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To cite this article: Thomas Spencer, Michel Colombier, Oliver Sartor, Amit Garg, Vineet Tiwari, Jesse Burton, Tara Caetano, Fergus Green, Fei Teng & John Wiseman (2018) The 1.5°C target and coal sector transition: at the limits of societal feasibility, *Climate Policy*, 18:3, 335-351, DOI: [10.1080/14693062.2017.1386540](https://doi.org/10.1080/14693062.2017.1386540)

To link to this article: <https://doi.org/10.1080/14693062.2017.1386540>



Published online: 04 Dec 2017.



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The 1.5°C target and coal sector transition: at the limits of societal feasibility

Thomas Spencer^a, Michel Colombier^a, Oliver Sartor^a, Amit Garg^b, Vineet Tiwari^c, Jesse Burton^d, Tara Caetano^d, Fergus Green^e, Fei Teng^f  and John Wiseman^g

^aInstitute for Sustainable Development and International Relations, Paris, France; ^bIndian Institute of Management Ahmedabad, Vastrapur, Gujarat, India; ^cIndian Institute of Information Technology, Allahabad, India; ^dEnergy Research Centre, University of Cape Town, Cape Town, South Africa; ^eDepartment of Government, London School of Economics & Political Science, London, UK; ^fInstitute of Energy, Environment and Economy, Tsinghua University, Beijing, People's Republic of China; ^gMelbourne Sustainable Society Institute and Professorial Fellow, Melbourne School of Population and Global Health, The University of Melbourne, Parkville, Australia

ABSTRACT

National and global mitigation scenarios consistent with 1.5°C require an early phase-out of coal in major coal-dependent countries, compared to standard technical and economic lifetimes. This appears particularly apparent in the light of recent massive investments in coal power capacity, the significant pipeline of coal power capacity coming online, as well as upstream supporting infrastructure. This article analyses the existing and planned capital stock in the coal power sector in the light of scenarios consistent with 1.5°C. The article analyses the political economy and labour aspects of this abrupt and significant transition, in the light of domestic equity and development objectives. Firstly, the article examines employment issues and reviews the existing literature and practice with support schemes for regional and sectoral structural adjustment for the reduction of coal sector activity. Secondly, the paper surveys the domestic political economy of coal sector transition in major coal using countries, namely Australia, South Africa, China and India. A final section provides conclusions and policy recommendations.

Key policy insights

- Achieving mitigation pathways in line with limiting warming to 1.5°C, or even well-below 2°C, would require the early retirement of coal sector assets in production and consumption.
- Historically, coal sector transition has often been associated with prolonged socio-economic dislocation in affected regions.
- Policies to accompany affected regions are thus a crucial part of policy mixes to limit warming to 1.5°C and even 2°C.
- Such policies should be anticipatory and long-term, as opposed to reactive policies focused on short-term measures to smooth the transition.
- A survey of major coal using countries shows that each is a long way from putting in place a long-term framework to transition the coal sector.

ARTICLE HISTORY

Received 24 April 2017
Accepted 13 September 2017

KEYWORDS

Coal mining sector; coal transition; 1.5°C target; political economy; regional policy

1. Introduction

Ambitious mitigation scenarios to limit warming to less than 2°C require a large-scale and rapid transition in the global coal sector. This is even more so for scenarios limiting warming to 1.5°C. Historically, however, policy efforts to transition away from coal have come up against a number of challenges.

When considering coal transition, we can distinguish between *demand-side* and *supply-side* challenges (see Table 1). To date, much research has focused on policy efforts to address demand-side aspects of coal sector

Table 1. Framework of policy challenges related to coal transition.

	Policy challenge	Example policy approach
Supply side	Importance of the coal sector as a (regional) employer and generator of value-added	Regional diversification plans or coal sector restructuring plans
Demand side	Importance of export revenues from coal export	Economic diversification strategies
	Economic and technological aspects of substitution away from coal	Payments for closure of coal plants; carbon pricing; renewables support schemes

Source: *authors*.

transition. This includes policies to promote alternatives to coal in the electricity sector such as renewables, and increasingly to retire existing coal-fired power plants (Agora Energiewende, 2016; Jotzo & Mazouz, 2015); to use coal assets strategically in the management of electricity systems with higher shares of the renewables (Agora Energiewende, 2017), or to the risks of stranded assets in the coal power sector (Caldecott & Mitchell, 2014; Caldecott, Dericks, et al., 2017; Johnson et al., 2015).

Exceptions to this demand-side focus in the literature include Lazarus, Erickson, and Tempest (2015) and a limited number of other studies (Mendelevitch, 2016; Richter, Mendelevitch, & Jotzo, 2016) that consider supply-side issues. In this vein, Caldecott et al. (2016) conducted a multi-risk review of the most globally significant coal miners. One important set of supply-side challenges relates to the importance of the coal mining sector as a source of employment and value-added, particularly in regional economies. It should be noted that coal extraction is not a large employer in aggregate, although the employment effects are frequently used to justify opposition to mine closures or limit the transition away from coal. For example, in 2016 coal mining accounted for just under 66,000 jobs in the US compared to a total employment of 153 million, but these jobs are concentrated in a small number of regions (BLS, 2017; EIA, 2016). Even in India, coal mining accounted for around 358,500 thousand direct jobs in 2012, out of a work force in the order of 490 million (MOSPI, 2016). However, coal is still a very important employer in certain regions in both these countries. A further set of supply-side challenges pertains to the potential loss of export revenues for coal exporting countries. For example, gross coal exports accounted for 15% of Australia's gross merchandise exports 2015, and 6% of South Africa's (UNCTAD, 2017).

A number of historical examples demonstrate that significant transition in the coal extraction sector has been accompanied by large, persistent and painful social dislocation, for example in the UK coal mining regions in the 1980s (Baeten, Swyngedouw, & Albrechts, 1999; Caldecott, 2017; Del Rio, 2017; Fothergill, 2017; Gales & Hölsgens, 2017; Harfst, 2015; Jonek Kowalska, 2015; Kok, 2017; Rečková, Rečka, & Ščasný, 2017; Szpor, 2017). Mindful of such historical examples, a central starting point of this article is that policies to drive coal transition from the demand side (such as carbon pricing and recycling of revenues, or power plant closure schemes) may be very challenging from a political economy perspective, unless effectively accompanied by policies to manage the supply side transition.

In addition to this distinction between supply and demand-side factors in coal sector transition, we can also distinguish between policies designed with strictly climate-change-related objectives in mind, and broader social, labour market, fiscal or regional development policies intended to smooth the political economy of transition (transition policies). All four aspects of coal transition (demand–supply; climate policy–transition policy) are important; however, this article focuses mainly on transition policies on the supply-side (although the national case studies in Section 4 do touch on other aspects).

Thus, in view of the very rapid coal sector transition that would be required to limit warming to 1.5°C, this article provides an overview and assessment of policies to manage the supply side transition in the coal sector. It is structured as follows: Section 2 reviews the scenario literature to draw out the implications of 1.5°C scenarios for the coal sector. Section 3 provides a typology and assessment of policy options to manage the supply side aspects of transition. Section 4 analyses these current policy efforts in the specific country context of four major coal-using economies. These case study countries also have a diversity of circumstances, with major producers and exporters, major consumers and importers, developed and developing countries among them. Together, they covered 64% of global coal production, and 64% of global coal demand in 2016 (Enerdata, 2017). Section 5 concludes.

2. Coal and 1.5°C mitigation scenarios

Limiting warming to 1.5°C would require an extremely rapid transition in the coal sector. In order to illustrate this, this article draws on scenarios consistent with limiting warming to 1.5°C. Although the literature has examined some scenarios of energy system characteristics consistent with 1.5°C (Rogelj et al., 2015), there has been only a limited focus on the supply-side and more specifically on the coal sector. The Prospective Outlook on Long-term Energy Systems model (POLES) world energy model 1.5°C scenario does, however, include results on primary consumption of coal (Luderer et al., 2016).

The POLES world energy model is calibrated to meet a net carbon budget of 400 Gt CO₂ between 2011 and 2100. The scenario assumes a continuation of current trends until 2020, and then from 2020 the abrupt implementation of policies consistent with the carbon budget, approximated in the model by a carbon price. Rogelj et al. (2015) report a range of cumulative emissions between 200–415 GtCO₂ over the period 2011–2100 for scenarios meeting the 1.5°C limit. Thus, the POLES scenario presented here falls in the upper end of 1.5°C budget.

Tables 2 and 3 display the main results of the POLES 1.5°C scenario as they pertain to coal. The decline in world primary consumption of coal is precipitous, averaging –7% per year in the period 2020 to 2050. Such a rapid transition requires either the stranding of existing coal assets on the production and consumption side, or massive retrofitting of carbon capture and storage (CCS), or a combination of both. This result is consistent with the results in Davis and Socolow (2014) which find that ‘committed emissions’¹ from existing coal power plant stock as of 2012 was 206 Gt CO₂. Using the commitment factor in Davis and Socolow (2014),² one can update committed emissions from global net coal capacity additions built between 2012 and 2016 (GlobalData, 2017), which add an estimated 39 Gt CO₂ to global committed emissions from coal. Thus the total committed emissions from coal electricity capacity amount to 245 Gt CO₂ in 2016, which compares with a global carbon budget from the electricity sector consistent with 1.5°C of 118 Gt CO₂ and 332 Gt CO₂ for 2°C (both at 50% probability) (Pfeiffer, Millar, Hepburn, & Beinhocker, 2016). Therefore, the current coal power capital stock implies committed emissions that are already more than double the electricity sector carbon budget for 1.5°C.

Given the slow uptake of CCS globally, and associated challenges with the technology, coal consumption in the electricity sector will need to fall even faster than the tables above suggest to meet a 1.5 degree target – even as new plants are planned and under construction (IEA, 2016). Indeed, as shown by Johnson et al. (2015) analysis for 2°C, unabated coal power must be phased out by 2050. Thus, mitigating climate change to 1.5°C is not possible without either the stranding of coal assets or massive retrofitting of CCS or both, as indeed is required in the scenario described in Tables 2 and 3.

By extension, 1.5°C pathways also imply the stranding of upstream coal reserves/resources and capital beyond that required for 2°C, where 80% of coal reserves cannot be burned (McGlade & Ekins, 2015). OCI (2016) found potential emissions of 425 Gt CO₂ contained within existing coal mining areas, highlighting that production from developed reserves (existing mines and mining areas) already exceeds a 1.5°C budget. CTI (2015) showed that limited investment was needed to 2035 in coal extraction in order to meet demand under a 2 degree scenario, and CTI (2014) that there are already high risks of wasted capital – up to USD 268bn for new coal mines. Alongside the costs of stranded reserves are stranded investments in supporting

Table 2. Primary consumption of coal, 1.5°C scenario (Mtoe).

	2010	2030	2050	% change yoy, 2000–20	% change yoy, 2020–50
<i>WORLD</i>	3725	1878	570	3	–7
Germany	77	30	32	–1	–2
Poland	55	22	2	–1	–10
China	1842	988	273	7	–7
India	291	170	47	5	–7
Australia, NZ & RJAN	52	13	1	–1	–11
South Africa	101	53	23	0	–4

Source: Authors, based on POLES scenario (Luderer et al., 2016).

Table 3. Installed electric power capacity from coal, 1.5C scenario, including CCS (GW).

	2010	2030	2050	% change yoy, 2000–20	% change yoy, 2020–50
<i>WORLD</i>	1692	2059	604	4	–4
Germany	53	40	23	0	–3
Poland	29	22	7	0	–5
China	707	1110	348	8	–4
India	118	194	70	5	–3
Australia, NZ & RJAN	31	16	2	0	–8
South Africa	38	31	27	1	–2

Source: Authors, based on POLES scenario (Luderer et al., 2016). N.B. includes CCS capacity.

infrastructure that also ‘lock-in’ or commit emissions and contribute to the value of assets that will be stranded (Lazarus et al., 2015). However, coal mining is less capital intensive than coal or gas production, with capital expenditure costs (CAPEX) representing sometimes less than 15% of the cost of coal (IEA & IRENA, 2017). This means that even if mines are closed before their depletion under a 1.5°C scenario, the low share of CAPEX in the production cost of coal limits the magnitude of physical stranded assets. Thus, stranded *physical* asset issues are of less concern in the coal mining sector than elsewhere in the energy system. On the other hand, stranded *financial* assets may be more significant, as the market capitalization of a firm is a function of its discounted future cash flows, which would be impacted by climate policy and market changes under a stringent mitigation scenario. For example, the average stock market decline from the five-year peak for major global coal market companies has been about 75% (Roberts, 2016).³

However, since coal mining regions often have limited other industry, the stranded asset risk may be less significant than the risk to labour and communities at the microeconomic scale. In this regard, historically, coal sector transition has often led to significant and sustained social dislocation in affected regions, due in part to the lack of anticipatory policy to accompany transition. It is important, however, to put the impact of a climate-policy driven transition into perspective. Between 1960 and 2015, the labour productivity of UK coal mining grew about 4.9% per year, and 7.2% per year in India between 2000 and 2012 (MOSPI, 2016). Similarly, South Africa’s labour productivity doubled between 1995 and 2001, which was coupled with an 18% reduction in employment in the coal mining sector. Thus, even the baseline implies significant labour productivity improvements, and a decreasing trend in the sector’s employment even without demand reduction (although increasing labour productivity should mean higher wages, all other things being equal). However, there is no doubt that a climate-policy induced transition, combined with endogenous labour productivity improvements and other market changes, could have significant regional employment impacts, which should be anticipated by policy, for example the judicious use of carbon tax revenues to smooth the political economy of transition. This is the topic of the next section.

3. Transition policies in the coal mining sector

3.1. An analytical framework

In a 1.5°C transition pathway, the coal mining sector will experience financial and job losses as a result of a combination of climate policy and endogenous changes such as the productivity improvements highlighted above. Governments at all relevant levels will be called upon to mitigate those losses in some way. This part of the article develops a framework for considering transitional policy options in the coal mining sector.

In the context of climate change, a transition policy can be defined as a government policy concerning:

- the nature, scope and magnitude of transitional assistance to be provided to those made worse-off as a result of a structural change in the economy associated with climate change mitigation policy (*substantive component*);
- the nature, scope and magnitude of consultation engaged in by the relevant government with affected agents in respect of the content of proposed climate policies and the associated substantive component of transition policies (*procedural component*) (Green, 2017).

One key substantive decision governments must make is *who*, if anyone, is to be given transitional assistance. The main classes of persons likely to be made worse-off as a result of structural change in the coalmining sector are:⁴

- Workers currently employed in the coalmining sector;
- Strongly indirectly affected persons, businesses or groups, such as communities or regions in which coalmining accounts for a large share of economic activity;
- Owners of coal sector-specific assets, such as coalmining companies and diversified mining companies with significant coalmining operations.

A more complex question is what the *content* of transition policy should be.⁵ Here a combination of (i) ethical/distributive, (ii) economic (efficiency) and (iii) political (or ‘political economy’) considerations bear on the choice of transition policy strategy and instrument(s) for particular kinds of beneficiaries. A wide variety of academic literatures, spanning multiple disciplines, has addressed issues relevant to transition policy from at least one of these three perspectives. Of greatest relevance are the various literatures that address structural transitions at the regional or sectoral level, including: the ‘regional resource curse’ literature (Fleming, Measham, & Paredes, 2015; Freeman, 2009; Iacono, 2016; Xu, Xu, Chen, & Che, 2016); the regional studies literature on the socio-economic challenges faced by so-called ‘old industrial regions’ (Boschma & Lambooy, 1999; Cooke, 1995; Eckart, Kowalke, & Mazeland, 2003; Hudson, 2005), which includes some case studies of coal mining regions (Baeten et al., 1999; Harfst, 2015; Harfst & Wirth, 2011; Jonek Kowalska, 2015; Wirth, 2012); the literature on mine closure and its impacts (Laurence, 2006; Neil, Tykkyläinen, & Bradbury, 1992); recent work examining the growth and innovation prospects of old industrial regions, which integrates insights from evolutionary economic geography and transition studies (Coenen, Moodysson, & Martin, 2015; Truffer & Coenen, 2012); and literature on the political economy of transition policies (Trebilcock, 2014). Taken together, these literatures provide a useful foundation for the design of transitional policy responses, especially at the community/regional level.

To the authors’ knowledge, however, there is no comprehensive, policy-focused literature concerned primarily with the comparison of transition policy strategies and instruments, either within the field of climate policy,⁶ or policy responses concerning structural change more generally. The ‘missing’ literature that is envisaged would be analogous to the literature on climate policy instrument choice (Goulder & Parry, 2008), insofar as it would develop theoretical and empirical insights into the benefits and drawbacks of transition policies with reference to their distributional/ethical, economic efficiency and political effects. Such a literature would provide much-needed theoretical and evidentiary guidance to inform the rapidly growing demand from policy-makers and civil society for transition policy advice (Green, *in press*), not least within the coal sector.

The typology of transition policies presented below in Table 4, and elaborated further in Green (2017), provides a first step toward the development of such a literature. Transition policies are classified by their object (agent-type) and by a broad ‘transition policy type’, which has been inductively developed based on the authors’ review of the above-mentioned literatures and the coal sector case studies discussed below in Section 3.2.

Category 2 transitional assistance is ‘backward-looking’ in the sense that it is primarily concerned to maintain the status quo, i.e. the position the agent would have been in but for the structural change, or to fulfil company obligations owed to workers with respect to existing entitlements. Category 3 is ‘forward-looking’ in the sense that it is primarily concerned to facilitate the agent’s adaptation to new economic and policy circumstances. Category 4 has both a backward- and a forward-looking component, and encompasses the agent’s adaptation to the new context in a manner that covers a wider range of well-being-related functionings and capabilities (in the case of persons) or social, cultural and environmental values (in the case of communities) (Green, 2017). Of course, a transition policy strategy can, and often does, encompass a range of instruments targeting more than one ‘agent-type’ combination.

The following section, which discusses examples from past coal transitions, illustrates how the typology can usefully be applied to classify variation in transition policies, thus providing an analytical basis for explanatory, evaluative and prescriptive work.

Table 4. Typology of substantive transition policy options.

	1. No support	2. Compensation or grandfathering (backward-looking)	3. Structural adjustment assistance (forward-looking, narrow)	4. Holistic adaptive support (broad)
Workers	No support	Compensation for losses, such as redundancy payments, early retirement benefits	Cash or in kind assistance to retrain or relocate; wage subsidies; targeted unemployment payments	Workers are given strong support not only to find new jobs but also to maintain or develop new valued attachments (of the kind that cannot easily be compensated), e.g. work of a similar social standing, or in the same community
Regions/ communities	No support	Compensation for losses, such as resource transfers to lower levels of government to compensate for reduced tax revenue	Affected communities/regions are supported economically to diversify, e.g. via direct investment in public goods such as infrastructure or innovation; subsidies or tax incentives to businesses in growth sectors; technical assistance.	Affected communities/regions are given broader social-cultural assistance, e.g. investment in social service provision or community cultural and recreational facilities.
Coal mining companies	No support	Compensation for lost asset value or existing assets are 'grandfathered' into the new regulatory regime. State-subsidization of company liabilities (e.g. financial liabilities to employees; site remediation liabilities) can also be considered in this category.	Business are provided cash or in-kind assistance to adapt to the new policy/context, e.g. tied grants for technology upgrading.	-

Source: Green (2017).

3.2. Transition policy examples from past coal transitions

A number of countries have already undergone significant transitions away from coalmining, including the US, UK, Spain, Netherlands, Czech Republic and Poland. Detailed case studies for these countries have been conducted in the context of the 'Coal Transitions Project', from which this article draws (summarized in Caldecott, Sartor, & Spencer, 2017). Table 5 classifies the policies adopted by countries using the typology developed in Table 4.

For example, in liberal market economies such as the US and UK, the historical tendency has been to let losses suffered by workers and firms lie where they fall, albeit supplemented by a mix of *ad hoc* support to workers and, in the US case, coal firms. By contrast, in countries whose political economy (in general or at least in the coal sector) is characterized by greater coordination between government, unions and industry groups, e.g. Spain, Poland and Czech Republic, policies to phase down coal have tended to be accompanied by high levels of compensatory assistance to workers and firms.

Evaluations of past transition policies can – with appropriate cautions about generalizability – not only identify the causes of variation in transition policies, but also contribute to normative debates about the desirable ends, and technical debates about the most effective means, of transitioning away from coal in other countries (Caldecott, Sartor, et al., 2017).

Analysis of these national case studies allows one to draw a number of general conclusions regarding the performance of policies deployed to accompany the transition.

Firstly, across the case studies assessed, one sees a distinct lack of anticipation of the speed of coal sector transition and the scale of the impacts on regional communities. In the case of Poland and the Czech Republic, coal sector transition was precipitated by the abrupt collapse of the planned and regionally integrated economy of the USSR. In other cases, notably the US, the rapidity of socio-economic changes to the coal sector resulting in its loss of economic competitiveness was underestimated by public policy-makers and industry actors. However,

Table 5. Typology of substantive transition policy options, with country examples.

	Compensatory assistance (compensation payments or grandfathering)	Structural adjustment assistance (narrow)	Holistic adaptive support (broad)
Workers	Poland (high, systematic) Czech Republic (high, systematic) Spain (high, systematic) UK (medium, ad hoc) US (medium, ad hoc) Netherlands (medium, systematic)	US (moderate, ad hoc) UK (moderate, ad hoc)	
Regions/ Communities	UK (moderate, systematic)	Spain (high, systematic) UK (moderate, systematic) US (moderate, ad hoc) UK (moderate, ad hoc) US (moderate, ad hoc)	Netherlands (moderate to high, systematic) Spain (moderate, systematic)
Corporations	Poland (high, systematic) Czech Republic (high, systematic) Spain (moderate, systematic)	US (moderate, systematic) Poland (high, systematic) Czech Republic (high, systematic)	

Source: Authors based on summary in (Caldecott, Sartor, et al., 2017) and individual case studies (Del Rio, 2017; Fothergill, 2017; Gales & Hölsgens, 2017; Kok, 2017; Rečková et al., 2017; Szpor, 2017). Systematic' means consistent over time and/or supported by legislation or entrenched policy processes (e.g. as with sectoral agreements/plans in Spain). Ad hoc means inconsistent over time and/or supported merely by budgetary appropriations or administrative programs.

in the case of the Netherlands anticipatory policy was able to ensure the implementation of timely and generous policy to accompany coal sector transition (Gales & Hölsgens, 2017).

Secondly, accompanying policies, once they were put in place, tended to be *ad hoc* and piecemeal, rather than coordinated and comprehensive (Caldecott, Sartor, et al., 2017). Significant public policy support went notably to short-term compensatory measures for coal sector workers, such as redundancy payments, early retirement packages, etc. In more neoliberal contexts, such support was often 'hidden' in the form of long-term disability benefits, which also helped to mask long-term structural unemployment in coal mining regions much higher than national averages (Fothergill, 2017). Although such compensatory policies helped to smooth the political economy of coal sector transition in the short-term, their effectiveness in the long-term seems to have been weak.

Finally, overall across the six countries, outcomes in terms of mitigating long-term socio-economic regional impacts of coal transition seem poor. Three factors appear to explain this. Firstly, there are numerous problems typical of 'old industrial regions': regions of low economic diversity, dependent on mature industries experiencing decline and poorly connected to the rest of the economy, have had great difficulty in developing alternative drivers of economic growth (see Boschma & Lambooy, 1999, 392–395). Secondly, the limits of labour markets as channels for mitigating regional mine closures seem to have been underappreciated. Workers have been shown to be less mobile than neoclassical theory suggests, even in countries with flexible labour markets and low formal internal barriers to migration (such as the US and UK).⁷ Thirdly, the early exit of miners from the labour force seems to have led to the longer-term decline of regional human capital, as explicit and tacit skills and attitudes useful in a changing labour market are not passed onto future generations.

4. National perspective on transition challenges and policy options

4.1. Australia

Australia's coal reserves rank fourth globally with 9% of the world's proven reserves of hard coal and 22% of the world's proven reserves of lignite. Australia is among the top ten largest coal producers, and accounts for around 7% of global coal production by volume. Australia is the second largest coal exporter by volume, accounting for a relatively stable share of global coal trade between 27% to 30% from 1995 to 2014. In the last decade, coal exports have grown by 5% a year with Australia now the largest exporter of metallurgical coal (58% share in global exports) and second largest exporter of thermal coal. Coal exports were valued at AUD 38 billion for 2014–2015 with metallurgical coal comprising AUD 22 billion of the total, down from a peak of over AUD 60

billion during the height of the resources boom. Japan, China, South Korea and India are the major export destinations for Australian coal exports (Australian Government, 2017).

Australia's coal production is dominated by hard coal for steaming (51% by weight in 2014), followed by coking coal (37%). Almost all hard coal resources are located in two states: New South Wales and Queensland. Production of hard coal has grown steadily (by around 4% per year from 2000 to 2014). Domestic coal consumption has declined by 1.6% a year on average over the last 10 years, including a decline of 5% in 2013–2014. The reduction in domestic consumption is mainly due to reduced demand from electricity generation and the iron and steel sector. The large majority of hard coal production is exported. Lignite (12%) is used for domestic electricity generation, mostly in the Latrobe Valley in the state of Victoria. Production of lignite has declined by around 1% per year on average since 2000. Although coal remains the largest source of electricity generation in Australia (61% in 2013–2014), this share has declined from 79% ten years ago (AER, 2016). The Australian coal mining sector employed 57,800 people in 2014 (around half of 1% of total Australian employment. Even in the major hard coal mining states of Queensland and New South Wales, coal mining employed less than 1% of the workforce in 2016 (ABS, 2016).

A range of Australian policy options enabling a managed transition away from coal have been proposed including market based policies, regulatory interventions, moratoria on new mines, declining coal mining quotas, direct mine closure and reverse auction mechanisms (Australian Senate, 2016; Spencer, Senit, & Drutschinin, 2012). The most significant challenges to rapid implementation of these policies continue to arise from the difficulty of addressing impacted stakeholders. Coal producers, electricity generators and owners of energy intensive industries have a clear and immediate interest in maintaining coal production, as do coal industry workers and communities. Australia's energy-intensive industries (e.g. steel, aluminium, cement and chemicals producers) are small in number, capital-intensive, own highly specific assets, and are politically well-organized. These industries are also skilled in capitalizing on their geographic concentration in particular regions in which they generate employment and wider economic activity, and in which they hold significant political influence. In contrast, the contribution of reduced coal production to emissions reduction and climate outcomes can seem far more long term and abstract.

The views of marginal voters are likely to be strongly influenced by the way in which energy and climate policies are framed; whether they are embedded in a compelling narrative about links with climate change mitigation and the opportunities created by a clean energy economy; and whether the distribution of transition costs and benefits is perceived to be fair. Evidence from recent Australian carbon price and coal closure debates, however, suggests that overly complex, poorly framed policies have left an open space for opposing interests to frame policies in undesirable ways (Chubb, 2014).

4.2. South Africa

South Africa is highly coal and energy-intensive, with an economy characterized by extremely high levels of poverty and inequality. The coal sector accounts for approximately 88% of electricity production and roughly 25% of liquid fuels consumption. Coal is also considered key to the economy as a large foreign exchange earner and employer. South Africa produces some 250 Mt saleable tons of coal per annum, of which 25–30% is exported (historically at about 50% or more of total earnings). Domestic consumption is concentrated in the state-owned power utility, Eskom (70%), and the coal-to-liquids energy company, Sasol (20%) (Eberhard, 2011). Domestic prices are substantially lower than export prices and have contributed to historically very low electricity prices.

Although new renewable capacity in South Africa is now cheaper than new coal or gas-fired generation capacity (CSIR, 2016) and is procured via a world-leading programme, various factors limit the transition away from coal. The long lifetimes of existing plants, new plants under construction and planned, as well as complex concerns about energy security in both electricity (there have been several years of supply shortages) and liquid fuels (Sasol serves an inland market with limited pipeline capacity from the coast) limit the technological transition. At the same time, the new political elite both within and outside of Eskom view the coal sector as a mechanism for what they term 'radical economic transformation' of the economy, and new political elites are connected to both existing and emerging mining houses (Burton & Winkler, 2014; Jaglin & Dubresson, 2016).

Eskom has become a key site where factional battles within the ruling party – around corruption, power and policy – are played out (Baker, Burton, Godinho, & Trollip, 2015). For the most part, instead of a national debate around the content of supply side transition policies and the distributive implications thereof, the debate in South Africa rests on whether or not a transition away from coal should even take place. Transition costs are used as a political barrier to argue for the continued use of coal, drawing on both economic and social welfare arguments.

South Africa furthermore faces severe development challenges: extremely high levels of unemployment (officially at 26.5% in 2016, with an expanded⁸ unemployment rate of 35.6%), inequality, and a poor schooling system (SSA, 2016). This makes the rhetoric around employment particularly powerful, especially when twinned with the rhetoric about broader economic transformation and the transfer of mining capital from apartheid-era firms to new black owners.

This is not to discount the very real economic costs of a rapid and unplanned transition, especially on the supply side. In terms of its economic contribution, coal mining employed 78,000 workers in 2015, of which 56% were semi and unskilled workers with limited employment options (Quantac, 2015). In an economy with approximately 37% unemployment, however, this is significant, especially since workers tend to support several dependents - an average of almost three per worker in key mining areas (MTP, 2015). However, increasing ‘casualization’ of coal labour means that many of these workers are not permanent full-time employees (43% were subcontractors in 2009) (Baartjes, 2011) with minimal union representation and reports of poor working conditions (Hallowes & Munnik, 2016).

More than 80% of coal mining takes place in Mpumalanga in the Central Basin, where mining is the largest contributor to gross domestic product (GDP) (TIPS, 2016). Despite (or perhaps because of) its large mineral wealth, Mpumalanga performs poorly on several economic indicators when compared to the rest of the country, reporting higher household poverty levels and a lower human development index than the national average. 47% of households lived below the poverty line in 2009, higher than the national average. And although mining is a large contributor to provincial GDP, it is a relatively smaller employer: mining as a whole accounts for only 6.7% of Mpumalanga’s employment (MTP, 2015, p. 11; Stats SA, 2016). Thus, the substitutability of coal in the energy sector, although technically possible, is constrained by real economic forces on the supply side. The incumbent utility is opposed to new privately owned renewable energy projects, and new political elites furthermore capitalize on these economic constraints and the notions of fairness and justice that they depend on, to protect their own political and economic interests.

Although coal has been a core element in South Africa’s political economy since the 1970s (Burton & Winkler, 2014) it has structurally shifted as more ‘emerging miners’ (the term used for black-owned junior mining firms) have contracted with Eskom, which has increasingly focused on developing new suppliers as part of a state strategy to expand black-owned coal interests. Coal has been seen as a viable option for new mining interests because of its relatively low capital intensity compared to other types of mining. Eskom is now able to frame any shift away from coal as an attack on post-apartheid economic transformation, even as high-profile incidences of corruption in Eskom coal contracting have come to light (Public Protector, 2016). The delay in formalising the supply-side aspects of an energy transition, and continued focus on emerging miners, risks an increase in compensatory demands when the transition does happen.

Indeed, Eskom’s recent announcements of ‘early’ plant closures (no consistent official closure dates exist) were accompanied by thousands of striking coal truck drivers, who shut down Pretoria in opposition to renewable energy producers allegedly driving the coal plants out of business. At the same time, the Congress of South African Trade Unions called early Eskom plant closures ‘a hostile act of provocation directed at workers and their unions’, and called for Eskom and the government to suspend the closures until ‘a just transition-solution is arrived at by all affected stakeholders’ (Business Daily, 2017). South African climate policy has the notion of a just transition embedded within it (RSA, 2011), though no detailed sector specific plans for coal companies, workers or communities exist, and Eskom’s consultation with organized labour is limited.

Although procedural dimensions on demand side policies (energy planning and climate policy) exist, no procedural dimension related to coal sector restructuring itself has taken place. The policy discussions that do take place use rhetoric that draws on notions of justice and fairness for the losers of redistributive policies on the demand side but typically focus on the need for coal to remain an important part of the energy mix. Substantive

transition policies for workers of the type implemented in other countries (e.g., early retirement, targeted welfare) have not been on the policy agenda; regional diversification and industrial policy have examined transitions to a 'green economy' but have not grappled meaningfully with how to implement the diversification of a minerals-extractive economy either at a national or sub-regional level. Opportunities for structural change in South Africa, namely in incentivising growth in agriculture and agro-processing (Altieri et al., 2015, 2016) have been shown to be promising from a development and social welfare perspective. However, trade-offs exist with limited arable land and water at the regional and national level.

4.3. India

Coal is the dominant energy resource in India, contributing 407 Mtoe, that is, over 58% of the total 700 Mtoe annual energy consumption in 2015–16 (Enerdata, 2017). All coal products combined accounted for 832 Mt of consumption with about 200 Mt imported.⁹ Coal consumption has grown at 8.2% per annum during 2005–2015, against 5.5% for the energy sector, 6.2% for power generation, and 5.7% for CO₂ emissions. Coal imports grew at 25% per year during 2010–15, but recorded a decline of 18 Mt in 2015–16. The Government of India has a stated position to reduce coal imports drastically (MoC, 2016). Power, iron and steel, and cement are the main sectors using coal. As of February 2017, the coal-based power generation capacity amounted to 188 GW out of a total of 314 GW (CEA, 2017). Average coal power generation efficiency is only 30% with a plant load factor (PLF) of 62.3% in 2015–2016 (CEA, 2016). There has been a decline in PLF since 2010 from a high of 75%, mainly due to coal shortages.

The total projected additional demand for coal in the power sector with enhanced PLF and additional capacity could be around 300 Mt/year (cf. CEA, 2016). Annual Indian coal consumption is thus projected to touch a billion tons within next 3 years. The government owned Coal India Ltd., one of the largest coal mining companies in the world, produced 538 Mt in 2016 (MoC, 2016) and has been increasing production by 20–25 Mt/year during the last 4 years. Realistically, it may add another 150 Mt by 2020. Enhanced energy efficiency by existing large coal consumers, under the 'Perform Achieve Trade' policy of the Indian government, could save 70 Mt/year. The newly auctioned coal-blocks and other captive mines, however, could produce around 150 Mt by 2020. This would still mean a demand–supply gap of around 100 Mt, which would be met through imports through CIL and private players. For instance, the Adani group of companies, a \$15 billion group in India, has invested \$3.5 billion in coal mining and exporting infrastructure in Australia and \$1.5 billion in 20 Mtpa coal import facilities in western India. India is, however, sensitive to promoting efficient use of coal as a strategy for national energy security and mitigating global climate change. Shearer, Fofrich, and Davis (2017) have indicated that current coal-based installed capacity (197 GW) and proposed/under construction capacity (243 GW) may be detrimental to India's resolve for ambitious mitigation, unless concerted efforts to adopt cleaner policies are implemented.

This highlights two key issues: coal is projected to remain a mainstay of the Indian energy system in the near to medium-term, and coal imports are most likely to continue around 100 Mt/year.

Coal is a major contributor to India's emissions, accounting for 1146 Mt of India's 2479 Mt-CO₂ emissions in 2013–2014. Clean coal technologies, including super critical pulverized coal power plants, coal washing, and enhancing combustion efficiency through renovation and modernization of existing plants could lead to some mitigation. India has already established 27.5 GW of supercritical units and around 50 GW capacities are under construction (India's Biennial Update Report to United Nations Framework Convention on Climate Change [UNFCCC], Government of India, 2015). The Government of India has already taken several initiatives to improve the efficiency of coal-based power plants, including plans to shut or complete technology switchover for 37 GW older coal plant capacity, mandating all new large coal-based generating stations to use highly efficient supercritical technology. Renovation and modernization, and life extension of existing old power stations is being undertaken in a phased manner. About 144 old thermal stations have been assigned mandatory targets for improving their energy efficiency. Coal beneficiation¹⁰ has been made mandatory. Introduction of ultra-supercritical technology, as and when it becomes commercially available, is part of future policy plans. In addition, stringent emission standards being contemplated for thermal plants would significantly reduce emissions. The Indian nationally determined contribution (NDC) under the 2015 Paris Agreement has also identified

Super Critical Pulverized Combustion, Ultra Super Critical, Pressurized Circulating Fluidized Bed Combustion, Combined Cycle, Integrated Gasifier Combined Cycle and Fuel Cell as priority clean coal technologies for India (GOI, 2015). About 50 GW installations using new clean coal technologies at around a 20% improvement in current efficiency of coal plants could mitigate about 700 Mt-CO_{2e} vis-a-vis traditional coal technologies during 2015–2030. These indicate large plans for cleaner coal in India. CCS technology could also provide a way forward to continue using coal in India without associated GHG emissions. Our preliminary estimates indicate that India has a potential to mitigate around 800 Mt-CO₂ each year through CCS at below \$60 per t-CO₂.

The average electricity CO₂ emission factor is estimated at 0.732 kg-CO₂/kWh (including renewables) in the year 2015–2016. Our models project that this may reduce to 0.581 kg-CO₂/kWh by 2021–2022 and to 0.522 kg-CO₂/kWh by 2026–2027. Emission intensity (kg-CO₂/GDP) from grid connected power stations is likely to reduce by 43% by 2021–2022 and by around 50% by 2026–27 from the year 2005 levels. However, crossover prices of renewables along with disruptive innovation in storage technologies to offset intermittency, may further strengthen the above claims.

Coal production, transport, usage and ash disposal employ almost one million persons. Income from coal royalties constitute almost 50% of the total earnings of states like Jharkhand and Odisha (Agarwal & Dhritiman, 2015; GoO, 2007), which are some of the least developed large Indian states. Path dependencies of coal use therefore have strong socio-economic and political linkages, in addition to the huge investments in coal infrastructure that would have to be managed in the case of an accelerated coal transition in India. On the other hand, the latest policy of a targeted and simultaneous strong push towards renewable energy in India, aiming at 100 GW of solar and 60 GW of wind capacity by 2030, is estimated to need additional investment to the tune of US\$ 140 billion (MNRE, 2015).

It is clear that coal, the abundant domestic energy resource, is facing transitions – due to adoption of super critical technologies for power generation, gradual retiring of old and inefficient sub-critical power plants, and coal's declining role under ambitious renewable penetration targets. These transitions have to be supported, to ensure both energy security for India and climate change mitigation security for the world. Key issues requiring consideration are the aggravation of energy security concerns for India, along with likely strong resistance from stakeholders in coal-rich states due to lost earnings and job. In this regard, it is important to consider how the mainstreaming of alternatives (notably, renewable energy) could help to resolve these issues. For instance, what would be the role of coal in integrating ambitious renewable targets into the Indian power grid? Could coal fired base-power plants be transitioned into peaker plants?

How to manage the transfer of investment and finances away from coal, especially towards meeting ambitious renewable energy targets, is another key issue. Coal infrastructure could become a partially stranded economic asset in such a high mitigation scenario. The coal sector will therefore require technology and management reforms, supported by facilitative policy. These would include mandatory improvement in coal combustion efficiency in all sectors supported by energy markets, mandatory retirement of inefficient coal plants, retrofitting base-load coal plants to become peaker plants to the extent possible, bringing the coal supply chain appropriately into the Goods and Services Tax (GST) regime implemented in India in mid-2017,¹¹ creating a domestic carbon market that would help to internalize environmental externalities, and retraining of personnel working in coal businesses.

4.4. China

China is both the largest coal consumer and coal producer in the world (Qi, Stern, Wu, Lu, & Green, 2016). In 2015, China produced 3.7 billion tons of coal and consumed 3.97 billion tons, accounting for 47% of global production and around 50% of global consumption (Enerdata, 2017). The energy mix in China is also dominated by coal with a share of 64% in primary energy, much higher than the world average of 28%. The four biggest coal consuming sectors are power generation, the iron and steel industry, the construction material industry and the chemical industry. Coal is also the biggest source of air pollutants in China, accounting for 91% of SO₂, 69% of NO_x and 52% of primary PM_{2.5} emissions. Coal consumption has grown very fast in past decades from 1.3 billion tons in 2000 to 3.5 billion tons in 2013, with an annual growth rate of 6.5% in the period 2000–2016 (Enerdata, 2017). In 2014, for the first time, coal consumption stopped growing and began to decrease by 3% (Qi et al.,

2016). In 2015 and 2016, coal consumption fell further by 3.4% and 4.7% respectively (Enerdata, 2017; Han, Chen, Long, & Cui, 2016).

Declining coal consumption in China is a combined effect of the broader slowdown in economic growth and restructuring known as the 'new normal' (Green & Stern, 2017; Grubb et al., 2015), as well as efforts to improve air quality and mitigate climate change (Qi et al., 2016; Yang & Teng, 2016, 2017). Air quality is a key driver in the process of coal transition in China. In the report on the global burden of disease by the World Health Organization, outdoor particulate matter ranked fourth among overall health burden risk factors of China (Sun, Fang, & Sun, 2016). Coal related PM_{2.5} emissions are responsible for about 670,000 premature deaths in 2012, through chronic obstructive, lung cancer, stroke and ischemic heart disease (Yang & Teng, 2016). The production, transportation and consumption of coal in China also generates wider environmental impacts, such as water scarcity, soil erosion, vegetation degradation and desertification. These environmental costs associated with coal are not fully reflected in the coal pricing system of China and are thus a 'hidden cost' of coal. There are estimates that the real damage costs of China's coal production and consumption are about 260 yuan/ton of coal (\$37.65/ton) (Yang & Teng, 2016). Although parts of China's coal and electricity pricing mechanisms take these costs into consideration, the extent of environmental taxes is not enough to internalize external costs. China's current coal pricing mechanism only imposes 30–50 yuan/ton of coal in environmental taxes, mostly focused on the production side, with only 5 yuan/ton in coal pollution fees on the consumption side.

In the thirteenth Five Year Plan (2016–2020), China included for the first time a target to cap coal consumption at 4.1 billion tons by 2020. The environmental protection chapter of the thirteenth Five Year Plan adds a goal of reducing the primary energy share of coal to 58% by 2020, from 64% in 2015. Recognizing that air quality is a regional issue, the Five Year Plan also establishes specific coal consumption reduction targets for specific regions, such as 10% for the Jing-Jin-Ji region and the Pearl River Delta, and 5% for the Yangtze Delta. Meeting these regional targets by 2020 would result in a reduction of 140 million tons of coal of coal consumption by 2020.

Although the need to transition towards a low carbon economy now enjoys political consensus in China, there remain barriers and challenges. The most important one is how market-based policy instruments can play a role in the transition. The Chinese Government has traditionally adopted command and control regulations to allocate targets to local governments and then to enterprises (Wang, Nie, Long, Shi, & Zhao, 2016). However, this top-down approach has triggered problems of data cheating and efficiency losses (Lin & Wang, 2015). Regional emissions trading schemes have already been introduced, and the national ETS is due to be rolled out in 2017; such a pricing-based approach to coal sector abatement is expected to bring efficiency improvements. By developing reasonable environmental taxes on coal production and consumption, it is possible to internalize the external damage costs generated by coal production and consumption, use price mechanisms to efficiently adjust the production and consumption of coal, and achieve adjustment and optimization of the energy structure.

The second challenge is the coordination with other policy transition processes, especially the liberalization of the power market. The electricity price in China is still under heavy regulation and not open to competition (Zhao et al., 2017). In past years, the coal price has decreased substantially due to lower demand, but the electricity price has failed to adjust accordingly. The mismatch between the coal and electricity price has led to the unintended competitiveness of coal-based power plants and thereby overinvestment in coal-based generation capacity. The inconsistency between climate policy and policies of the power sector in China indicates that the current level of policy coordination is still low. Improved domestic policy coordination is clearly needed, to increase the probability of a successful low-carbon transition.

The third challenge is the phase out of so called 'dispersed coal' in residential heating and cooking and small-industrial boilers without any end-of-pipe treatment. Although the GHG Control Plan and Environmental Protection Plan aim to replace these dispersed coal uses by natural gas and electric heating, it should be noted that most of these coal-dependent facilities are either poor families or small-scale businesses: they either do not have access to gas, or simply cannot afford gas and electric heating. Fourthly, the issue of social equity poses another challenge for the coal transition. Coal-rich provinces who have built their revenue system on coal resources will have to face the problem of job losses and related socio-economic problems. The coal transition policy needs to be compensated by other policies, e.g. labour policy to facilitate the reemployment of mine workers, and financial transfer policies to ease the transition in coal-dependent industries and cities.

5. Conclusions, cross cutting challenges and lessons for policy makers

This article has surveyed the political economy of coal sector transition in the context of the requirements of ambitious climate mitigation scenarios to limit warming to 1.5°C, or at least well-below 2°C. Several overarching conclusions can be drawn from the preceding discussion.

Firstly, it is evident that ambitious mitigation scenarios to limit warming to 1.5°C would require the large-scale stranding of coal production and consumption assets, even if one is confident about the prospects of massive CCS deployment. This will inevitably pose major political economy challenge at various points of friction in the value-chain. For the capital-intensive parts, notably coal power plants, owners of capital would be the most impacted. Coal mining itself is not particularly capital-intensive, but it is often deeply integrated in regional economies in terms of employment, fiscal revenues and regional value-added, as illustrated by the case-studies explored above. Although the labour productivity of coal mining is often high (and falling rapidly in regions where it is still low), regional employment can be highly concentrated. Thus, the coal sector's 'entanglement' in regional economies emerges as a key challenge of coal sector transition, and one that merits further study. Thus the main challenge of moving to a 1.5°C trajectory in terms of the coal sector is not stranded assets, thought of in terms of physical or financial capital, but rather 'stranded regions' where workers, regional governments and the regional economy more broadly are dependent on the coal sector.

Secondly, historical examples of large-scale coal sector transitions are not particularly reassuring. Coal sector transition historically was often poorly anticipated and poorly managed, leading to long-term social dislocation with persistent below-average social and economic performance in coal regions. Short-term policies focusing on smoothing sector exit for firms and workers do not mitigate long-term factors by which the shock is perpetuated, in particular the weakness of migration opportunities, the degradation of human capital and the inability to develop other sources of regional economic activity.

Thirdly, the survey of four national contexts of coal dependent countries reveals that, while marginal policies are being deployed or mooted, none are actively preparing for large-scale coal sector transition. This is certainly the case when one keeps in mind the scale and speed of the transition required for limiting warming to 1.5°C. The lack of urgency and anticipation should raise certain alarm bells, given the historical experience of other countries that have gone through large-scale coal sector transitions. The survey of four major coal using economies reveals a lack of clarity regarding the long-term trajectory of the sector, which makes bringing actors to the table to discuss transition policies more difficult. At the same time, transition policies cannot be implemented without the buy-in and participation of local stakeholders from multiple sectors. The role of climate policies in more effectively signalling the future of the sector thus appears crucial to break the loop between the uncertain future of coal and the unwillingness of actors to engage in discussion on transition. Nonetheless, it is clear from this survey that without major efforts to accelerate the establishment of supply-side transition policies in coal-mining regions, coal demand will not be curbed at the rate required and the 1.5°C target will quickly be out of reach.

Notes

1. Committed emissions can be defined as the future emissions implied in the running of existing capital stock for its natural economic lifetime.
2. $6 \text{ GW}_{\text{coal}} \approx 1 \text{ Gt CO}_2$ committed emissions over the lifetime of the plant
3. It should be noted that this is also due to the bursting of the commodity super cycle, not solely climate policy or energy market effects.
4. Households could also be adversely affected by downstream increases in electricity prices resulting from reduced coal supply, though such changes are somewhat remote and are likely to be temporary, especially in jurisdictions where alternative energy sources are cost-competitive with coal-fired power generation. Landowners, where they are not covered by the listed categories would be a further relevant stakeholder affected by coal mining closures. For simplicity, we leave these classes of affected agents out of the present analysis.
5. We focus here on the *substantive* component of transition policy, though the content of the procedural component of transition policy is also an important question that we leave aside here purely due to space constraints.
6. Some academic work within climate change economics and policy has begun to consider transition policies. Menezes, Quiggin, and Wagner (2009) considered the normative and efficiency case for various kinds of transitional policy in the

context of Australia's carbon pricing scheme. Caldecott and Mitchell (2014) consider the design of compensation for owners of sub-critical coal-fired power generation assets. González-eguino, Galarraga, and Ansuategi (2012) examine the specific effects of climate policies on old industrial regions in Europe and offer general transitional policy recommendations. And there is a voluminous, but more narrowly focused, literature on 'carbon leakage', though the rationale for leakage mitigation policies differs from the potential rationales for transition policy.

7. For a fascinating sociological account of some of the *informal* barriers to internal migration in former British coalmining regions, see Strangleman (2001).
8. Which includes people who have stopped looking for work and are hence not included in unemployment rate statistics
9. The Indian domestic coal's average heat value was 3500 Kcal/Kg in 2013–14 with average ash content of 41%, and 0.51% sulfur by weight. These parameters for imported coal (taken as average of coal imported from Indonesia, South Africa, USA and Australia) were about 6000 Kcal/kg, ash 13% and 1% sulfur by weight.
10. Coal beneficiation is a process by which the quality of raw coal is improved by either reducing the extraneous matter that gets extracted along with the mined coal or reducing the associated ash or both.
11. Imposing a GST would increase the costs for renewable energy technologies by 10–15% (<http://energy.economictimes.indiatimes.com/news/policy/how-will-gst-impact-indias-energy-sector/53526262>), making coal relatively cheaper. On the other hand, solar power is becoming increasingly attractive and recently touched the lowest mark of INR 2.97/kWh in reverse auction bidding. In addition, there is and there is a federal clean energy cess of INR 400/ton on coal, which is significant against an average pre-tax price of INR 1500/ton for power plants.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by a grant made by the KR Foundation under the grant 'Comprehensive, Whole of Government Strategies on Coal Transition in Major Coal Using Countries'. It also received support from the French government in the framework of the programme 'Investissements d'avenir', managed by ANR (the French National Research Agency) under the reference ANR-10-LABX-01.

ORCID

Fei Teng  <http://orcid.org/0000-0003-0371-1142>

References

- ABS. (2016). *Labour force*. Australia.
- AER. (2016). *State of the energy market*. Melbourne.
- Agarwal, N., & Dhritiman, R. (2015). *Jharkhand to earn Rs 14k cr in coal royalties*. Retrieved April 10, 2017, from <http://timesofindia.indiatimes.com/india/Jharkhand-to-earn-Rs-14k-cr-in-coal-royalties/articleshow/46354084.cms>
- Agora Energiewende. (2016). *Eleven principles for a consensus on coal: Concept for a stepwise decarbonisation of the German power sector*. Berlin. Retrieved from https://www.agora-energiewende.de/fileadmin/Projekte/2015/Kohlekonsens/Agora_Kohlekonsens_KF_EN_WEB.pdf
- Agora Energiewende. (2017). *Flexibility in thermal power plants – With a focus on existing coal-fired power plants*. Berlin. Retrieved from https://www.agora-energiewende.de/fileadmin/Projekte/2017/Flexibility_in_thermal_plants/115_flexibility-report-WEB.pdf
- Altieri, K. E., Trollip, H., Caetano, T., Hughes, A., Merven, B., & Winkler, H. (2015). *Pathways to deep decarbonization in South Africa*. Paris: IDDRI and SDSN.
- Altieri, K. E., Trollip, H., Caetano, T., Hughes, A., Merven, B., & Winkler, H. (2016). Achieving development and mitigation objectives through a decarbonization development pathway in South Africa. *Climate Policy*, 16(sup1), S78–S91. doi:10.1080/14693062.2016.1150250
- Australian Government. (2017). *Department of Science, Industry and Innovation*. Retrieved March 20, 2017, from <https://industry.gov.au/Pages/default.aspx>
- Australian Senate. (2016). *Retirement of coal fired power stations: Interim report*. Retrieved from http://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/Coal_fired_power_stations/Interim_Report
- Baartjes, N. (2011). *South African mining sector employment forecast to 2025*. Pretoria: Centre for Poverty Employment and Growth, Human Sciences Research Council.
- Baeten, G., Swyngedouw, E., & Albrechts, L. (1999). Politics, institutions and regional restructuring processes: From managed growth to planned fragmentation in the reconversion of Belgium's last coal mining region. *Regional Studies*, 33(3), 247–258. doi:10.1080/00343409950082436

- Baker, L., Burton, J., Godinho, C., & Trollip, H. (2015). *The political economy of decarbonisation: Exploring the dynamics of South Africa's electricity sector*. Cape Town: Energy Research Centre, University of Cape Town.
- BLS. (2017). *Current employment statistics survey (National)*.
- Boschma, R., & Lambooy, J. (1999). The prospects of an adjustment policy based on collective learning in old industrial regions. *GeoJournal*, 49, 391–399.
- Burton, J., & Winkler, H. (2014). *South Africa's planned coal infrastructure expansion: Drivers, dynamics and impacts on greenhouse gas emissions*. Cape Town: Energy Research Centre, University of Capetown, South Africa.
- Business Daily. (2017). Shutting of power stations is “hostile act” by Eskom, Cosatu says. Retrieved April 6, 2016, from <https://www.businesslive.co.za/bd/companies/energy/2017-03-07-shutting-of-power-stations-is-hostile-act-by-eskom-cosatu-says/>
- Caldecott, B. (2017). Introduction to special issue: Stranded assets and the environment. *Journal of Sustainable Finance & Investment*, 7 (1), 1–13. doi:10.1080/20430795.2016.1266748
- Caldecott, B., Dericks, G., Tulloch, D. J., Liao, X., Kruitwagen, L., & Bouveret, G. (2017). *Stranded assets and thermal coal in China: An analysis of environment-related risk exposure*. Oxford: IDDRI and Climate Strategies.
- Caldecott, B., Kruitwagen, L., Dericks, G., Tulloch, D. J., Kok, I., & Mitchell, J. (2016). *Stranded assets and thermal coal: An analysis of environment-related risk exposure*. Oxford. Retrieved from <http://www.smithschool.ox.ac.uk/research-programmes/stranded-assets/satc.pdf>
- 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*, 16(1), 59–69.
- Caldecott, B., Sartor, O., & Spencer, T. (2017). *Lessons from previous “Coal Transitions”: High level summary for decision-makers*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_synthesisreport_v04.pdf
- CEA. (2016). *Draft National Electricity Plan (volume 1) generation*. New Delhi.
- CEA. (2017). *Power sector Dec 2016*. New Delhi.
- Chubb, P. (2014). *Power failure: The inside story of climate politics*. Melbourne: Black Ink.
- Coenen, L., Moodysson, J., & Martin, H. (2015). Path renewal in old industrial regions: Possibilities and limitations for regional innovation policy. *Regional Studies*, 49(5), 850–865. doi:10.1080/00343404.2014.979321
- Cooke, P. (Ed.). (1995). *Rise of the rustbelt: Revitalizing older industrial regions*. London: UCL Press.
- CSIR. (2016). *Least-cost electricity mix for South Africa by 2040: Scenarios for South Africa's future electricity mix*. Cape Town. Retrieved from http://www.ee.co.za/wp-content/uploads/2016/11/RE-Futures-Windaba-CSIR-3Nov2016_FINAL.pdf
- CTI. (2014). *Carbon supply cost curves: Evaluating financial risk to coal capital expenditures*. London.
- CTI. (2015). *The \$2 trillion stranded assets danger zone: How fossil fuel firms risk destroying investor returns*. London.
- Davis, S. J., & Socolow, R. H. (2014). Commitment accounting of CO₂ emissions. *Environmental Research Letters*, 9(8), 084018. doi:10.1088/1748-9326/9/8/084018
- Del Rio, P. (2017). *Coal transition in Spain*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_es_v04.pdf
- Eberhard, A. (2011). *The future of South African coal: Market, investment, and policy challenges* (Working Paper #100). Freeman Spogli Institute for International Studies, Program on Energy and Sustainable Development, Stanford University.
- Eckart, K., Kowalke, H., & Mazeland, J. (2003). *Social, economic and cultural aspects in the dynamic changing process of old industrial regions*. Munster: LIT.
- EIA. (2016). *Annual coal report 2015*.
- Enerdata. (2017). *Global energy and CO₂ data*. Retrieved December 6, 2016, from <http://globaldata.enerdata.net/home/>
- Fleming, D. A., Measham, T. G., & Paredes, D. (2015). Understanding the resource curse (or blessing) across national and regional scales: Theory, empirical challenges and an application. *Australian Journal of Agricultural and Resource Economics*, 59, 624–639. doi:10.1111/1467-8489.12118
- Fothergill, S. (2017). *Coal transition in the United Kingdom*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_uk_v04.pdf
- Freeman, D. G. (2009). The “resource curse” and regional US development. *Applied Economics Letters*, 16, 527–530. doi:10.1080/13504850601032107
- Gales, B., & Hölsgens, R. (2017). *Coal transition in the Netherlands*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_nl_v04.pdf
- GlobalData. (2017). *GlobalData Capacity and Generation Database*. Retrieved February 27, 2017, from <https://power.globaldata.com/>
- GOI. (2015). *India's intended nationally determined contribution*. New Delhi. Retrieved from <http://www4.unfccc.int/submissions/INDC/Published Documents/India/1/INDIA INDC TO UNFCCC.pdf>
- González-eguino, M., Galarraga, I., & Ansuategi, A. (2012). The future of old industrial regions in a carbon-constrained world carbon-constrained world. *Climate Policy*, 12(2), 164–186. doi:10.1080/14693062.2011.605707
- GoO. (2007). *Economics of mining in Orissa*. Bhubaneswar. Retrieved from <http://odisha.gov.in/e-magazine/Orissareview/nov-2007/engpdf/Pages69-76.pdf>
- Goulder, L. H., & Parry, I. W. H. (2008). Instrument choice in environmental policy. *Review of Environmental Economics and Policy*, 2(2), 152–174. doi:10.1093/reep/ren005
- Government of India. (2015). *India: First biennial update report to the United Nations framework convention on climate change. Ministry of Environment, Forest and Climate Change, Government of India*. Retrieved from <http://unfccc.int/resource/docs/natc/indbur1.pdf>

- Green, F. (2017). *Transitional policies for climate change mitigation: Who, what, why and how?* Australian National University, Crawford School of Government.
- Green, F. (in press). The normative foundations of climate legislation. In A. Averchenkova, S. Fankhauser, & M. Nachmany (Eds.), *Trends in climate change legislation*. London: Edward Elgar. Retrieved from <http://www.e-elgar.com/shop/trends-in-climate-change-legislation>
- Green, F., & Stern, N. (2017). China's changing economy: Implications for its carbon dioxide emissions. *Climate Policy*, 17(4), 423–442. doi:10.1080/14693062.2016.1156515
- Grubb, M., Sha, F., Spencer, T., Hughes, N., Zhang, Z., & Agnolucci, P. (2015). A review of Chinese CO₂ emission projections to 2030: The role of economic structure and policy. *Climate Policy*, 15(Suppl 1), S7–S39. doi:10.1080/14693062.2015.1101307
- Hallowes, D., & Munnik, V. (2016). *The destruction of the highveld part 1: Digging coal*. Pietermaritzburg. Retrieved from <http://www.groundwork.org.za/reports/gWReport2016.pdf>
- Han, S., Chen, H., Long, R., & Cui, X. (2016). Peak coal in China: A literature review. *Resources, Conservation and Recycling*. doi:10.1016/j.resconrec.2016.08.012
- Harfst, J. (2015). Utilizing the past: Valorizing post-mining potential in Central Europe. *The Extractive Industries and Society*, 2, 217–224. doi:10.1016/j.exis.2015.01.003
- Harfst, J., & Wirth, P. (2011). Structural change in former mining regions: Problems, potentials and capacities in multi-level-governance systems. *Procedia – Social and Behavioral Sciences*, 14, 167–176. doi:10.1016/j.sbspro.2011.03.033
- Hudson, R. (2005). Rethinking change in old industrial regions: Reflecting on the experiences of North East England. *Environment and Planning A*, 37, 581–596. doi:10.1068/a36274
- Iacono, R. (2016). No blessing, no curse? On the benefits of being a resource-rich southern region of Italy. *Research in Economics*, 70(2), 346–359. doi:10.1016/j.rie.2015.03.003
- IEA. (2016). *Medium term coal market report 2016*. Paris.
- IEA, & IRENA. (2017). *Perspectives for the energy transition: Investment needs for a low-carbon energy system*. Berlin.
- Jaglin, S., & Dubresson, A. (2016). *Eskom: Electricity and technopolitics in South Africa*. Cape Town: University of Cape Town Press.
- Johnson, N., Krey, V., McCollum, D. L., Rao, S., Riahi, K., & Rogelj, J. (2015). Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants. *Technological Forecasting and Social Change*, 90, 89–102. doi:10.1016/j.techfore.2014.02.028
- Jonek Kowalska, I. (2015). Challenges for long-term industry restructuring in the Upper Silesian Coal Basin: What has polish coal mining achieved and failed from a twenty-year perspective? *Resources Policy*, 44, 135–149. doi:10.1016/j.resourpol.2015.02.009
- Jotzo, F., & Mazouz, S. (2015). Brown coal exit: A market mechanism for regulated closure of highly emissions intensive power stations. *Economic Analysis and Policy*, 48, 71–81. doi:10.1016/j.eap.2015.11.003
- Kok, I. (2017). *Coal transition in the United States*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_us_v04.pdf
- Laurence, D. (2006). Optimisation of the mine closure process. *Journal of Cleaner Production*, 14, 285–298. doi:10.1016/j.jclepro.2004.04.011
- Lazarus, M., Erickson, P., & Tempest, K. (2015). *Supply-side climate policy: The road less taken*. Seattle. Retrieved from http://sei-us.org/Publications_PDF/SEI-WP-2015-13-Supply-side-climate-policy.pdf
- Lin, B., & Wang, A. (2015). Estimating energy conservation potential in China's commercial sector. *Energy*, 82, 147–156. doi:10.1016/j.energy.2015.01.021
- Luderer, G., Kriegler, E., Delisa, L., Edelenbosch, O., Emmerling, J., Krey, V., ... Wilson, C. (2016). *Deep decarbonisation towards 1.5°C - 2°C stabilisation: Policy findings from the ADVANCE project*.
- McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2°C. *Nature*, 517 (7533), 187–190. doi:10.1038/nature14016
- Mendelevitch, R. (2016). *Testing supply-side climate policies for the global steam coal market – Can they curb coal consumption? FFS reform and coal mine moratoria* (No. DIW Discussion Paper 1604). Berlin.
- Menezes, F., Quiggin, J., & Wagner, L. (2009). Grandfathering and greenhouse: The role of compensation and adjustment assistance in the introduction of a carbon emissions trading scheme for Australia. *Economic Papers: A Journal of Applied Economics and Policy*, 28 (2), 82–92. doi:10.1111/j.1759-3441.2009.00024.x
- MNRE. (2015). *RE-INVEST, 2016*. New Delhi.
- MoC. (2016). *Production and supplies*. Retrieved April 10, 2017, from <http://coal.nic.in/content/production-supplies>
- MOSPI. (2016). *India statistical yearbook 2016*.
- MTP. (2015). *Socio-economic review and outlook of Mpumalanga*.
- Neil, C., Tykkyläinen, M., & Bradbury, J. (Eds.). (1992). *Coping with closure: An international comparison of mine town experiences*. London: Routledge.
- OCI. (2016). *The sky's the limit: Why the Paris agreement requires the managed decline of the fossil fuel industry*. Washington, DC.
- Pfeiffer, A., Millar, R., Hepburn, C., & Beinhocker, E. (2016). *The "2°C capital stock" for electricity generation: Cumulative committed carbon emissions and climate change* (INET Oxford Working Paper No. 2015–9). Oxford.
- Public Protector. (2016). *State of capture*. Pretoria.
- Qi, Y., Stern, N., Wu, T., Lu, J., & Green, F. (2016). China's post-coal growth. *Nature Geosci, Advance on*. doi:10.1038/ngeo2777
- Quantac. (2015). *Coal industry structure*. Retrieved April 6, 2017, from <http://www.quantec.co.za>

- Rečková, D., Rečka, L., & Ščasný, M. (2017). *Coal transition in the Czech Republic*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_cz_v04.pdf
- Richter, P., Mendelevitch, R., & Jotzo, F. (2016). *Market power rents and climate change mitigation: A rationale for coal taxes* (No. DIW Discussion Paper 1471). Berlin.
- Roberts, A. (2016). *Happy new year, coal producers! Or maybe not*. Retrieved April 6, 2017, from <https://www.woodmac.com/blog/happy-new-year-coal-producers-or-maybe-not/>
- Rogelj, J., Luderer, G., Pietzcker, R. C., Kriegler, E., Schaeffer, M., Krey, V., & Riahi, K. (2015). Energy system transformations for limiting end-of-century warming to below 1.5°C. *Nature Climate Change*, 5(6), 519–527. doi:10.1038/nclimate2572
- RSA. (2011). *National climate change response white paper*. Pretoria. Retrieved from https://www.environment.gov.za/sites/default/files/legislations/national_climatechange_response_whitepaper.pdf
- Shearer, C., Fofrich, R., & Davis, S. (2017). Future CO₂ emissions and electricity generation from proposed coal-fired power plants in India. *Earth's Future*, 5, 408–416. doi:10.1002/2017EF000542
- Spencer, T., Senit, C.-A., & Druschinin, A. (2012). *The political economy of Australia's climate change and clean energy legislation: Lessons learned*. Paris: IDDRI.
- SSA. (2016). *Quarterly labour force survey – QLFS Q4:2016*. Retrieved from <http://www.statssa.gov.za/?p=9561>
- Stats SA. (2016). *Quarterly labour force survey: Q2 2016. Statistical release P0211*. Pretoria. Retrieved from <http://www.statssa.gov.za/publications/P0211/P02112ndQuarter2016.pdf>
- Strangleman, T. (2001). Networks, place and identities in post-industrial mining communities. *International Journal of Urban and Regional Research*, 25(2), 253–267.
- Sun, D., Fang, J., & Sun, J. (2016). Health-related benefits of air quality improvement from coal control in China: Evidence from the Jing-Jin-Ji region. *Resources, Conservation and Recycling*. doi:10.1016/j.resconrec.2016.09.021
- Szpor, A. (2017). *Coal transition in Poland*. Paris. Retrieved from https://coaltransitions.files.wordpress.com/2016/09/coal_pl_v04.pdf
- TIPS. (2016). *The REB provincial review 2016 Mpumalanga*. Pretoria. Retrieved from https://www.tips.org.za/images/The_REB_Provincial_Review_2016_Mpumalanga.pdf
- Trebilcock, M. J. (2014). *Dealing with losers: The political economy of policy transitions*. Oxford: Oxford University Press.
- Truffer, B., & Coenen, L. (2012). Environmental innovation and sustainability transitions in regional studies. *Regional Studies*, 46(1), 1–21.
- UNCTAD. (2017). *Merchandise trade matrix – detailed products, exports in thousands of dollars, annual, 1995-2015*.
- Wang, D., Nie, R., Long, R., Shi, R., & Zhao, Y. (2016). Scenario prediction of China's coal production capacity based on system dynamics model. *Resources, Conservation and Recycling*. doi:10.1016/j.resconrec.2016.07.013
- Wirth, P. (2012). *Post-mining regions in central Europe: Problems, potentials, possibilities*. München: OEKOM.
- Xu, X., Xu, X., Chen, Q., & Che, Y. (2016). The research on generalized regional “resource curse” in China's new normal stage. *Resources Policy*, 49, 12–19. doi:10.1016/j.resourpol.2016.04.002
- Yang, X., & Teng, F. (2016). The air quality co-benefit of coal control strategy in China. *Resources, Conservation and Recycling*. doi:10.1016/j.resconrec.2016.08.011
- Yang, X., & Teng, F. (2017). Air quality benefit of China's mitigation target to peak its emission by 2030. *Climate Policy*, 21, 1–12. doi:10.1080/14693062.2016.1244762
- Zhao, C., Zhang, W., Wang, Y., Liu, Q., Guo, J., Xiong, M., & Yuan, J. (2017). The economics of coal power generation in China. *Energy Policy*, 105, 1–9. doi:10.1016/j.enpol.2017.02.020