio | 0.45 | | | |
| No.of obs. | 360 | | | |

| | 3-month Holding Period | | | |
|---|---|---|---|---|
| | Excess Return | CAPM alpha | Three-factor alpha | Four-factor alpha |
| Mean | 0.72 | 0.71 | 0.72 | 0.80 |
| t-stat | 2.38 | 2.34 | 2.35 | 2.58 |
| Std.Dev | 5.74 | | | |
| Sharpe Ratio | 0.43 | | | |
| No.of obs. | 360 | | | |

| | 1-month Holding Period | | | |
|---|---|---|---|---|
| | Excess Return | CAPM alpha | Three-factor alpha | Four-factor alpha |
| Mean | 0.57 | 0.56 | 0.56 | 0.66 |
| t-stat | 1.84 | 1.81 | 1.79 | 2.09 |
| Std.Dev | 5.86 | | | |
| Sharpe Ratio | 0.34 | | | |
| No.of obs. | 360 | | | |

Table 6: International Evidence: Predicting 12-month Non-overlapping Food Portfolio Return

This table presents the results from forecasting the food industry portfolio excess returns over future 12 months, using the moving averages of the PDSI values over the past 36 months (PDSI36m). The regressions are run by pooling all countries together and including a country fixed effect. The dependent variable is the food return over the future 12 months. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return (FOODRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12) and the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

| Dependent Variable: Future 12-month FOODRET, Non-overlapping | | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| PDSI36m | | | 3.4796** |
| | | | (2.26) |
| FOODRET12m | | -0.0777 | -0.0714 |
| | | (-0.74) | (-0.64) |
| FOODPB12 | | -12.2938** | -12.5436*** |
| | | (-2.61) | (-2.92) |
| MRET12 | 0.2025 | 0.2351 | 0.2388 |
| | (0.85) | (0.84) | (0.74) |
| INF12 | 2.4152 | 2.1613 | 1.8519 |
| | (1.37) | (1.35) | (1.24) |
| DP12 | -0.2435*** | -0.3446*** | -0.3512*** |
| | (-5.99) | (-12.41) | (-5.34) |
| MVOL12 | 1.9336** | 1.9493** | 1.9918* |
| | (2.08) | (2.11) | (1.99) |
| Ave.R-sq | 0.167 | 0.195 | 0.213 |
| N.of Obs. | 624 | 612 | 584 |

Table 7: International Evidence: Predicting Food Industry Portfolio Non-overlapping Returns over Different Horizons

This table presents the results from forecasting the food industry portfolio excess returns (FOODRETs) at various horizons, using the moving averages of the PDSI values over the past 36 months (PDSI36m). The regressions are run by pooling all countries together and including a country fixed effect. The dependent variable 1m is the food return over the next month, and those dependent variables of 3m to 6m are the food returns over the next 3 months and 6 months, respectively. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return (FOODRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12), the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

| Dependent Variable: Future FOODRET over 1m, 3m and 6m, Non-overlapping | | | |
|---|---|---|---|
| | 1m | 3m | 6m |
| PDSI36m | 0.1752* | 0.5970** | 1.3033** |
| | (2.00) | (2.38) | (2.12) |
| FOODRET12m | -0.0016 | 0.0078 | 0.0424 |
| | (-0.31) | (0.42) | (0.98) |
| FOODPB12 | -0.9897*** | -2.9013*** | -4.9145** |
| | (-3.25) | (-3.24) | (-2.70) |
| MRET12 | 0.0375* | 0.0903 | 0.1260 |
| | (1.87) | (1.34) | (0.84) |
| INF12 | 0.1239 | 0.5134 | 0.4594 |
| | (1.14) | (1.43) | (0.69) |
| DP12 | -0.0106* | -0.0288 | -0.1583*** |
| | (-1.73) | (-1.37) | (-3.25) |
| MVOL12 | 0.1197* | 0.5046* | 1.0844** |
| | (1.70) | (1.83) | (2.37) |
| Ave.R-sq | 0.055 | 0.134 | 0.174 |
| N.of Obs. | 6918 | 2310 | 1154 |

Table 8: International Evidence: Predicting Non-overlapping Food Portfolio net of Market Return over Different Horizons

This table presents the results from forecasting the future non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, using the 36-month moving average of the weighted PDSI values (PDSI36m). The dependent variable (forecast) is the non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, over the next 1 months to 12 months. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return net of market return (FOODXMRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12) and the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

| Dependent Variable: Future FOODXMRET over 1m, 3m, 6m and 12m, Non-overlapping | | | | |
|---|---|---|---|---|
| | 1m | 3m | 6m | 12m |
| PDSI36m | 0.1360* | 0.2882 | 0.5881 | 1.3526** |
| | (1.83) | (1.44) | (1.43) | (2.09) |
| FOODXMRET12m | -0.0225 | -0.0180 | -0.0384 | 0.0034 |
| | (-1.34) | (-0.83) | (-0.75) | (0.05) |
| FOODPB12 | -0.5487** | -1.2048* | -2.3425 | -4.1423 |
| | (-2.04) | (-1.81) | (-1.65) | (-1.48) |
| MRET12 | -0.0039 | 0.0043 | 0.0082 | 0.0312* |
| | (-0.87) | (0.59) | (0.41) | (1.81) |
| INF12 | -0.0043 | 0.1437 | -0.0100 | -0.5649 |
| | (-0.09) | (1.29) | (-0.05) | (-1.14) |
| DP12 | -0.0143 | -0.0137 | -0.0101 | -0.0376 |
| | (-1.18) | (-0.61) | (-0.80) | (-1.04) |
| MVOL12 | 0.0342 | 0.1563 | 0.0665 | -0.1167 |
| | (1.28) | (1.45) | (0.27) | (-0.31) |
| Ave.R-sq | 0.009 | 0.020 | 0.036 | 0.062 |
| N.of Obs. | 6909 | 2290 | 1134 | 564 |

Table 9: International Evidence: Predicting 12-month Non-overlapping Food Portfolio Return in subsamples based on Past Mean PDSI36m

This table presents the results from forecasting the food industry portfolio excess returns over future 12 months, using the moving averages of the PDSI values over the past 36 months (PDSI36m). Panel A reports the mean PDSI36m for each country using data up to 1974. Panel B reports the return predictability of PDSI36m for 3 groups of countries based on the past mean PDSI36m. Panel C reports the return predictability of Dry/Wet dummy for low and high past PDSI countries. Dry (Wet) is a dummy equal to one when the demeand PDSI36m is less (greater) than -1 (+1). The result for countries with mean PDSI36m in the lowest (highest) tercile is reported under Column "Low PDSI tercile" ("High PDSI tercile"). The regressions are run by pooling all countries within a group together and including a country fixed effect. In column (3) of Panel B, We interact PDSI36m with a dummy HighPDSI indicating a country is in the highest past PDSI36m tercile. We do not include countries in the middle tercile of PDSI in Column (3). The dependent variable is the food return over the future 12 months. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return (FOODRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12) and the market volatility (MVOL12). The sample period is from January 1975 to December 2015. Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively.

Panel A: Mean PDSI36m

| Country | Mean PDSI36m |
|---|---|
| Israel | 3.023 |
| Peru | 0.624 |
| Chile | 0.594 |
| Thailand | 0.513 |
| Turkey | 0.438 |
| Poland | 0.429 |
| Malaysia | 0.400 |
| Finland | 0.365 |
| Netherlands | 0.364 |
| Belgium | 0.364 |
| Brazil | 0.290 |
| Japan | 0.219 |
| Greece | 0.183 |
| Philippines | 0.164 |
| Denmark | 0.024 |
| Switzerland | 0.017 |
| Germany | 0.015 |
| United Kingdom | -0.014 |
| South Africa | -0.107 |
| France | -0.168 |
| United States of America | -0.174 |
| Indonesia | -0.188 |
| Norway | -0.195 |
| Russian Federation | -0.273 |
| South Korea | -0.315 |
| India | -0.368 |
| Mexico | -0.697 |
| Canada | -0.712 |
| Portugal | -0.804 |
| China | -0.979 |
| New Zealand | -1.000 |
| Australia | -1.074 |

## Table 9 Continued

Panel B: Subsample Return Predictability of PDSI

| | Low PDSI tercile | High PDSI tercile | |
|---|---|---|---|
| PDSI36m | 2.8261 | 5.9049** | 1.7059 |
| | (1.48) | (2.54) | (0.73) |
| PDSI36m*HighPDSI | | | 3.8232* |
| | | | (1.93) |
| FOODRET12m | 0.0685 | -0.2061 | -0.1088 |
| | (0.62) | (-1.13) | (-0.63) |
| FOODPB12 | -10.4033* | -15.1159* | -14.0648** |
| | (-2.13) | (-2.18) | (-2.47) |
| MRET12 | -0.2008 | 0.4941 | 0.2989 |
| | (-1.46) | (1.02) | (0.70) |
| INF12 | -96.5665** | 1.7356 | 2.0021 |
| | (-2.50) | (0.60) | (0.75) |
| DP12 | -0.4874 | -0.4716** | -0.4061*** |
| | (-0.42) | (-2.84) | (-3.46) |
| MVOL12 | 0.9775 | 2.4168 | 2.4785 |
| | (0.77) | (1.69) | (1.72) |
| Ave.R-sq | 0.097 | 0.363 | 0.260 |
| N.of Obs. | 159 | 198 | 357 |

## Table 9 Continued

Panel C: Subsample Return Predictability of Dry/Wet Dummy

| | Low PDSI tercile | High PDSI tercile |
|---|---|---|
| Dry | -7.2535 | -12.7872* |
| | (-1.02) | (-2.18) |
| Wet | 5.6888 | 7.5794* |
| | (0.59) | (1.96) |
| FOODRET12 | 0.0710 | -0.1822 |
| | (0.65) | (-0.84) |
| FOODPB12 | -10.2587* | -14.8729* |
| | (-2.13) | (-1.91) |
| MRET12 | -0.2114 | 0.4767 |
| | (-1.08) | (0.86) |
| INF12 | -97.8097** | 1.7718 |
| | (-2.53) | (0.59) |
| DP12 | -0.5193 | -0.4368* |
| | (-0.41) | (-2.11) |
| MVOL12 | 0.8883 | 2.2851 |
| | (0.66) | (1.44) |
| Ave.R-sq | 0.100 | 0.357 |
| N.of Obs. | 159 | 198 |

Figure 1: Historical PDSI for Selective Countries

This figure plots the time series of monthly PDSI value for Australia, India, Russia, Japan and Israel. The sample period runs from January of 1927 to December of 2014. The PDSI value is shown on the vertical axis. The horizontal axis is time.

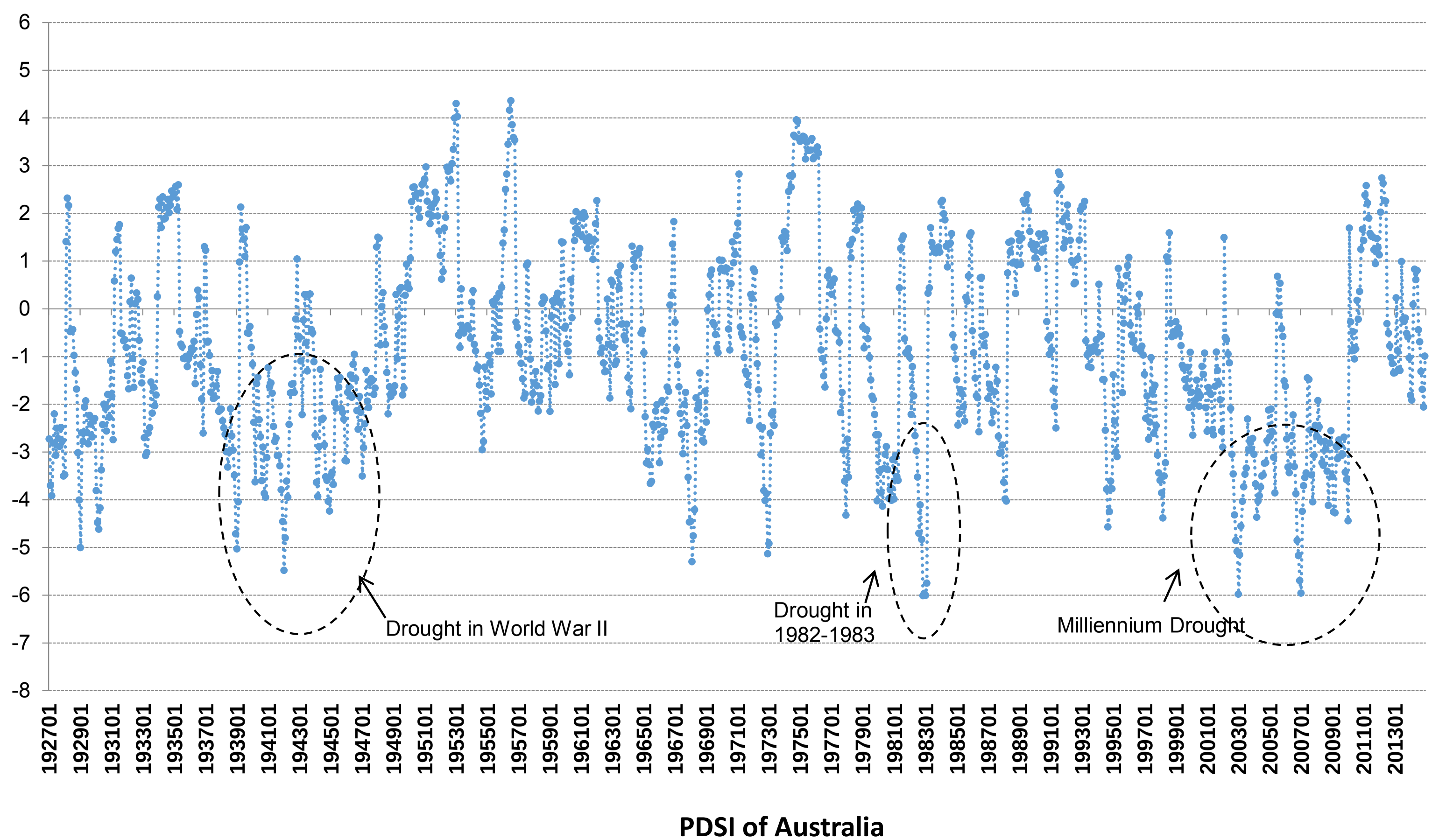
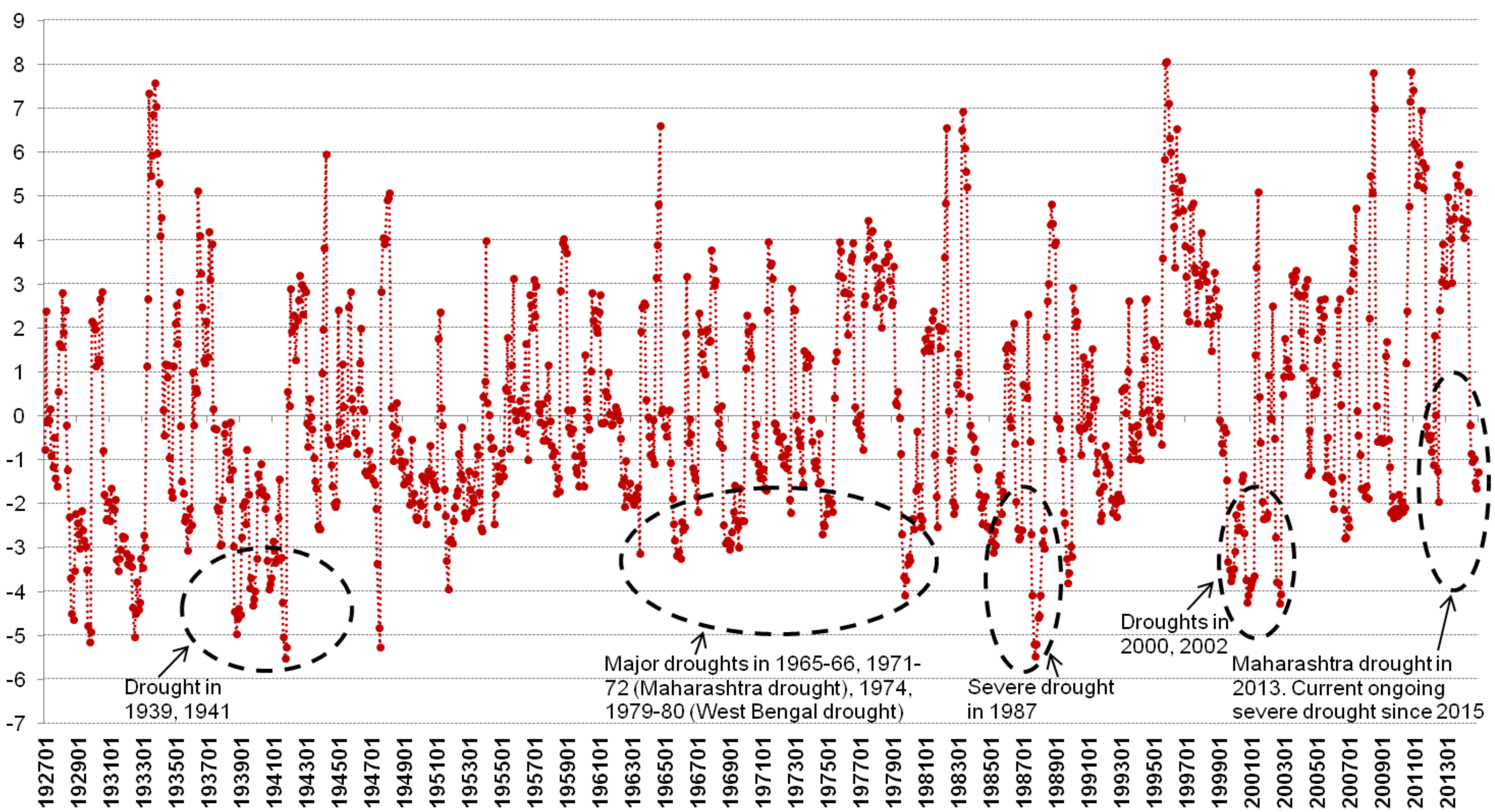
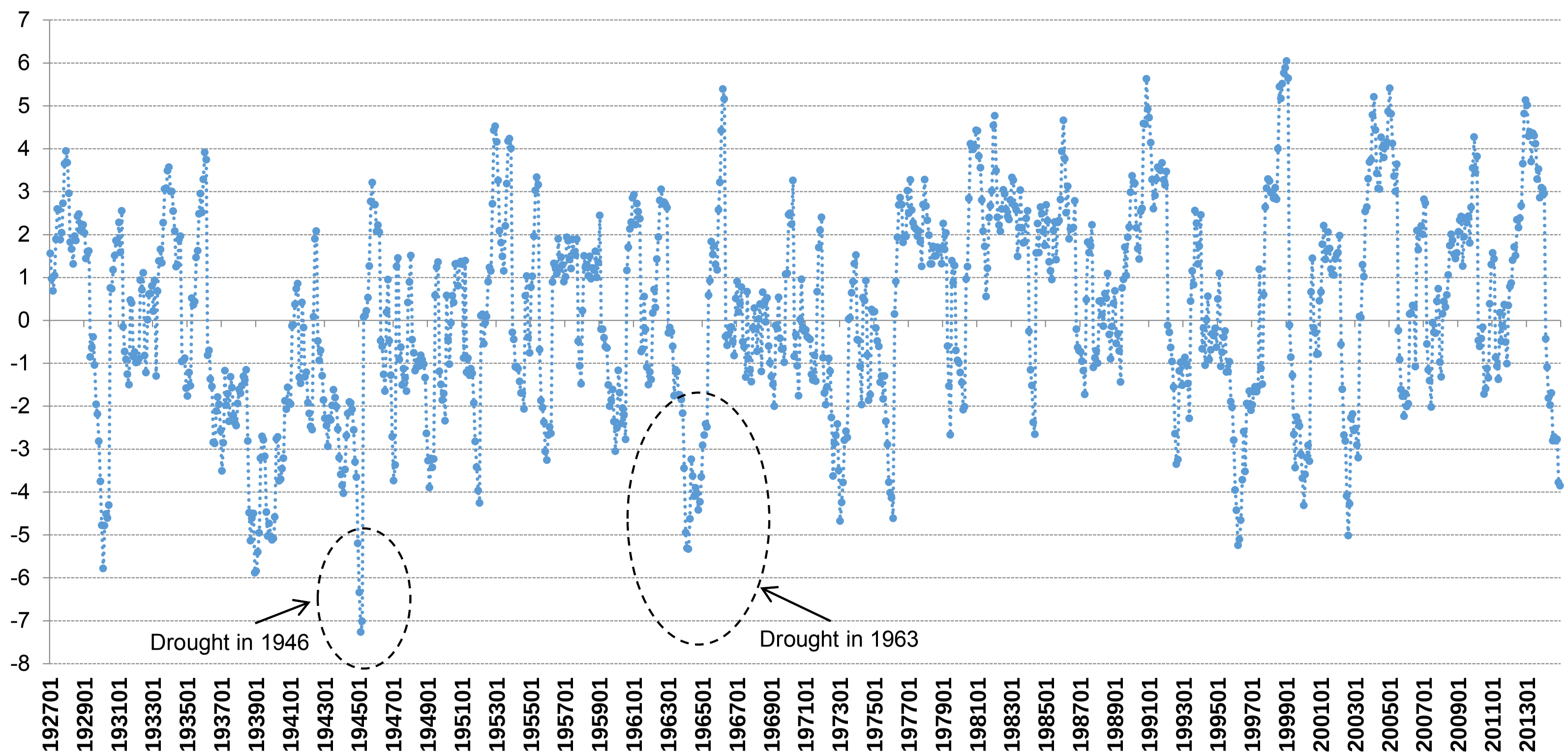


**Figure 1 Continued**



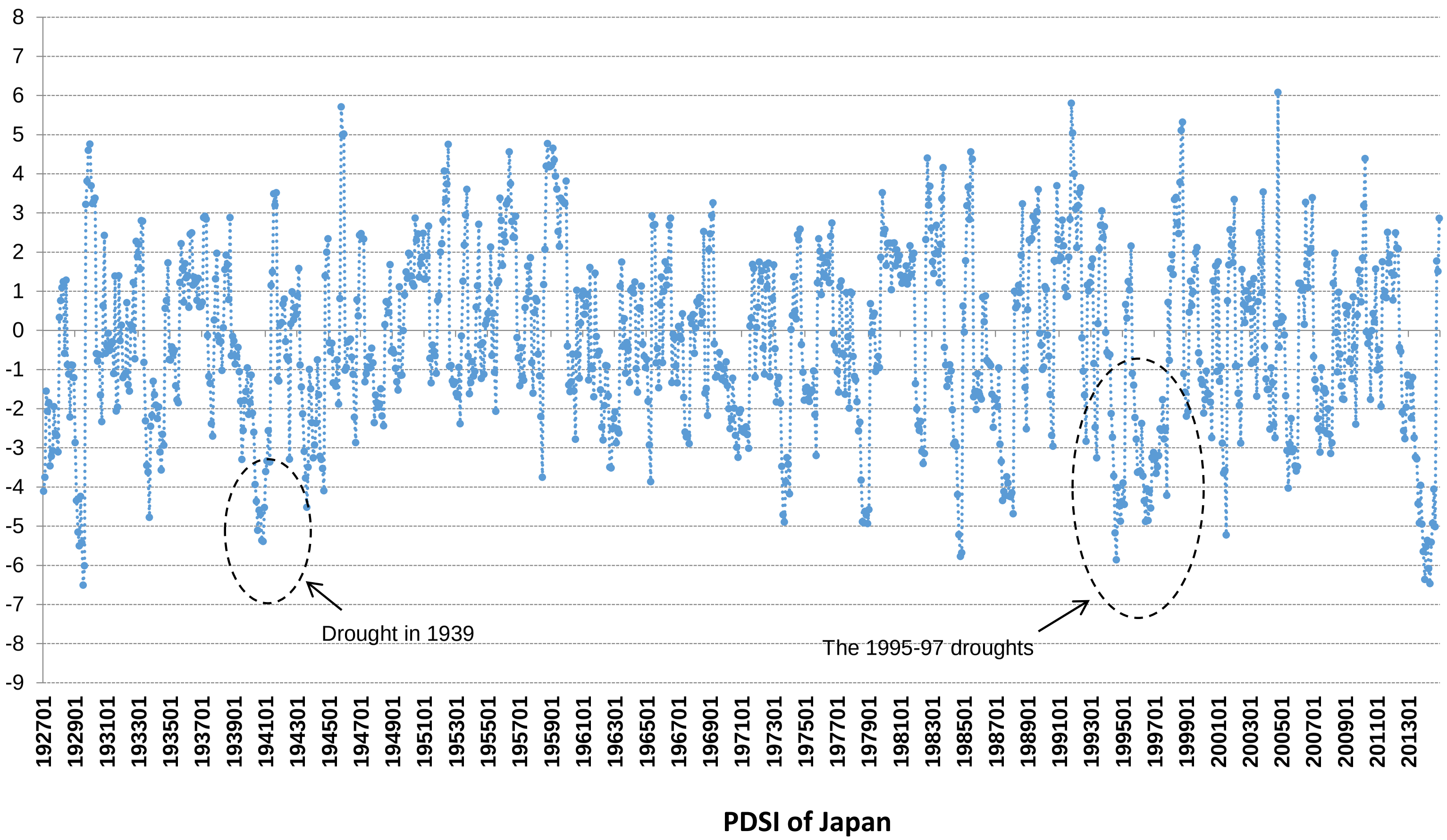

**PDSI of India**

## Figure 1 Continued

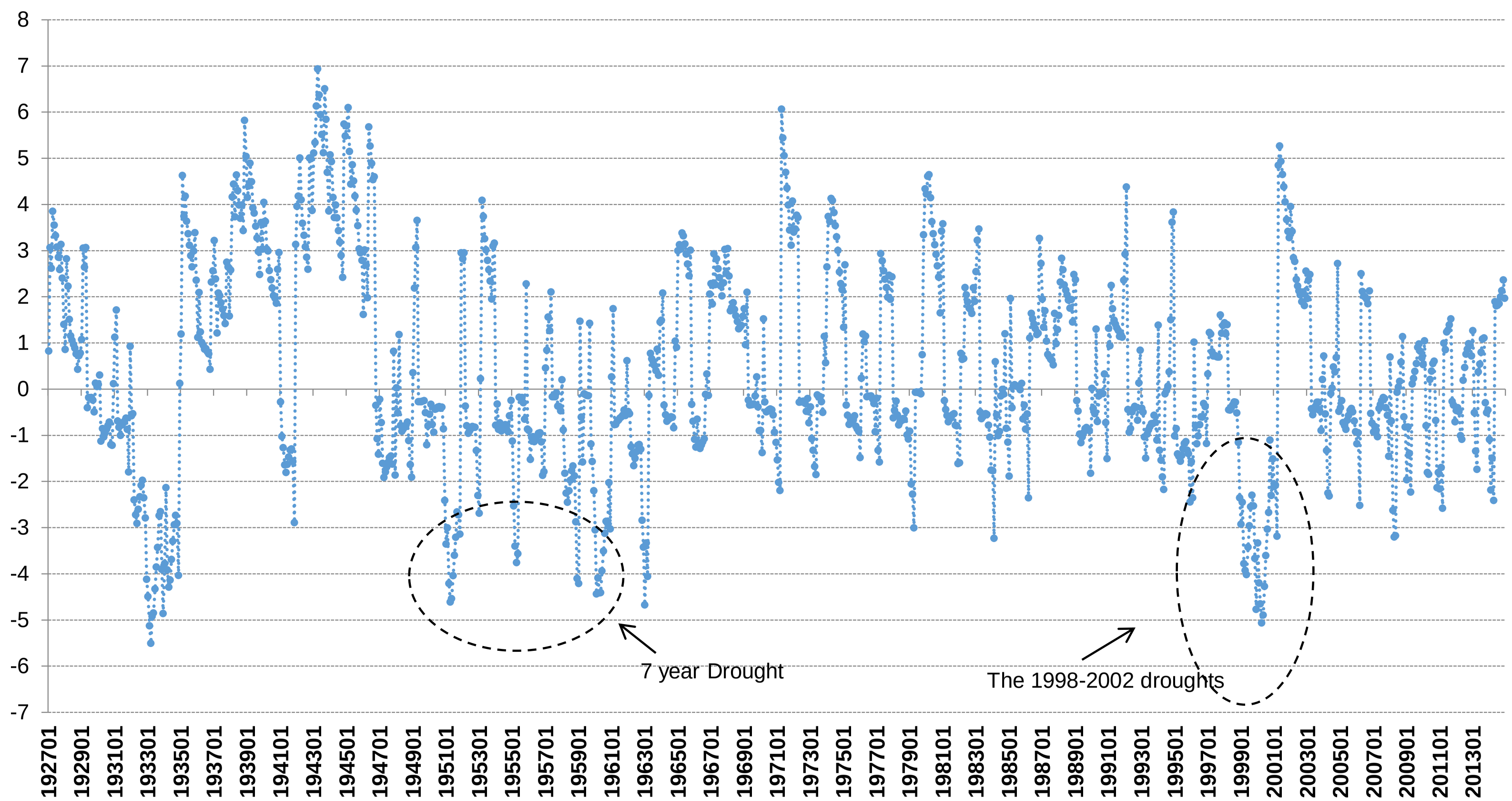



**PDSI of Russia**

# Figure 1 Continued



# Figure 1 Continued




**PDSI of Israel**

Figure 2: Historical PDSI of the US

This figure illustrates the historical PDSI of the US produced directly by the US NOAA. The PDSI value is shown on the vertical axis. The horizontal axis is time. The PDSI of the US is essentially a land-area weighted average of the PDSI values from all climate divisions in the US.

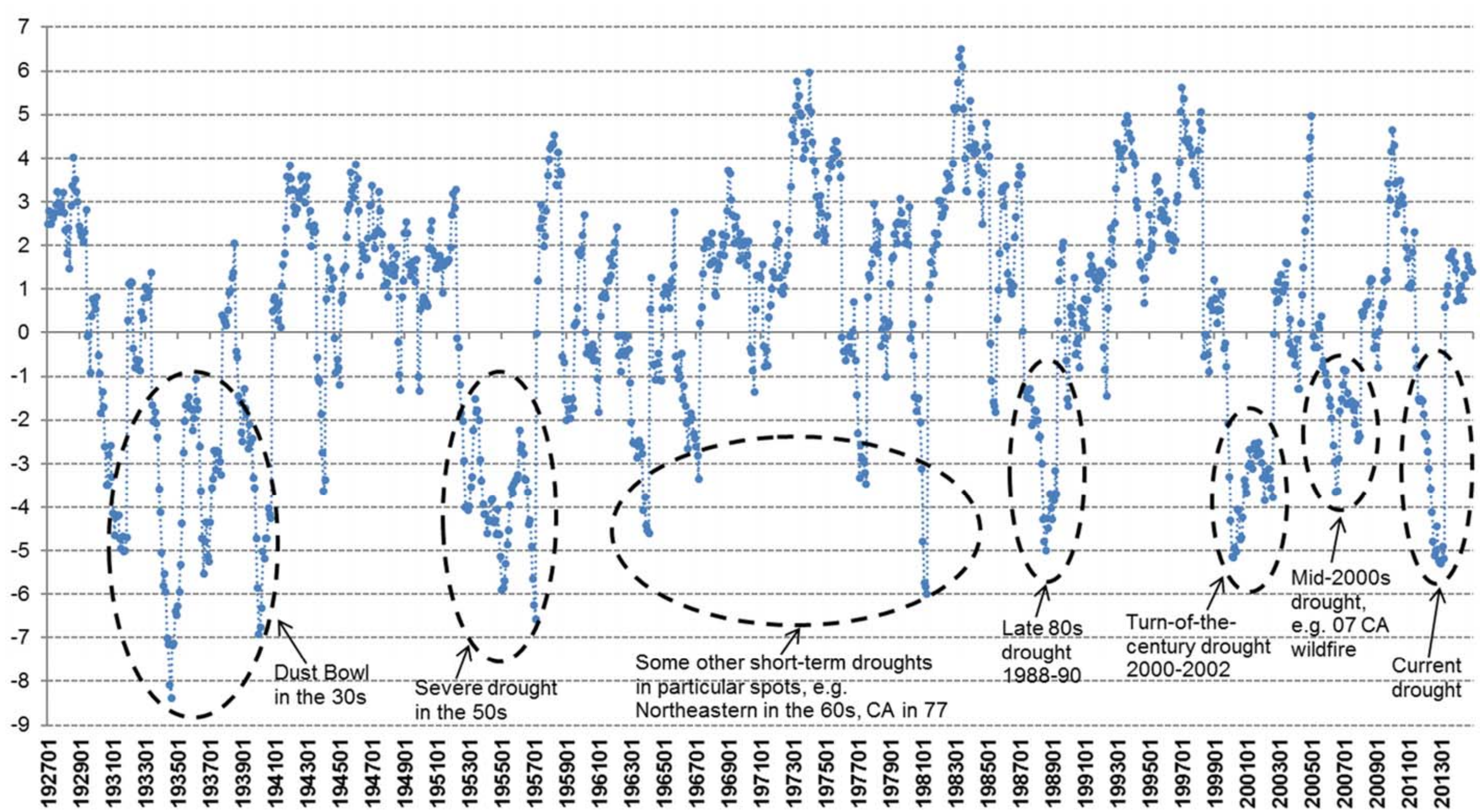


Figure 3: Future Non-overlapping 12-month Return of Food net of Market Portfolio and Past 36-month Moving Average of PDSIWA, Time-series Plot

This figure depicts the time-series plot of the future non-overlapping 12-month return of the food net of market portfolio against our main predictor variable PDSIWA36m, the past 36-month moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is January 1927 to December 2014. The plot starts in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.

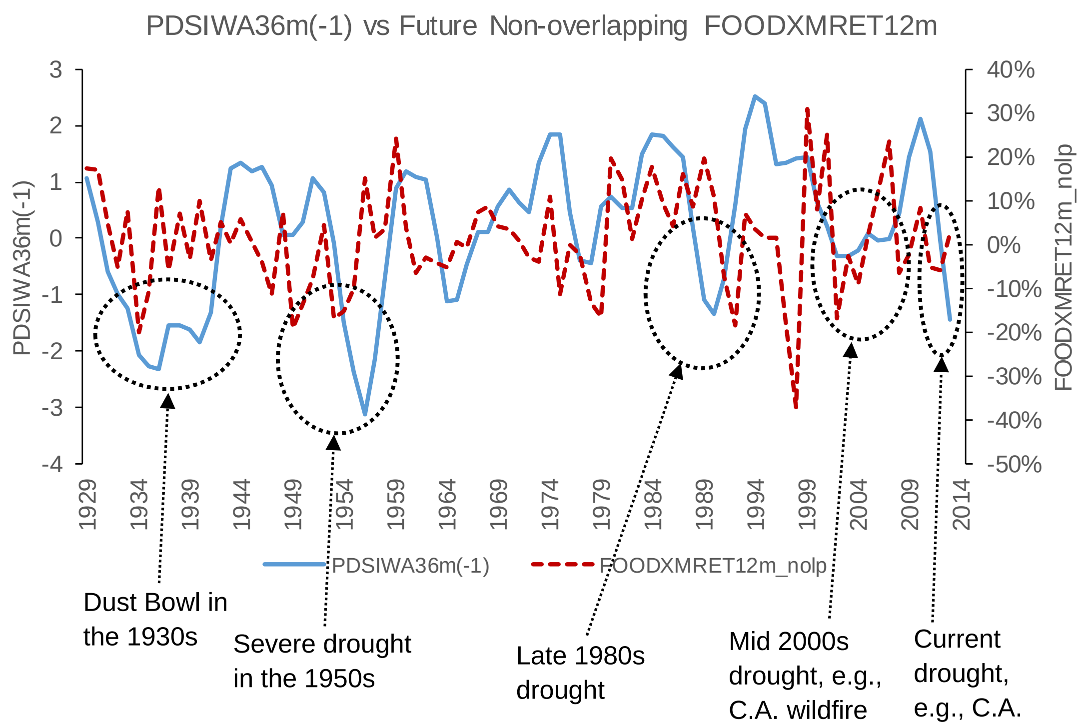


Figure 4: Global Annual Temperature Anomaly, 1880 to 2014

This figure shows the global annual temperature anomalies from 1880 to 2014 as recorded by NASA (red line), NOAA (green line), the Japan Meteorological Agency (purple line), and the Met Office Hadley Centre in the UK (blue line), downloaded from NASA's website (source: `http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php`). The vertical axis is the annual temperature anomaly and the horizontal axis is time.

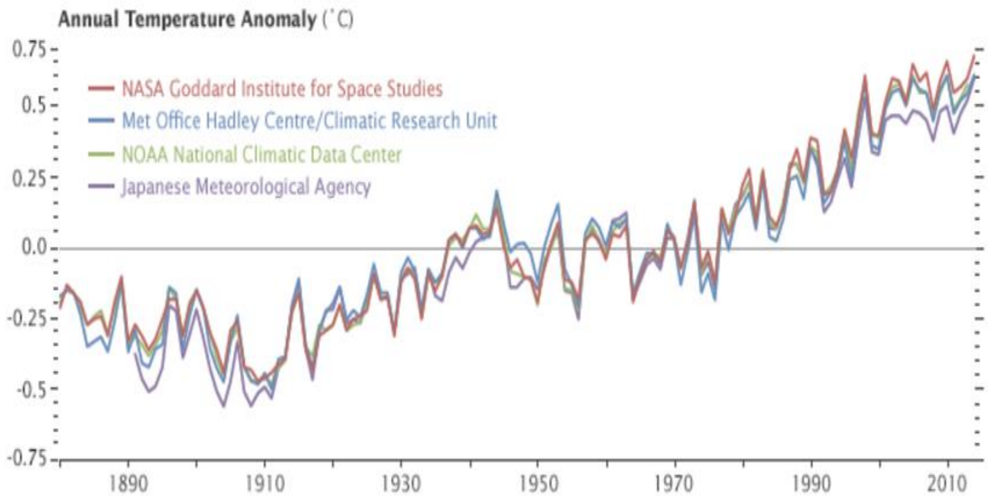
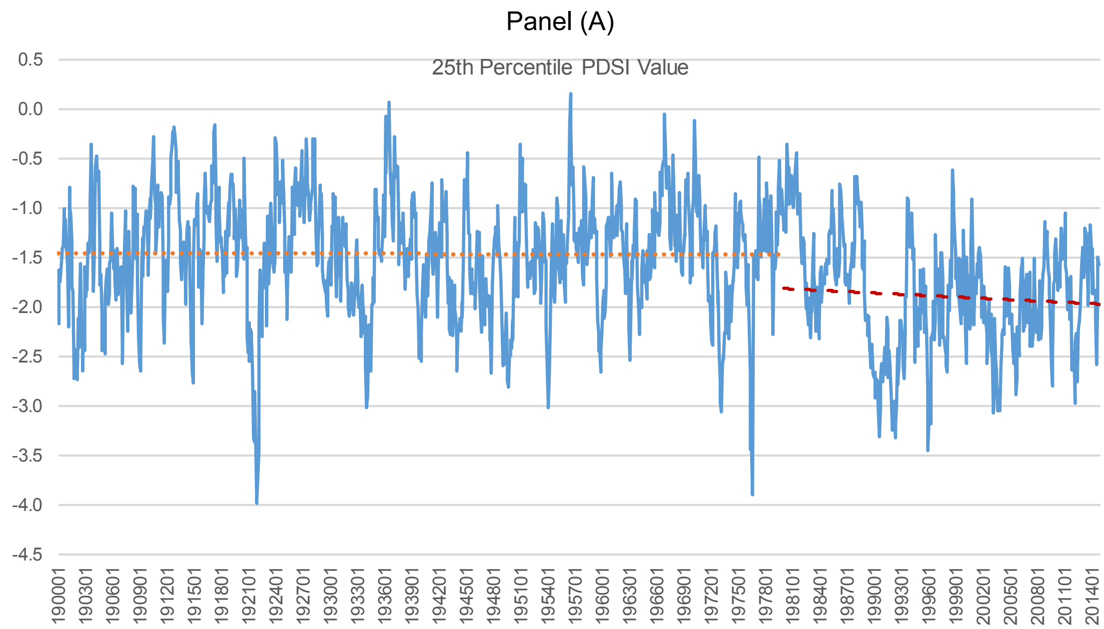


Figure 5: Monthly Quartile PDSI Values of International Countries over Time

This figure depicts the monthly lower quartile (25th percentile) PDSI value of international countries (including the US) over time. The vertical axis is the corresponding PDSI variable value, and the horizontal axis is time. We also plot the best-fitted linear trend line and allow for a structural break in trend at Jan 1980. The orange dotted line and the red dashed line in the graph are the best-fitted linear trend lines before the structural break in trend (before Jan 1980) and after the structural break in trend (after Jan 1980) respectively. The sample period is from 190001 (January 1900) to 201412 (December 2014).



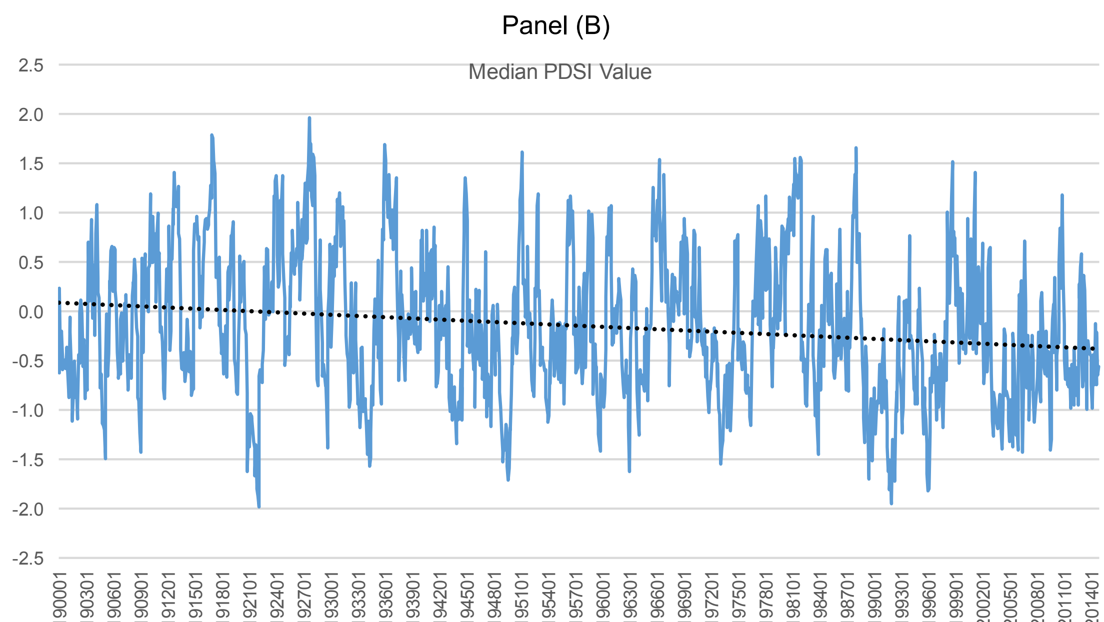



Figure 6: International Evidence: Future 1-year Change in Food Industry Profitability (CP) Residual and Past 36-month Moving Average of PDSI, Scatter Plot

This figure depicts the scatter plot of the future 1-year change in the food industry profitability (CP) residual against our main predictor variable PDSI36m, the past 36-month moving average of PDSI value, for our international sample including the US. The sample period is from January 1975 to December 2015.

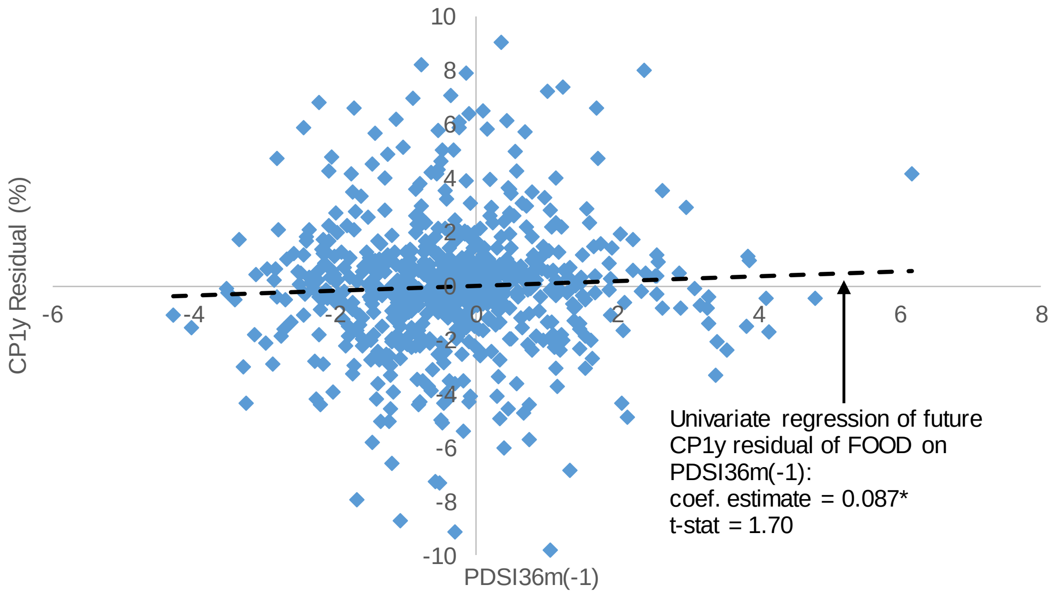


Figure 7: International Evidence: Future Non-overlapping 12-month Food Portfolio Return Residual and Past 36-month Moving Average of PDSI, Scatter Plot

This figure depicts the scatter plot of the future non-overlapping 12-month food portfolio return residual against our main predictor variable PDSI36m, the past 36-month moving average of PDSI value. The sample period is from January 1975 to December 2015.

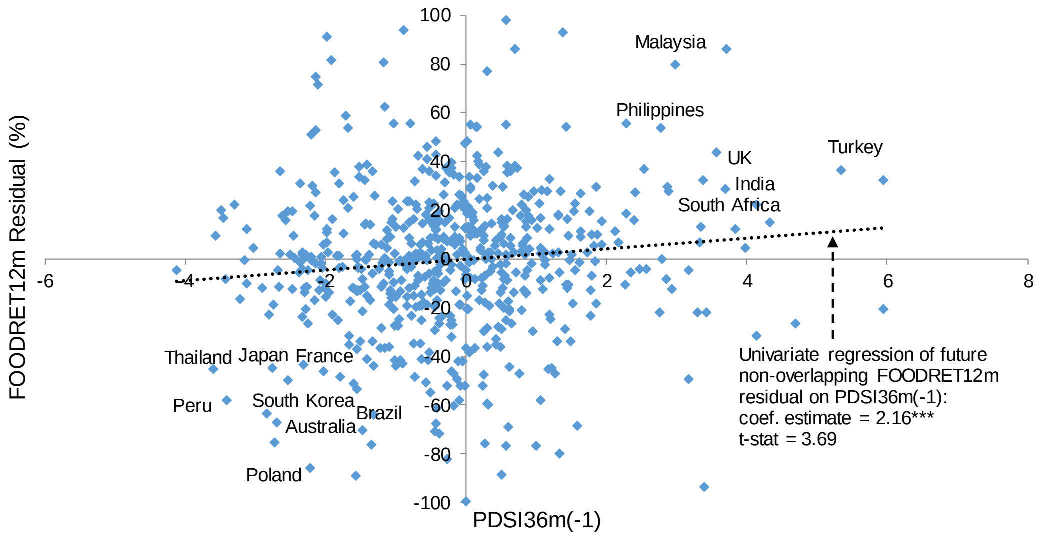
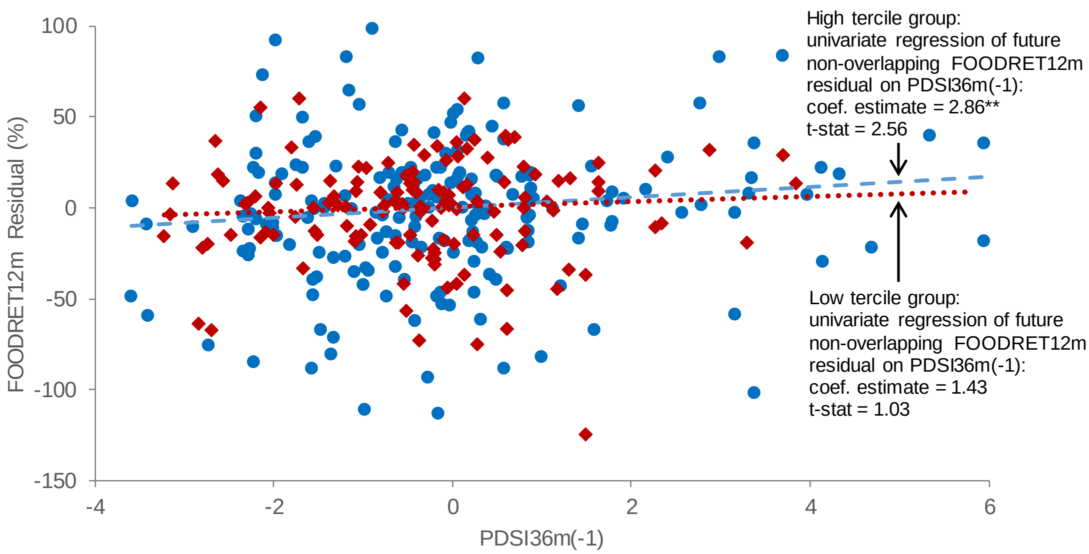


Figure 8: International Evidence: Future Non-overlapping 12-month Food Portfolio Return Residual and Past 36-month Moving Average of PDSI, Subsamples based on Past Mean PDSI36m

This figure depicts the scatter plot of the future non-overlapping 12-month food portfolio return residual against our main predictor variable PDSI36m, the past 36-month moving average of PDSI value. The blue circle indicates countries whose past mean PDSI36m values are in the highest tercile (high tercile group), while the red diamond indicates countries whose past mean PDSI36m values are in the lowest tercile (low tercile group). The sample period is from January 1975 to December 2015.



# Internet Appendix For Online Publication Only

# Appendix Tables and Figures

Appendix Table 1: International Evidence: Predicting 12-month Non-overlapping Food Portfolio Return with Moving Average of PDSI at Different Frequencies

This table presents the results from forecasting the food industry portfolio excess returns over future 12 months, using the moving averages of the PDSI values over different frequencies. The regressions are run by pooling all countries together and including a country fixed effect. The dependent variable is the food return over the future 12 months. PDSI12m to PDSI30m are the moving average of the PDSI values over the previous 12 months, 18 months, 24 months and 30 months, respectively. The returns are non-overlapping. All of the regressions include these other forecasting variables over the past 12 months: lagged food industry return (FOODRET12m), lagged market return (MRET12), lagged inflation rate (INF12), log of food industry price-to-book ratio (FOODPB12), the log of the market dividend price ratio (DP12) and the market volatility (MVOL12). Standard errors are clustered at both the country and month dimensions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The sample period is from January 1975 to December 2015.

| Dependent Variable: Future 12-month FOODRET, Non-overlapping | | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| PDSI12m | 1.8019 | | | |
| | (1.42) | | | |
| PDSI18m | | 1.9335 | | |
| | | (1.40) | | |
| PDSI24m | | | 2.5839* | |
| | | | (1.74) | |
| PDSI30m | | | | 3.1015** |
| | | | | (2.07) |
| FOODRET12 | -0.0642 | -0.0649 | -0.0679 | -0.0705 |
| | (-0.59) | (-0.59) | (-0.62) | (-0.64) |
| FOODPB12 | -12.3973*** | -12.5065*** | -12.6034*** | -12.5605*** |
| | (-2.96) | (-2.91) | (-2.89) | (-2.91) |
| MRET12 | 0.2351 | 0.2340 | 0.2362 | 0.2393 |
| | (0.76) | (0.75) | (0.76) | (0.75) |
| INF12 | 1.9168 | 1.9174 | 1.8901 | 1.8570 |
| | (1.26) | (1.26) | (1.24) | (1.22) |
| DP12 | -0.3365*** | -0.3348*** | -0.3341*** | -0.3430*** |
| | (-14.02) | (-12.81) | (-8.91) | (-6.70) |
| MVOL12 | 2.0001** | 1.9964** | 2.0033** | 2.0032* |
| | (2.07) | (2.05) | (2.07) | (2.04) |
| Ave.R-sq | 0.209 | 0.208 | 0.211 | 0.213 |
| N.of Obs. | 584 | 584 | 584 | 584 |

Appendix Table 2: Predicting 12-month Non-overlapping Food Portfolio Return with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) at the 12-month horizon, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) is the non-overlapping food portfolio excess return (FOODRET) over the next 12 months. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. *t*-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample period is January 1927 to December 2014. Estimations start in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.

| | Dependent Variable: Future 12-month FOODRET, Non-overlapping | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| PDSIWA36m | | | 2.005** |
| | | | (2.532) |
| FOODRET12m | | 0.012 | -0.022 |
| | | (0.118) | (-0.186) |
| FOODBM12 | | 14.709 | 16.899 |
| | | (0.970) | (1.016) |
| MRET12 | -0.080 | -0.224 | -0.206 |
| | (-1.098) | (-1.125) | (-1.105) |
| INF12 | 0.189 | 0.199 | 0.031 |
| | (0.738) | (0.987) | (0.125) |
| DP12 | 7.782*** | -4.707 | -5.511 |
| | (6.537) | (-0.384) | (-0.411) |
| MVOL12 | -0.463* | -0.343 | -0.362 |
| | (-1.805) | (-1.235) | (-1.373) |
| NTIS12 | -2.376*** | -2.204*** | -2.263*** |
| | (-6.921) | (-6.707) | (-6.990) |
| DSPR12 | 1.573 | -0.193 | 0.222 |
| | (0.686) | (-0.061) | (0.083) |
| TSPR12 | 2.300*** | 2.926*** | 2.761*** |
| | (5.937) | (4.267) | (3.631) |
| CONST | 37.938*** | 5.600 | 4.750 |
| | (5.768) | (0.178) | (0.137) |
| $R^2$ | 0.22 | 0.24 | 0.26 |
| $N$ | 85 | 85 | 85 |

## Appendix Table 3: Predicting Non-overlapping Food Portfolio Returns over Different Horizons with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) over different horizons, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variables (forecasts) are the non-overlapping food portfolio excess returns (FOODRET) over the next 1 month, 3 months and 6 months in columns 1m, 3m and 6m respectively. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. $t$-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample period is January 1927 to December 2014.

| | Dependent Variables: Future FOODRET over 1m, 3m and 6m, Non-overlapping | | |
|---|---|---|---|
| | 1m | 3m | 6m |
| PDSIWA36m | 0.185* | 0.558 | 1.062** |
| | (1.648) | (1.620) | (2.260) |
| FOODRET12m | -0.001 | -0.027 | -0.011 |
| | (-0.038) | (-0.491) | (-0.125) |
| FOODBM12 | 0.488 | 1.929 | 6.604 |
| | (0.716) | (0.676) | (1.171) |
| MRET12 | 0.004 | -0.011 | -0.111 |
| | (0.235) | (-0.212) | (-1.371) |
| INF12 | -0.058 | -0.143 | -0.340** |
| | (-0.897) | (-0.856) | (-2.091) |
| DP12 | 0.428 | 1.135 | -0.048 |
| | (0.702) | (0.475) | (-0.010) |
| MVOL12 | -0.008 | -0.039 | -0.308*** |
| | (-0.274) | (-0.613) | (-2.791) |
| NTIS12 | -0.237*** | -0.877*** | -1.345*** |
| | (-3.003) | (-3.837) | (-3.576) |
| DSPR12 | -0.102 | -0.389 | -0.600 |
| | (-0.280) | (-0.458) | (-0.490) |
| TSPR12 | 0.139 | 0.456** | 1.382* |
| | (1.618) | (2.134) | (1.883) |
| CONST | 2.856 | 9.138 | 14.329 |
| | (1.545) | (1.422) | (1.133) |
| $R^2$ | 0.02 | 0.06 | 0.14 |
| $N$ | 1020 | 340 | 170 |

## Appendix Table 4: Predicting 12-month Non-overlapping Food Portfolio Return with Moving Averages of PDSIWA at Different Frequencies

This table shows the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) at the 12-month horizon, using the moving averages of the weighted PDSI values (PDSIWA) over different frequencies. The dependent variable (forecast) is the non-overlapping food portfolio excess return (FOODRET) over the next 12 months. The key explanatory (forecasting) variables, PDSIWA12m to PDSIWA30m, are the moving averages of the weighted PDSI values (PDSIWA) over the previous 12 months, 18 months, 24 months and 30 months respectively. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. *t*-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ and the number of observations ($N$) in each regression are also reported. The sample period is January 1927 to December 2014. Estimations start in December 1929 to be consistent with our baseline Table 2.

| | Dep. Var.: Future 12-month Non-overlapping FOODRET | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| PDSIWA12m | 0.673 | | | |
| | (0.454) | | | |
| PDSIWA18m | | 0.752 | | |
| | | (0.907) | | |
| PDSIWA24m | | | 1.264** | |
| | | | (2.245) | |
| PDSIWA30m | | | | 1.749*** |
| | | | | (2.719) |
| FOODRET12m | 0.003 | 0.002 | -0.004 | -0.015 |
| | (0.025) | (0.022) | (-0.040) | (-0.130) |
| FOODBM12 | 15.681 | 15.719 | 16.154 | 16.651 |
| | (0.914) | (0.966) | (1.012) | (1.024) |
| MRET12 | -0.224 | -0.224 | -0.220 | -0.209 |
| | (-1.190) | (-1.178) | (-1.172) | (-1.131) |
| INF12 | 0.110 | 0.099 | 0.051 | 0.018 |
| | (0.491) | (0.485) | (0.219) | (0.074) |
| DP12 | -5.246 | -5.161 | -5.273 | -5.370 |
| | (-0.391) | (-0.402) | (-0.412) | (-0.411) |
| MVOL12 | -0.357 | -0.357 | -0.362 | -0.355 |
| | (-1.452) | (-1.375) | (-1.351) | (-1.326) |
| NTIS12 | -2.233*** | -2.246*** | -2.265*** | -2.280*** |
| | (-6.906) | (-6.934) | (-7.040) | (-7.089) |
| DSPR12 | -0.057 | -0.064 | 0.019 | 0.072 |
| | (-0.021) | (-0.022) | (0.007) | (0.026) |
| TSPR12 | 2.840*** | 2.855*** | 2.811*** | 2.792*** |
| | (4.626) | (4.040) | (3.700) | (3.649) |
| CONST | 4.882 | 5.224 | 5.279 | 5.200 |
| | (0.146) | (0.161) | (0.161) | (0.155) |
| $R^2$ | 0.25 | 0.25 | 0.25 | 0.26 |
| $N$ | 85 | 85 | 85 | 85 |

Appendix Table 5: Predicting 12-month Non-overlapping Food Portfolio Return with Alternative PDSIWA Measures

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) at the 12-month horizon, using the 36-month moving averages of alternative PDSIWA measures. The dependent variable (forecast) is the non-overlapping food portfolio excess return (FOODRET) over the next 12 months. The key explanatory (forecasting) variables in columns (1) to (3) are the 36-month moving averages of, respectively, the weighted average (based on cropland areas) of the PDSI values of all 48 contiguous US states (PDSIASWA), the weighted average PDSI of all 48 states with the gross cash income of the farm sector in each state as weight (PDSIASCAWA), and the PDSI of USA produced directly by the US NOAA (PDSIUSA). Other control variables, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. $t$-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample period is January 1927 to December 2014.

| | Dependent Variable: Future 12-month FOODRET, Non-overlapping | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| PDSIASWA36m | 2.510** | | |
| | (2.392) | | |
| PDSIASCAWA36m | | 2.516* | |
| | | (1.939) | |
| PDSIUSA36m | | | 1.263* |
| | | | (1.774) |
| FOODRET12m | -0.018 | -0.012 | -0.015 |
| | (-0.154) | (-0.108) | (-0.131) |
| FOODBM12 | 17.122 | 16.599 | 17.578 |
| | (1.022) | (1.006) | (1.061) |
| MRET12 | -0.217 | -0.220 | -0.231 |
| | (-1.198) | (-1.217) | (-1.354) |
| INF12 | 0.022 | 0.024 | 0.015 |
| | (0.086) | (0.100) | (0.063) |
| DP12 | -5.616 | -5.572 | -6.923 |
| | (-0.416) | (-0.420) | (-0.525) |
| MVOL12 | -0.379 | -0.352 | -0.337 |
| | (-1.404) | (-1.246) | (-1.196) |
| NTIS12 | -2.309*** | -2.310*** | -2.321*** |
| | (-7.351) | (-7.385) | (-7.498) |
| DSPR12 | 0.404 | 0.062 | -0.008 |
| | (0.150) | (0.022) | (-0.003) |
| TSPR12 | 2.875*** | 2.923*** | 2.946*** |
| | (3.611) | (3.747) | (3.503) |
| CONST | 4.516 | 4.445 | 0.471 |
| | (0.130) | (0.130) | (0.014) |
| $R^2$ | 0.26 | 0.26 | 0.26 |
| $N$ | 85 | 85 | 85 |

# Appendix Table 6: Predicting 12-month Non-overlapping Food Portfolio net of Market Return with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, at the 12-month horizon, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) is the non-overlapping FOODXMRET, the food portfolio return net of the return of the market excluding food (MXF) portfolio, over the next 12 months. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, FOODXMRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the FOODXMRET, the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. *t*-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample period is January 1927 to December 2014.

| | Dependent Variable: Future 12-month FOODXMRET, Non-overlapping | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| PDSIWA36m | | | 1.230*** |
| | | | (3.013) |
| FOODXMRET12m | | 0.011 | -0.008 |
| | | (0.127) | (-0.092) |
| FOODBM12 | | 9.413*** | 10.737** |
| | | (2.764) | (2.601) |
| MRET12 | -0.111** | -0.194*** | -0.203*** |
| | (-2.609) | (-3.068) | (-2.983) |
| INF12 | 0.097 | 0.105 | 0.001 |
| | (0.864) | (0.732) | (0.010) |
| DP12 | -5.240 | -13.237*** | -13.710** |
| | (-1.609) | (-2.669) | (-2.387) |
| MVOL12 | -0.334** | -0.257* | -0.269* |
| | (-2.166) | (-1.688) | (-1.761) |
| NTIS12 | 0.240 | 0.354 | 0.318 |
| | (0.241) | (0.356) | (0.319) |
| DSPR12 | 4.675*** | 3.542** | 3.804*** |
| | (2.890) | (2.437) | (2.718) |
| TSPR12 | -0.794 | -0.397 | -0.499 |
| | (-1.381) | (-0.756) | (-1.028) |
| CONST | -16.251 | -36.973** | -37.445* |
| | (-1.139) | (-2.007) | (-1.821) |
| $R^2$ | 0.07 | 0.09 | 0.10 |
| $N$ | 85 | 85 | 85 |

## Appendix Table 7: Predicting 1-year Food Industry Change in Profitability (CP) with 36-month Moving Average of PDSIWA

This table presents the results from forecasting the future 1-year CP, the change in profitability of the food industry over the next year, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) is the CP, the future change in the food industry profitability, over the next year. The key explanatory (forecasting) variable, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 3 years (36 months). The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, CP1y, FOODRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the change in the food industry profitability, the food industry portfolio return (FOODRET), the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous year (12 months). CONST is the constant term. *t*-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample period is 1950 to 2014.

| | Dependent Variable: Future 1-year Change in Food Industry Profitability | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| PDSIWA36m | | | 0.100** |
| | | | (2.412) |
| CP1y | | -0.101 | -0.125 |
| | | (-0.942) | (-0.969) |
| FOODRET12m | | -0.016*** | -0.017*** |
| | | (-3.668) | (-4.455) |
| FOODBM12 | | 0.148 | 0.299 |
| | | (0.714) | (1.388) |
| MRET12 | -0.003 | 0.008* | 0.008 |
| | (-0.633) | (1.788) | (1.436) |
| INF12 | -0.078*** | -0.084*** | -0.094*** |
| | (-3.101) | (-3.198) | (-3.480) |
| DP12 | 0.157 | 0.033 | -0.068 |
| | (1.648) | (0.142) | (-0.282) |
| MVOL12 | 0.031*** | 0.027*** | 0.026*** |
| | (3.227) | (3.761) | (2.804) |
| NTIS12 | 0.119** | 0.089* | 0.088** |
| | (2.518) | (1.978) | (2.018) |
| DSPR12 | 0.285 | 0.319* | 0.280 |
| | (1.396) | (1.796) | (1.453) |
| TSPR12 | -0.002 | 0.020 | 0.009 |
| | (-0.105) | (0.666) | (0.283) |
| CONST | 0.026 | -0.192 | -0.361 |
| | (0.065) | (-0.299) | (-0.528) |
| $R^2$ | 0.22 | 0.27 | 0.29 |
| $N$ | 63 | 63 | 63 |

Appendix Table 8: Predicting Non-overlapping Returns of Other Fama-French 17-Industry Portfolios with 36-month Moving Average of PDSIWA

This table shows the results from forecasting the future non-overlapping industry portfolio excess returns of all Fama-French 17 industries over different horizons, using the 36-month moving average of the weighted PDSI values (PDSIWA). The dependent variable (forecast) for each industry is the non-overlapping industry portfolio excess return over the next 1 month (first set of 3 columns), 3 months (second set of 3 columns), 6 months (third set of 3 columns), or 12 months (last set of 3 columns). The key explanatory (forecasting) variable in each regression, PDSIWA36m, is the moving average of the weighted PDSI values (PDSIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. All regressions include other control variables, INDUSRET12m, INDUSBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12. They denote, respectively, the industry portfolio excess return (INDUSRET), the log of the industry book-to-market ratio (INDUSBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. For clarity, we only show the coefficient estimates and $t$-statistics for our main predictor variable PDSIWA36m. $t$-statistics are based on Newey-West HAC standard errors with a lag order of 36 for all of the regressions. Results are ranked based on the magnitude of the $t$-statistics. The sample period is January 1927 to December 2014.

| Non-overlapping 1m Return | | | Non-overlapping 3m Return | | | Non-overlapping 6m Return | | | Non-overlapping 12m Return | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Industry | PDSIWA36m | $t$-stat | Industry | PDSIWA36m | $t$-stat | Industry | PDSIWA36m | $t$-stat | Industry | PDSIWA36m | $t$-stat |
| **Food** | **0.185** | **1.648** | **Food** | **0.558** | **1.671** | **Food** | **1.062** | **2.260** | **Food** | **2.005** | **2.532** |
| Rtail | 0.157 | 1.349 | Cars | 0.461 | 1.142 | Rtail | 0.712 | 1.164 | Utils | 0.730 | 0.966 |
| Clths | 0.163 | 1.077 | Rtail | 0.429 | 1.124 | Trans | 0.840 | 0.972 | Rtail | 1.055 | 0.915 |
| Other | 0.124 | 1.075 | Trans | 0.440 | 0.874 | Other | 0.604 | 0.917 | Trans | 1.290 | 0.886 |
| Cars | 0.172 | 1.044 | Clths | 0.384 | 0.87 | Clths | 0.604 | 0.783 | Other | 0.698 | 0.746 |
| Finan | 0.136 | 0.929 | Finan | 0.347 | 0.861 | Utils | 0.401 | 0.706 | Clths | 1.138 | 0.682 |
| Trans | 0.143 | 0.922 | Other | 0.327 | 0.844 | Mines | 0.228 | 0.371 | Cars | 0.786 | 0.648 |
| Cnstr | 0.128 | 0.803 | Cnstr | 0.364 | 0.827 | Cnsum | 0.216 | 0.300 | Finan | 0.619 | 0.539 |
| Utils | 0.094 | 0.685 | Mines | 0.292 | 0.69 | Cnstr | 0.157 | 0.219 | Cnstr | 0.464 | 0.524 |
| Mines | 0.105 | 0.636 | Utils | 0.204 | 0.644 | Finan | 0.149 | 0.208 | Cnsum | 0.648 | 0.497 |
| Cnsum | 0.067 | 0.541 | Cnsum | 0.151 | 0.362 | Oil | 0.062 | 0.137 | Chems | 0.773 | 0.442 |
| Chems | 0.043 | 0.344 | Chems | 0.055 | 0.141 | Cars | 0.154 | 0.130 | Oil | 0.186 | 0.208 |
| Machn | 0.046 | 0.316 | Oil | 0.047 | 0.135 | Machn | -0.222 | -0.148 | Mines | 0.042 | 0.040 |
| Durbl | 0.049 | 0.286 | Durbl | 0.077 | 0.129 | Durbl | -0.151 | -0.171 | Durbl | -0.440 | -0.332 |
| Oil | 0.026 | 0.176 | Machn | 0.021 | 0.038 | Chems | -0.368 | -0.288 | Machn | -0.956 | -0.393 |
| Steel | -0.101 | -0.521 | FabPr | -0.240 | -0.611 | FabPr | -0.689 | -0.933 | FabPr | -1.440 | -1.398 |
| FabPr | -0.067 | -0.530 | Steel | -0.597 | -1.149 | Steel | -1.679 | -1.441 | Steel | -4.168 | -2.015 |

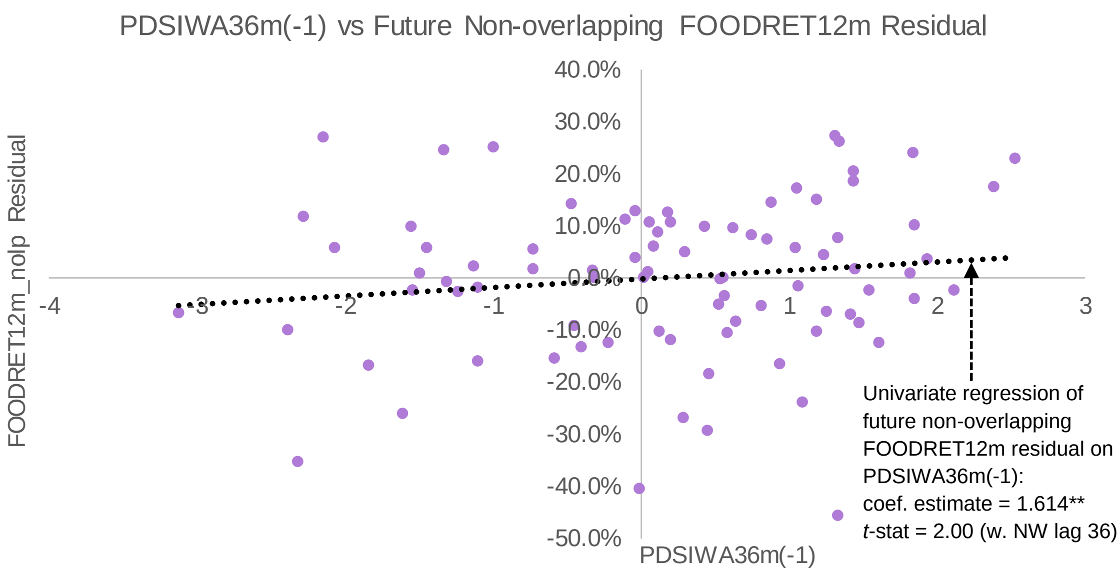
## Appendix Table 9: Predicting Non-overlapping Food Portfolio Returns and Food Industry Change in Profitability with 36-month Moving Average of PMDIWA

This table presents the results from forecasting the future non-overlapping food industry portfolio excess returns (FOODRET) over different horizons and the future 1-year change in profitability of the food industry, using the 36-month moving average of the weighted PMDI (Modified Palmer Drought Severity Index) values. The dependent variables (forecasts) are the non-overlapping food portfolio excess returns (FOODRET) over the next 1 month, 3 months, 6 months and 12 months (Future FOODRET1m to Future FOODRET12m), the non-overlapping food portfolio return net of the return of the market excluding food (MXF) portfolio over the next 12 months (Future FOODXMRET12m), and the future change in the food industry profitability over the next year (Future CP1y). The key explanatory (forecasting) variable, PMDIWA36m, is the moving average of the weighted PMDI values (PMDIWA) over the previous 36 months. The weighted average is over the top 10 food-producing states using cropland area as weight. Other control variables, CP1y, FOODRET12m, FOODXMRET12m, FOODBM12, MRET12, INF12, DP12, MVOL12, NTIS12, DSPR12 and TSPR12 denote, respectively, the change in the food industry profitability (CP), the food portfolio return (FOODRET), the food portfolio net of market return (FOODXMRET), the log of the food industry book-to-market ratio (FOODBM), the market excess return (MRET), the inflation rate (INF), the log of the market dividend price ratio (DP), the market volatility (MVOL), the net equity expansion ratio (NTIS), the default spread (DSPR) and the term spreads (TSPR), all over the previous 12 months. CONST is the constant term. *t*-statistics based on Newey-West HAC standard errors are shown in parentheses, with a lag order of 36 for all of the regressions. *, **, *** denote statistical significance at 10%, 5%, 1% respectively. The $R^2$ for each regression is also reported. $N$ is the number of observation points in each regression. The sample period is January 1927 to December 2014 for the return regressions and 1950 to 2014 for the change in profitability regression.

| | Dependent Variable | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | Future FOODRET1m | Future FOODRET3m | Future FOODRET6m | Future FOODRET12m | Future FOODXMRET12m | Future CP1y |
| PMDIWA36m | 0.188 | 0.565 | 1.122** | 2.104*** | 1.344*** | 0.108** |
| | (1.635) | (1.611) | (2.368) | (2.674) | (2.941) | (2.380) |
| CP1y | | | | | | -0.132 |
| | | | | | | (-0.990) |
| FOODRET12m | -0.000 | -0.026 | -0.011 | -0.021 | | -0.017*** |
| | (-0.029) | (-0.488) | (-0.129) | (-0.185) | | (-4.442) |
| FOODXMRET12m | | | | | -0.009 | |
| | | | | | (-0.100) | |
| FOODBM12 | 0.489 | 1.935 | 6.672 | 17.095 | 10.917*** | 0.319 |
| | (0.717) | (0.680) | (1.187) | (1.028) | (2.687) | (1.449) |
| MRET12 | 0.004 | -0.011 | -0.110 | -0.206 | -0.203*** | 0.007 |
| | (0.236) | (-0.211) | (-1.352) | (-1.096) | (-2.984) | (1.401) |
| INF12 | -0.057 | -0.140 | -0.339** | 0.032 | -0.002 | -0.094*** |
| | (-0.884) | (-0.812) | (-2.054) | (0.129) | (-0.011) | (-3.460) |
| DP12 | 0.436 | 1.157 | -0.032 | -5.534 | -13.744** | -0.083 |
| | (0.712) | (0.489) | (-0.007) | (-0.411) | (-2.386) | (-0.336) |
| MVOL12 | -0.007 | -0.038 | -0.307*** | -0.355 | -0.266* | 0.026*** |
| | (-0.265) | (-0.563) | (-2.775) | (-1.348) | (-1.728) | (2.819) |
| NTIS12 | -0.236*** | -0.875*** | -1.344*** | -2.265*** | 0.315 | 0.089* |
| | (-3.016) | (-3.756) | (-3.584) | (-6.910) | (0.316) | (2.005) |
| DSPR12 | -0.107 | -0.407 | -0.616 | 0.127 | 3.754*** | 0.271 |
| | (-0.293) | (-0.463) | (-0.508) | (0.048) | (2.698) | (1.365) |
| TSPR12 | 0.138 | 0.452** | 1.374* | 2.742*** | -0.515 | 0.007 |
| | (1.599) | (2.039) | (1.868) | (3.578) | (-1.081) | (0.229) |
| CONST | 2.877 | 9.201 | 14.426 | 4.797 | -37.436* | -0.392 |
| | (1.557) | (1.459) | (1.139) | (0.138) | (-1.804) | (-0.565) |
| $R^2$ | 0.02 | 0.06 | 0.14 | 0.26 | 0.11 | 0.29 |
| $N$ | 1020 | 340 | 170 | 85 | 85 | 63 |

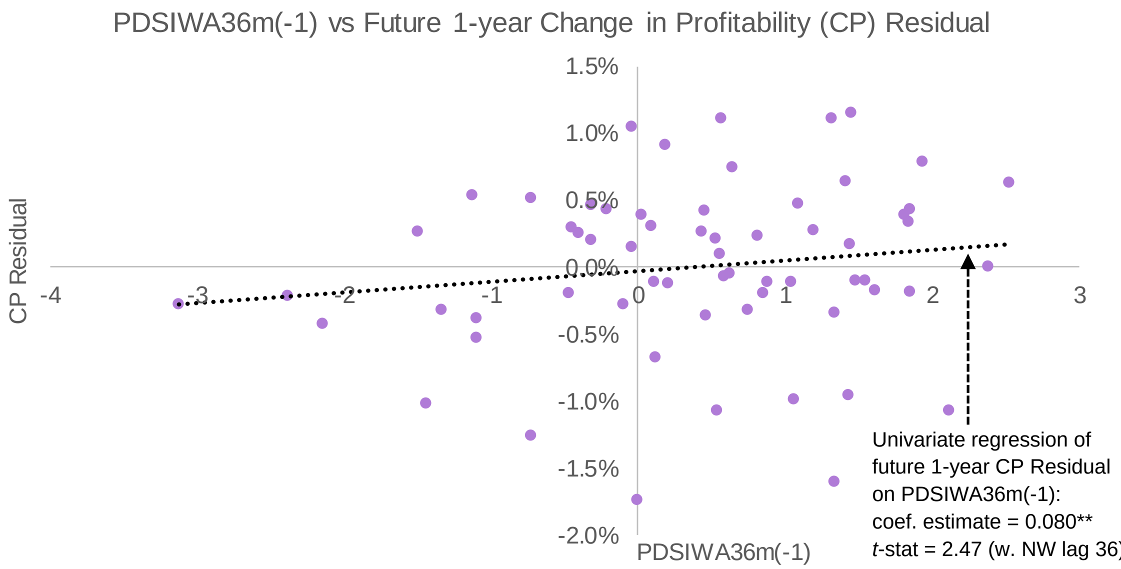
Appendix Figure 1: Future Non-overlapping 12-month Food Portfolio Return Residual and Past 36-month Moving Average of PDSIWA, Scatter Plot

This figure depicts the scatter plot of the future non-overlapping 12-month food portfolio return residual against our main predictor variable PDSIWA36m, the past 36-month moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is January 1927 to December 2014. The plot starts in December 1929 as the first 36 months are used to obtain the first value of PDSIWA36m.



Appendix Figure 2: Future 1-year Change in Food Industry Profitability (CP) Residual and Past 36-month Moving Average of PDSIWA, Scatter Plot

This figure depicts the scatter plot of the future 1-year change in the food industry profitability (CP) residual against our main predictor variable PDSIWA36m, the past 36-month (3-year) moving average of the weighted average (by cropland area) PDSI value of the top 10 food-producing states in the US. The sample period is 1950 to 2014.



**Final Report**

# Recommendations of the Task Force on Climate-related Financial Disclosures

TCFD | TASK FORCE ON CLIMATE-RELATED FINANCIAL DISCLOSURES

June 2017

June 15, 2017

Mr. Mark Carney
Chairman
Financial Stability Board
Bank for International Settlements
Centralbahnplatz 2
CH-4002 Basel
Switzerland

Dear Chairman Carney,

On behalf of the Task Force on Climate-related Financial Disclosures, I am pleased to present this final report setting out our recommendations for helping businesses disclose climate-related financial information.

As you know, warming of the planet caused by greenhouse gas emissions poses serious risks to the global economy and will have an impact across many economic sectors. It is difficult for investors to know which companies are most at risk from climate change, which are best prepared, and which are taking action.

The Task Force's report establishes recommendations for disclosing clear, comparable and consistent information about the risks and opportunities presented by climate change. Their widespread adoption will ensure that the effects of climate change become routinely considered in business and investment decisions. Adoption of these recommendations will also help companies better demonstrate responsibility and foresight in their consideration of climate issues. That will lead to smarter, more efficient allocation of capital, and help smooth the transition to a more sustainable, low-carbon economy.

The industry Task Force spent 18 months consulting with a wide range of business and financial leaders to hone its recommendations and consider how to help companies better communicate key climate-related information. The feedback we received in response to the Task Force's draft report confirmed broad support from industry and others, and involved productive dialogue among companies and banks, insurers, and investors. This was and remains a collaborative process, and as these recommendations are implemented, we hope that this dialogue and feedback continues.

Since the Task Force began its work, we have also seen a significant increase in demand from investors for improved climate-related financial disclosures. This comes amid unprecedented support among companies for action to tackle climate change.

I want to thank the Financial Stability Board for its leadership in promoting better disclosure of climate-related financial risks, and for its support of the Task Force's work. I am also grateful to the Task Force members and Secretariat for their extensive contributions and dedication to this effort.

The risk climate change poses to businesses and financial markets is real and already present. It is more important than ever that businesses lead in understanding and responding to these risks—and seizing the opportunities—to build a stronger, more resilient, and sustainable global economy.

Sincerely,

Michael R. Bloomberg

# Executive Summary

## Financial Markets and Transparency

One of the essential functions of financial markets is to price risk to support informed, efficient capital-allocation decisions. Accurate and timely disclosure of current and past operating and financial results is fundamental to this function, but it is increasingly important to understand the governance and risk management context in which financial results are achieved. The financial crisis of 2007-2008 was an important reminder of the repercussions that weak corporate governance and risk management practices can have on asset values. This has resulted in increased demand for transparency from organizations on their governance structures, strategies, and risk management practices. Without the right information, investors and others may incorrectly price or value assets, leading to a misallocation of capital.

> Increasing transparency makes markets more efficient and economies more stable and resilient.
> —Michael R. Bloomberg

## Financial Implications of Climate Change

One of the most significant, and perhaps most misunderstood, risks that organizations face today relates to climate change. While it is widely recognized that continued emission of greenhouse gases will cause further warming of the planet and this warming could lead to damaging economic and social consequences, the exact timing and severity of physical effects are difficult to estimate. The large-scale and long-term nature of the problem makes it uniquely challenging, especially in the context of economic decision making. Accordingly, many organizations incorrectly perceive the implications of climate change to be long term and, therefore, not necessarily relevant to decisions made today.

The potential impacts of climate change on organizations, however, are not only physical and do not manifest only in the long term. To stem the disastrous effects of climate change within this century, nearly 200 countries agreed in December 2015 to reduce greenhouse gas emissions and accelerate the transition to a lower-carbon economy. The reduction in greenhouse gas emissions implies movement away from fossil fuel energy and related physical assets. This coupled with rapidly declining costs and increased deployment of clean and energy-efficient technologies could have significant, near-term financial implications for organizations dependent on extracting, producing, and using coal, oil, and natural gas. While such organizations may face significant climate-related risks, they are not alone. In fact, climate-related risks and the expected transition to a lower-carbon economy affect most economic sectors and industries. While changes associated with a transition to a lower-carbon economy present significant risk, they also create significant opportunities for organizations focused on climate change mitigation and adaptation solutions.

For many investors, climate change poses significant financial challenges and opportunities, now and in the future. The expected transition to a lower-carbon economy is estimated to require around $1 trillion of investments a year for the foreseeable future, generating new investment opportunities.[1] At the same time, the risk-return profile of organizations exposed to climate-related risks may change significantly as such organizations may be more affected by physical impacts of climate change, climate policy, and new technologies. In fact, a 2015 study estimated the value at risk, as a result of climate change, to the total global stock of manageable assets as

[1] International Energy Agency, *World Energy Outlook Special Briefing for COP21*, 2015.

ranging from $4.2 trillion to $43 trillion between now and the end of the century.[2] The study highlights that "much of the impact on future assets will come through weaker growth and lower asset returns across the board." This suggests investors may not be able to avoid climate-related risks by moving out of certain asset classes as a wide range of asset types could be affected. Both investors and the organizations in which they invest, therefore, should consider their longer-term strategies and most efficient allocation of capital. Organizations that invest in activities that may not be viable in the longer term may be less resilient to the transition to a lower-carbon economy; and their investors will likely experience lower returns. Compounding the effect on longer-term returns is the risk that present valuations do not adequately factor in climate-related risks because of insufficient information. As such, long-term investors need adequate information on how organizations are preparing for a lower-carbon economy.

Furthermore, because the transition to a lower-carbon economy requires significant and, in some cases, disruptive changes across economic sectors and industries in the near term, financial policymakers are interested in the implications for the global financial system, especially in terms of avoiding financial dislocations and sudden losses in asset values. Given such concerns and the potential impact on financial intermediaries and investors, the G20 Finance Ministers and Central Bank Governors asked the Financial Stability Board to review how the financial sector can take account of climate-related issues. As part of its review, the Financial Stability Board identified the need for better information to support informed investment, lending, and insurance underwriting decisions and improve understanding and analysis of climate-related risks and opportunities. Better information will also help investors engage with companies on the resilience of their strategies and capital spending, which should help promote a smooth rather than an abrupt transition to a lower-carbon economy.

## Task Force on Climate-related Financial Disclosures

To help identify the information needed by investors, lenders, and insurance underwriters to appropriately assess and price climate-related risks and opportunities, the Financial Stability Board established an industry-led task force: the Task Force on Climate-related Financial Disclosures (Task Force). The Task Force was asked to develop voluntary, consistent climate-related financial disclosures that would be useful to investors, lenders, and insurance underwriters in understanding material risks. The 32-member Task Force is global; its members were selected by the Financial Stability Board and come from various organizations, including large banks, insurance companies, asset managers, pension funds, large non-financial companies, accounting and consulting firms, and credit rating agencies. In its work, the Task Force drew on member expertise, stakeholder engagement, and existing climate-related disclosure regimes to develop a singular, accessible framework for climate-related financial disclosure.

The Task Force developed four widely adoptable recommendations on climate-related financial disclosures that are applicable to organizations across sectors and jurisdictions (Figure 1). Importantly, the Task Force's recommendations apply to financial-sector organizations, including banks, insurance companies, asset managers, and asset owners. Large asset owners and asset managers sit at the top of the investment chain and, therefore, have an

Figure 1

**Key Features of Recommendations**

- Adoptable by all organizations
- Included in financial filings
- Designed to solicit decision-useful, forward-looking information on financial impacts
- Strong focus on risks and opportunities related to transition to lower-carbon economy

[2] The Economist Intelligence Unit, "The Cost of Inaction: Recognising the Value at Risk from Climate Change," 2015. Value at risk measures the loss a portfolio may experience, within a given time horizon, at a particular probability, and the stock of manageable assets is defined as the total stock of assets held by non-bank financial institutions. Bank assets were excluded as they are largely managed by banks themselves.

important role to play in influencing the organizations in which they invest to provide better climate-related financial disclosures.

In developing and finalizing its recommendations, the Task Force solicited input throughout the process.[3] First, in April 2016, the Task Force sought public comment on the scope and high-level objectives of its work. As the Task Force developed its disclosure recommendations, it continued to solicit feedback through hundreds of industry interviews, meetings, and other touchpoints. Then, in December 2016, the Task Force issued its draft recommendations and sought public comment on the recommendations as well as certain key issues, receiving over 300 responses. This final report reflects the Task Force's consideration of industry and other public feedback received throughout 2016 and 2017. Section E contains a summary of key issues raised by the industry as well as substantive changes to the report since December.

### Disclosure in Mainstream Financial Filings

The Task Force recommends that preparers of climate-related financial disclosures provide such disclosures in their mainstream (i.e., public) annual financial filings. In most G20 jurisdictions, companies with public debt or equity have a legal obligation to disclose material information in their financial filings—including material climate-related information. The Task Force believes climate-related issues are or could be material for many organizations, and its recommendations should be useful to organizations in complying more effectively with existing disclosure obligations.[4] In addition, disclosure in mainstream financial filings should foster shareholder engagement and broader use of climate-related financial disclosures, thus promoting a more informed understanding of climate-related risks and opportunities by investors and others. The Task Force also believes that publication of climate-related financial information in mainstream annual financial filings will help ensure that appropriate controls govern the production and disclosure of the required information. More specifically, the Task Force expects the governance processes for these disclosures would be similar to those used for existing public financial disclosures and would likely involve review by the chief financial officer and audit committee, as appropriate.

Importantly, organizations should make financial disclosures in accordance with their national disclosure requirements. If certain elements of the recommendations are incompatible with national disclosure requirements for financial filings, the Task Force encourages organizations to disclose those elements in other official company reports that are issued at least annually, widely distributed and available to investors and others, and subject to internal governance processes that are the same or substantially similar to those used for financial reporting.

### Core Elements of Climate-Related Financial Disclosures

The Task Force structured its recommendations around four thematic areas that represent core elements of how organizations operate: governance, strategy, risk management, and metrics and targets (Figure 2, p. v). The four overarching recommendations are supported by recommended disclosures that build out the framework with information that will help investors and others understand how reporting organizations assess climate-related risks and opportunities.[5] In addition, there is guidance to support all organizations in developing climate-related financial disclosures consistent with the recommendations and recommended disclosures. The guidance assists preparers by providing context and suggestions for implementing the recommended disclosures. For the financial sector and certain non-financial sectors, *supplemental* guidance was developed to highlight important sector-specific considerations and provide a fuller picture of potential climate-related financial impacts in those sectors.

[3] See Appendix 2: Task Force Objectives and Approach for more information.

[4] The Task Force encourages organizations where climate-related issues could be material in the future to begin disclosing climate-related financial information outside financial filings to facilitate the incorporation of such information into financial filings once climate-related issues are determined to be material.

[5] See Figure 4 on p. 14 for the Task Force's recommendations and recommended disclosures.

Figure 2

## Core Elements of Recommended Climate-Related Financial Disclosures


**Governance**
The organization's governance around climate-related risks and opportunities

**Strategy**
The actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning

**Risk Management**
The processes used by the organization to identify, assess, and manage climate-related risks

**Metrics and Targets**
The metrics and targets used to assess and manage relevant climate-related risks and opportunities

### Climate-Related Scenarios

One of the Task Force's key recommended disclosures focuses on the resilience of an organization's strategy, taking into consideration different climate-related scenarios, including a 2° Celsius or lower scenario.[6] An organization's disclosure of how its strategies might change to address potential climate-related risks and opportunities is a key step to better understanding the potential implications of climate change on the organization. The Task Force recognizes the use of scenarios in assessing climate-related issues and their potential financial implications is relatively recent and practices will evolve over time, but believes such analysis is important for improving the disclosure of decision-useful, climate-related financial information.

## Conclusion

Recognizing that climate-related financial reporting is still evolving, the Task Force's recommendations provide a foundation to improve investors' and others' ability to appropriately assess and price climate-related risk and opportunities. The Task Force's recommendations aim to be ambitious, but also practical for near-term adoption. The Task Force expects to advance the quality of mainstream financial disclosures related to the potential effects of climate change on organizations today and in the future and to increase investor engagement with boards and senior management on climate-related issues.

Improving the quality of climate-related financial disclosures begins with organizations' willingness to adopt the Task Force's recommendations. Organizations already reporting climate-related information under other frameworks may be able to disclose under this framework immediately and are strongly encouraged to do so. Those organizations in early stages of evaluating the impact of climate change on their businesses and strategies can begin by disclosing climate-related issues as they relate to governance, strategy, and risk management practices. The Task Force recognizes the challenges associated with measuring the impact of climate change, but believes that by moving climate-related issues into mainstream annual financial filings, practices and techniques will evolve more rapidly. Improved practices and techniques, including data analytics, should further improve the quality of climate-related financial disclosures and, ultimately, support more appropriate pricing of risks and allocation of capital in the global economy.

[6] A 2° Celsius (2°C) scenario lays out an energy system deployment pathway and an emissions trajectory consistent with limiting the global average temperature increase to 2°C above the pre-industrial average. The Task Force is not recommending organizations use a specific 2°C scenario.

# Contents

# B Climate-Related Risks, Opportunities, and Financial Impacts

Figure 4

## Recommendations and Supporting Recommended Disclosures

| Governance | Strategy | Risk Management | Metrics and Targets |
|---|---|---|---|
| Disclose the organization's governance around climate-related risks and opportunities. | Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material. | Disclose how the organization identifies, assesses, and manages climate-related risks. | Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material. |
| **Recommended Disclosures** | **Recommended Disclosures** | **Recommended Disclosures** | **Recommended Disclosures** |
| a) Describe the board's oversight of climate-related risks and opportunities. | a) Describe the climate-related risks and opportunities the organization has identified over the short, medium, and long term. | a) Describe the organization's processes for identifying and assessing climate-related risks. | a) Disclose the metrics used by the organization to assess climate-related risks and opportunities in line with its strategy and risk management process. |
| b) Describe management's role in assessing and managing climate-related risks and opportunities. | b) Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning. | b) Describe the organization's processes for managing climate-related risks. | b) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks. |
| | c) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario. | c) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management. | c) Describe the targets used by the organization to manage climate-related risks and opportunities and performance against targets. |

Box 2

## Determination of Non-Financial Groups

In an effort to focus supplemental guidance on those non-financial sectors and industries with the highest likelihood of climate-related financial impacts, the Task Force assessed three factors most likely to be affected by both transition risk (policy and legal, technology, market, and reputation) and physical risk (acute and chronic)—GHG emissions, energy usage, and water usage.

The underlying premise in using these three factors is that climate-related physical and transition risks will likely manifest themselves primarily and broadly in the form of constraints on GHG emissions, effects on energy production and usage, and effects on water availability, usage, and quality. Other factors, such as waste management and land use, are also important, but may not be as determinative across a wide range of industries or may be captured in one of the primary categories.

In taking this approach, the Task Force consulted a number of sources regarding the ranking of various sectors and industries according to these three factors. The various rankings were used to determine an overall set of sectors and industries that have significant exposure to transition or physical risks related to GHG emissions, energy, or water. The sectors and industries were grouped into four categories of industries that have similar economic activities and climate-related exposures.

These four groups and their associated industries are intended to be indicative of the economic activities associated with these industries rather than definitive industry categories. Other industries with similar activities and climate-related exposures should consider the supplemental guidance as well.

The Task Force validated its approach using a variety of sources, including:

1. The TCFD Phase I report public consultation, soliciting more than 200 responses which ranked Energy, Utilities, Materials, Industrials and Consumer Staples/Discretionary, in that order, as the Global Industry Classification Standard (GICS) sectors most important for disclosure guidelines to cover.

2. Numerous sector-specific disclosure guidance documents to understand various breakdowns by economic activity, sector, and industries, including from the following sources: CDP, GHG Protocol, Global Real Estate Sustainability Benchmark (GRESB), Global Reporting Initiative (GRI), Institutional Investors Group on Climate Change (IIGCC), IPIECA (the global oil and gas industry association for environmental and social issues), and the Sustainability Accounting Standards Board (SASB).

3. The Intergovernmental Panel on Climate Change (IPCC) report "Climate Change 2014 – Mitigation of Climate Change" that provides an analysis of global direct and indirect emissions by economic sector. The IPCC analysis highlights the dominant emissions-producing sectors as Energy; Industry; Agriculture, Forestry, and Other Land Use; and Transportation and Buildings (Commercial and Residential).

4. Research and documentation from non-governmental organizations (NGOs) and industry organizations that provide information on which industries have the highest exposures to climate change, including those from Cambridge Institute of Sustainability Leadership, China's National Development and Reform Commission (NDRC), Environmental Resources Management (ERM), IEA, Moody's, S&P Global Ratings, and WRI/UNEPFI.

Based on its assessment, the Task Force identified the four groups and their associated industries, listed in the table below, as those that would most benefit from supplemental guidance.

| Energy | Transportation | Materials and Buildings | Agriculture, Food, and Forest Products |
|---|---|---|---|
| – Oil and Gas<br>– Coal<br>– Electric Utilities | – Air Freight<br>– Passenger Air Transportation<br>– Maritime Transportation<br>– Rail Transportation<br>– Trucking Services<br>– Automobiles and Components | – Metals and Mining<br>– Chemicals<br>– Construction Materials<br>– Capital Goods<br>– Real Estate Management and Development | – Beverages<br>– Agriculture<br>– Packaged Foods and Meats<br>– Paper and Forest Products |

Table A4.1

## Select Disclosure Frameworks: Governments

| Region: Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **Australia:** National Greenhouse and Energy Reporting Act (2007) | Financial and non-financial firms that meet emissions or energy production or consumption thresholds | General public | Mandatory if thresholds are met | Based on emissions above a certain threshold | GHG emissions, energy consumption, and energy production | Report to government | Regulator may, by written notice to corporation, require an audit of its disclosures |
| **European Union (EU):** EU Directive 2014/95 regarding disclosure of non-financial and diversity information (2014) | Financial and non-financial firms that meet size criteria (i.e., have more than 500 employees) | Investors, consumers, and other stakeholders | Mandatory; applicable for the financial year starting on Jan. 1, 2017 or during the 2017 calendar year | None specified | Land use, water use, GHG emissions, use of materials, and energy use | Corporate financial report or separate report (published with financial report or on website six months after the balance sheet date and referenced in financial report) | Member States must require that statutory auditor checks whether the non-financial statement has been provided<br><br>Member States may require independent assurance for information in non-financial statement |
| **France:** Article 173, Energy Transition Law (2015) | Listed financial and non-financial firms<br><br>Additional requirements for institutional investors | Investors, general public | Mandatory | None specified | Risks related to climate change, consequences of climate change on the company's activities and use of goods and services it produces. Institutional investors: GHG emissions and contribution to goal of limiting global warming | Annual report and website | Mandatory review on the consistency of the disclosure by an independent third party, such as a statutory auditor |
| **India:** National Voluntary Guidelines on Social, Environmental, and Economic Responsibilities of Business (2011) | Financial and non-financial firms | Investors, general public | Voluntary | None specified | Significant risk, goals and targets for improving performance, materials, energy consumption, water, discharge of effluents, GHG emissions, and biodiversity | Not specified; companies may furnish a report or letter from owner/chief executive officer | Guidelines include third-party assurance as a "leadership indicator" of company's progress in implementing the principles |

Table A4.1

## Select Disclosure Frameworks: Governments *(continued)*

| Region: Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **United Kingdom:** Companies Act 2006 (Strategic Report and Directors' Report) Regulations 2013 | Financial and non-financial firms that are "Quoted Companies," as defined by the Companies Act 2006 | Investors / shareholders ("members of the company") | Mandatory | Information is material if its omission or misrepresentation could influence the economic decisions shareholders take on the basis of the annual report as a whole (section 5 of the UK FRC June 2014 Guidance on the Strategic Report) | The main trends and factors likely to affect the future development, performance, and position of the company's business, environmental matters (including the impact of the company's business on the environment), and GHG emissions | Strategic Report and Directors' Report | Not required, but statutory auditor must state in report on the company's annual accounts whether in the auditor's opinion the information given in the Strategic Report and the Directors' Report for the financial year for which the accounts are prepared is consistent with those accounts |
| **United States:** NAICs, 2010 Insurer Climate Risk Disclosure Survey | Insurers meeting certain premium thresholds - $100M in 2015 | Regulators | Mandatory if thresholds are met | None specified | General disclosures about climate change-related risk management and investment management | Survey sent to state regulators | Not specified |
| **United States:** SEC Guidance Regarding Disclosure Related to Climate Change | Financial and non-financial firms subject to Securities and Exchange Commission (SEC) reporting requirements | Investors | Mandatory | US securities law definition | Climate-related material risks and factors that can affect or have affected the company's financial condition, such as regulations, treaties and agreements, business trends, and physical impacts | Annual and other reports required to be filed with SEC | Depends on assurance requirements for information disclosed |

Table A4.2

## Select Disclosure Frameworks: Exchange Listing Requirements and Indices

| Region: Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **Australia:**<br>Australia Securities Exchange<br>Listing Requirement 4.10.3; Corporate Governance Principles and Recommendations (2014) | Listed financial and non-financial firms | Investors | Mandatory (comply or explain) | A real possibility that the risk in question could substantively impact the listed entity's ability to create or preserve value for security holders over the short, medium or long term | General disclosure of material environmental risks | Annual report must include either the corporate governance statement or company website link to the corporate governance statement on company's website | Not specified, may depend on assurance requirements for annual report |
| **Brazil:**<br>Stock Exchange (BM&FBovespa)<br>Recommendation of report or explain (2012) | Listed financial and non-financial firms | Investors, regulator | Voluntary (comply or explain) | Criteria explained in Reference Form (Annex 24) of the Instruction CVM nº 480/09 | Social and environmental information including methodology used, if audited/reviewed by an independent entity, and link to information (i.e., webpage) | Discretion of company | Not specified |
| **China:**<br>Shenzhen Stock Exchange<br>Social Responsibility Instructions to Listed Companies (2006) | Listed financial and non-financial firms | Investors | Voluntary: social responsibilities Mandatory: pollutant discharge | None specified | Waste generation, resource consumption, and pollutants | Not specified | Not specified; companies shall allocate dedicated human resources for regular inspection of implementation of environmental protection policies |
| **Singapore:**<br>Singapore Exchange<br>Listing Rules 711A & 711B and Sustainability Reporting Guide (2016) ("Guide") | Listed financial and non-financial firms | Investors | Mandatory (comply or explain) | Guidance provided in the Guide, paragraphs 4.7-4.11 | Material environmental, social, and governance factors, performance, targets, and related information specified in the Guide | Annual report or standalone report, disclosed through SGXNet reporting platform and company website | Not required |

Table A4.2

## Select Disclosure Frameworks: Exchange Listing Requirements and Indices *(continued)*

| Region: Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **South Africa:**<br>Johannesburg Stock Exchange<br>Listing Requirement Paragraph 8.63; King Code of Governance Principles (2009) | Listed financial and non-financial firms | Investors | Mandatory; (comply or explain) | None specified | General disclosure regarding sustainability performance | Annual report | Required |
| **World, regional, and country-specific indices:**<br>S&P Dow Jones Indices<br>Sustainability Index, Sample Questionnaires | Financial and non-financial firms | Investors | Voluntary | None specified | GHG emissions, SOx emissions, energy consumption, water, waste generation, environmental violations, electricity purchased, biodiversity, and mineral waste management | Nonpublic | Disclose whether external assurance was provided and whether it was pursuant to a recognized standard |

Table A4.3

## Select Disclosure Frameworks: Non-Governmental Organizations

| Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **Global:** Asset Owners Disclosure Project 2017 Global Climate Risk Survey | Pension funds, insurers, sovereign wealth funds ≥$2bn AUM | Asset managers, investment industry, government | Voluntary | None specified | Information on whether climate change issues are integrated in investment policies, engagement efforts, portfolio emissions intensity for scope 1 emissions, climate change-related portfolio risk mitigation actions | Survey responses; respondents are asked whether responses may be made public | Disclose whether external assurance was provided |
| **Global:** CDP Annual Questionnaire (2016) | Financial and non-financial firms | Investors | Voluntary | None specified | Information on risk management procedures related to climate change risks and opportunities, energy use, and GHG emissions (Scope 1-3) | CDP database | Encouraged; information requested about verification and third party certification |
| **Global:** CDSB CDSB Framework for Reporting Environmental Information & Natural Capital | Financial and non-financial firms | Investors | Voluntary | Environmental information is material if (1) the environmental impacts or results it describes are, due to their size and nature, expected to have a significant positive or negative effect on the organization's current, past or future financial condition and operational results and its ability to execute its strategy or (2) omitting, misstating, or mis-interpreting it could influence decisions that users of mainstream reports make about the organization | Environmental policies, strategy, and targets, including the indicators, plans, and timelines used to assess performance; material environmental risks and opportunities affecting the organization; governance of environmental policies, strategy, and information; and quantitative and qualitative results on material sources of environmental impact | Annual reporting packages in which organizations are required to deliver their audited financial results under the corporate, compliance or securities laws of the country in which they operate | Not required, but disclose if assurance has been provided over whether reported environmental information is in conformance with the CDSB Framework |

Table A4.3

## Select Disclosure Frameworks: Non-Governmental Organizations *(continued)*

| Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **Global:**<br>CDSB<br>Climate Change Reporting Framework, Ed. 1.1 (2012) | Financial and non-financial firms | Investors | Voluntary | Allow "investors to see major trends and significant events related to climate change that affect or have the potential to affect the company's financial condition and/or its ability to achieve its strategy" | The extent to which performance is affected by climate-related risks and opportunities; governance processes for addressing those effects; exposure to significant climate-related issues; strategy or plan to address the issues; and GHG emissions | Annual reporting packages in which organizations are required to deliver their audited financial results under the corporate, compliance or securities laws of the territory or territories in which they operate | Not required unless International Standards on Auditing 720 requires the auditor of financial statements to read information accompanying them to identify material inconsistencies between the audited financial statements and accompanying information |
| **Global:**<br>GRESB<br>Infrastructure Asset Assessment & Real Estate Assessment | Real estate asset/portfolio owners | Investors and industry stakeholders | Voluntary | None specified | Real estate sector-specific requirements related to fuel, energy, and water consumption and efficiencies as well as low-carbon products | Data collected through the GRESB Real Estate Assessment disclosed to participants themselves and:<br>• for non-listed property funds and companies, to those of that company or fund's investors that are GRESB Investor Members;<br>• for listed real estate companies, to all GRESB Investor Members that invest in listed real estate securities. | Not required, but disclose whether external assurance was provided |
| **Global:**<br>GRI<br>Sustainability Reporting Standards (2016) | Organizations of any size, type, sector, or geographic location | All stakeholders | Voluntary | Topics that reflect the reporting organization's significant economic, environmental, and social impacts or substantively influence the decisions of stakeholders | Materials, energy, water, biodiversity, emissions, effluents and waste, environmental compliance, and supplier environmental assessment | Stand-alone sustainability reports or annual reports or other published materials that include sustainability information | Not required, but advised |

Table A4.3

## Select Disclosure Frameworks: Non-Governmental Organizations *(continued)*

| Framework | Target Reporter | Target Audience | Mandatory or Voluntary | Materiality Standard | Types of Climate-Related Information | Disclosure Location | External Assurance Required |
|---|---|---|---|---|---|---|---|
| **Global:** IIGCC<br>Oil & Gas (2010) | Oil and gas industries | Investors | Voluntary | None specified | GHG emissions and clean technologies data | Not specified | Not specified |
| Automotive (2009) | Automotive industry | Investors | Voluntary | None specified | GHG emissions and clean technologies data | Company's discretion | Not specified |
| Electric Utilities (2008) | Electrical utilities | Investors | Voluntary | None specified | GHG emissions and electricity production | Company's discretion | Disclose how GHG emissions information was verified |
| **Global:** IIRC<br>International Integrated Reporting Framework (2013) | Public companies traded on international exchanges | Investors | Voluntary | Substantively affect the company's ability to create value over the short, medium, and long term | General challenges related to climate change, loss of ecosystems, and resource shortages | Standalone sustainability or integrated report | Not specified; discussion paper released on issues relating to assurance |
| **Global:** IPIECA<br>Oil and gas industry guidance on voluntary sustainability reporting | Oil and gas industries | All stakeholders | Voluntary | Material sustainability issues are those that, in the view of company management and its external stakeholders, affect the company's performance or strategy and/or assessments or decisions about the company | Energy consumption | Sustainability reporting | Not required, but encouraged |
| **Global:** PRI<br>Reporting Framework (2016) | Investors | Investors | Voluntary | None specified | Investor practices | Transparency report | Not specified |
| **United States:** SASB<br>Conceptual Framework (2013) and SASB Standards (Various) | Public companies traded on US exchanges | Investors | Voluntary | A substantial likelihood that the disclosure of the omitted fact would have been viewed by the reasonable investor as having significantly altered the "total mix" of the information made available | Information on sustainability topics that are deemed material, standardized metrics tailored by industry | SEC filings | Depends on assurance requirements for information disclosed |