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Testing Supply-Side Climate Policies for the Global Steam Coal Market – Can They Curb Coal Consumption?

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Abstract

The achieved international consensus on the 1.5-2°C target entails that most of current fossil fuel reserves must remain unburned. Currently, a majority of climate policies aiming at this goal are directed towards the demand side. In the absence of a global carbon regime these polices are prone to carbon leakage and other adverse effects. Supply-side climate policies present an alternative and more direct approach to reduce the consumption of fossil fuels by addressing their production. Here, coal as both, the most abundant and the most emission-intensive fuel, plays a pivotal role. In this paper, I employ a numerical model of the international steam coal market (COALMOD-World) to examine two alternative supply-side policies: 1) a production subsidy reform introduced in major coal producing countries, in line with the G20 initiative to reduce global fossil fuel subsidies; 2) a globally implemented moratorium on new coal mines. The model is designed to replicate global patterns of coal supply, demand and international trade. It features endogenous investments in production and transportation capacities in a multi-period framework and allows for substitution between imports and domestic production of steam coal. Hence, short-run adjustments (e.g. import substitution effects) and long-run reactions (e.g. capacity expansions) of exporting and importing countries are endogenously determined. Results show that a subsidy removal, while associated with a small positive total welfare effect, only leads to an insignificant reduction of global emissions. By contrast, a mine moratorium induces a much more pronounced reduction in global coal consumption by effectively limiting coal availability and strongly increasing prices. Depending on the specification of reserves, the moratorium can achieve a coal consumption path consistent with the 1.5-2°C target.

Keywords: Supply-side climate policy, coal markets, reserves, subsidy removal, International trade

JEL Codes: C72, H25, Q35

1 Introduction

The COP21 Paris agreement has brought about a clear commitment to reduce anthropogenic greenhouse gas (GHG) emissions to a level that will most likely keep the increase of global mean temperature below 2°C[1] and striving for 1.5°C. McGlade and Ekins (2015) estimate that achieving the 2°C target requires refraining from using a large share of current fossil fuel reserves but leaving them in the ground. Given its limited use for other than heat generation and resulting low economic value (Collier and Venables 2014) on the one hand and its abundance on the other hand, 82%-88% of current coal reserves need to be left unburned until 2050 (McGlade and Ekins 2015). The difference in the two numbers accounts for possible future use of Carbon Capture, Transport and Storage (CCTS), a technology which is currently not available at a demonstration scale[2] and which has thus far not lived up to the high hopes put in it (Reiner 2016).

While there is consensus that reducing CO_2 emissions and refraining from coal consumption are inseparably linked, there is major inertia hindering the transformation of the energy system. Incumbent industries in countries that have a long history of using coal as the primary fuel in their energy mix are reluctant to adapt their business models and to bring forward decarbonization (Fulton, Spedding, et al. 2015). Although a large number of demand-side policy instruments exist (see section 2) they are not sufficient to achieve required emission reductions. In fact, the IEA World Energy Outlook New Policies Scenario (IEA 2015a) which assumes the implementation of most of currently announced climate policies, including most of the Intended Nationally Determined Contributions (INDCs)[3] under the United Nations Framework Convention on Climate Change (UNFCCC), still projects a 15% increase of annual global emissions until 2040. Coal production is expected to increases by 18% during the same period. Even though the scenario fails to incorporate some of the major trends with respect to the restructuring of global energy systems[4], the general conclusion that currently discussed policies will not lead to a deep decarbonization, is still valid.

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[1] Hereafter referred to as the “2°C target”.

[2] The only existing CCTS infrastructure at Boundary Dam in Saskatchewan, Canada (in operation since October 2014), used the CO_2 for enhancing oil recovery and thus cannot be considered an emission reducing project. See Oei, Herold, and Mendelevitch (2014) and Hirschhausen, Herold, and Oei (2012) for more details on CCTS.

[3] With one major exemption: INDCs submitted by India are not fully incorporated but rather the original target of 100 GW of solar PV installed until 2022 is reduced to 40 GW (IEA 2015a, 498).

[4] Namely, the scenario misses current developments in the U.S., China, and the EU. As an example, important regulations like the Clean Power Plan in the U.S. (EIA 2015b) are incorporated but not logically extrapolated to 2040. Moreover, the peak in coal consumption (NBSC 2015) and a moratorium on new coal power plants and mines in China are not accounted for (see The State Council of the People’s Republic of China (2016): “Coal Capacity Guideline Issued.” February 5. http://english.gov.cn/policies/latest_releases/2016/02/05/content_281475284701738.htm., and Boren (2016): “China Stops Building New Coal-Fired Power Plants.” *Energydesk*. March 24. http://energydesk.greenpeace.org/2016/03/24/china-crackdown-new-coal-power-plants/). Likewise, the ban of coal from the energy mix in a number of European countries like in the UK is not included in the central scenario (cf. Rudd (2015): “Amber Rudd’s Speech on a New Direction for UK Energy Policy - Speeches - GOV.UK.” *Gov.uk*. November 18. https://www.gov.uk/government/speeches/amber-rudds-speech-on-a-new-direction-for-uk-energy-policy.).

While most of these policies are directed towards the demand-side of fossil fuels, many scholars argue that supply-side policies hold promise to be more effective in achieving desired emission reductions (see e.g., Lazarus, Erickson, and Tempest 2015). The contribution of this paper is to quantify the effects of two supply-side policies that are currently discussed to complement the wide range of demand-side policies in further reducing fossil fuel consumption: The first instrument is a removal of coal production subsidies to reveal the "real" cost of coal supply. This policy measure can be seen as one part of the international strive to phase out fossil fuel subsidies, as agreed on, e.g., by the G20 (2009). This paper contributes to the literature by summarizing available information on coal production subsidies in the major producing countries and providing an estimate on the mark-up resulting from removing respective subsidies. The level varies significantly between 0.1 USD/t in Poland and 3.4 USD/t for coal from the U.S. Powder River Basin (PRB). Depending on the producer this corresponds to less than 1% of production cost for Poland and South Africa, up to 34% for PRB coal.

The second policy examined in this chapter is a permanent moratorium on new coal mines, as suggested by President Tong of the Republic of Kiribati (Tong 2015) and supported by many scholars (see section 4). This policy could be implemented in various ways, e.g., by stopping to issue licenses for new mining projects and by not renewing those of inactive projects. To assess the consequences of such an intervention detailed information on existing mining operations is a crucial issue. There is a lack of publically available data, therefore I compile an own data set of reserves in operating mines based on publically available information. Based on this data, about one third of global reserves reported in international surveys (e.g., BGR 2015) are located in currently active mines. This share is largest in South Africa (69%) and smallest in the U.S. (8%).

Taking these two policies as scenarios, the paper uses a comprehensive model of the world steam coal market COALMOD-World (see Mendelevitch et al. (forthcoming) for a detailed description of the model) to assess their effects on patterns of global steam coal trade, prices and CO_2 emissions from coal consumption as well as their distribution effects. The two policies are assumed to be introduced in 2020. Although, generally the model works with perfect foresight, the policies are implemented in a way to ensure no anticipation effects. The subsidy removal policy leads to an insignificant reduction in CO_2 emissions of, on average, 82 $MtCO_2$ per year but still leaves a gap of 3.5 $GtCO_2$ to be addressed by other measures to achieve emission reductions consistent with a 2°C target. Nevertheless, the policy generates considerable additional income for emerging countries (China 31.5 bn USD, India 8.1 bn USD, Indonesia 7.2 bn USD) in the period 2020 to 2040. This additional income can be used to finance additional measures to reduce CO_2 emissions. Moreover, the policy generates additional revenue for infra-marginal producers that benefit from an average increase of coal prices by about 1% per year from 2020 to 2040, compared to the reference case. By contrast, a global moratorium on new mining projects could be a major contribution to closing the gap towards a coal consumption that is consistent with the 2° target. In fact, the "Mine Moratorium" scenario exceeds reductions implied by the WEO 450ppm scenario. The supply path in this scenario is, however, in line with McGlade and Ekins' (2015) calculations on "unburnable" coal reserves. These are required to stay in the ground in order to achieve the 2°C target, without relying on CCTS.

The results of the two scenario analyses can be understood as a benchmark for the maximum ability of these policies to close the gap between the current consumption path and one that is consistent with the 2° target. The partial equilibrium setting of the underlying model does not specify the substitute that is used to compensate reduced steam coal consumption and therefore does not account for potential CO_2 emissions from alternative sources. Also the model does not take into account welfare effects of recycling funds freed up by the removal of subsidies on coal production. (see Mendelevitch et al. (forthcoming) for a discussion of model limitations).

The remainder of the paper is organized as follows: the next section presents an overview of demand-side climate policies currently implemented and supply-side policies currently discussed. The subsequent section takes a closer look at coal producer subsidies and discusses findings from literature on their removal, and present own calculations on effects of subsidy removal. Section 4 discusses a moratorium on new coal mines as a potential supply side climate policy and details coal reserves in operating mines for the largest producers of steam coal. Furthermore, it gives a quantitative assessment of effects of a mine moratorium on the international steam coal market based on different specifications. Section 5 concludes.

2 Instruments of climate policy

One common metric to categorize climate policies accounts for the side of the market for emission-intensive goods (in the scope of this paper steam coal) that they address: those policies targeting the consumers are referred to as demand-side policies, while those addressing the production are referred to as supply-side policies (Kolstad et al. 2014, 364). Each policy has its specific advantages and disadvantages. Typical policy evaluation criteria assess the efficiency, the effectiveness, and the feasibility of a policy intervention (Perman et al. 2012). The Grantham Research Institute maintains a database of global climate legislation which details different policies that have been implemented (Grantham Research Institute 2015a).[5]

2.1.1 Demand-side policies

Demand-side policies for reducing CO_2 emissions have received the most attention in the academic literature and have been most commonly introduced in practice. Carbon pricing instruments place an explicit price on emissions – either directly, as a carbon tax, or indirectly, through a cap-and-trade scheme (OECD 2013). Such instruments have been implemented (or are scheduled to be implemented) in 39 countries, and at the jurisdictional level in a further three countries (Kossoy et al. 2015, 22).

There are many other policy instruments which generate an implicit carbon price through regulatory intervention. Prominent examples are emissions performance standards, minimum flexibility requirements, renewable portfolio obligations (see Oei et al. (2014) for a discussion of regulatory options to reduce CO_2 emission in the power sector. Other demand-side policies include measures

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[5] The following two sections are based on earlier work from Collins and Mendelevitch (2015).

that promote energy efficiency and reduced energy consumption (as discussed in articles in Economics of Energy & Environmental Policy Symposium on “Energy Efficiency”: Gandhi et al. 2016; R. Hahn and Metcalfe 2016; Rosenow et al. 2016; Houde and Spurlock 2016).

In the absence of full participation in a global climate policy, demand-side policies are susceptible to carbon leakage: emissions-intensive activities shift to non-participating countries, such that emissions reductions in the participating countries are partly offset by emissions increases in the non-participating countries (see e.g. Felder and Rutherford 1993; Sinn 2008). Richter (2015) provides an overview of empirical studies of the carbon leakage effect, which is undisputed in existence, but controversial in magnitude.

Moreover, a “green paradox” has also been theorized, where the expectation of future demand-side policies could induce resource producers to increase their present rates of extraction in order to maximize net present value (Sinn 2015). For coal, Haftendorn, Kemfert, and Holz (2012) suggest that in practice the green paradox may not be relevant, while Bauer et al. (2013) find a short term reduction of coal prices due to stringent climate policy. Gerlagh (2011) argues that the green paradox relies on oversimplified model assumptions with total depletion of the resource and high substitutability between energy fuels. Hoel (2012) adds that the paradox is only prevailing if policies target low cost suppliers while it is absent if it affects mainly high-cost suppliers of fossil fuel.

2.1.2 Supply-side policies

Supply-side policies represent an alternative and more direct route to address negative effects of fossil fuel combustion. One important factor to consider when deciding between a demand-side and a supply-side policy is the ratio of demand vs. supply elasticity, as it drives the leakage risk for the respective policy. Lazarus, Erickson, and Tempest (2015) calculate this ratio for different fuels and regions based on various studies and find mixed evidence for supply-side and demand-side leakage risk for coal. Collier and Venables (2014) argue that for coal, supply-side policy may be less prone to leakage, and Hoel (2013) suggests the green paradox could be eliminated with a supply-side policy that targets high-cost coal deposits. Lazarus, Erickson and Tempest conclude that such climate policies are more likely to limit over-supply of fossil fuels and associated “carbon lock-in” effects.

One type of supply-side policy acts to directly remove coal reserves from production – whether to a partial extent (focusing on high-extraction-cost reserves for economic efficiency) (Harstad 2012), or to a further extreme, the progressive closure of the entire coal industry (Collier and Venables 2014). Another type of supply-side policy is a depletion tax (or alternatively, a depletion quota), which is analogous to the demand-side policy of a carbon tax (or for a depletion quota, a carbon budget). For instance, in Richter, Mendelevitch, and Jotzo (2015) propose a tax on the energy content of steam coal, levied by a coalition of major coal exporters. A supply-side policy for coal could also take the form of an export-licensing regime adopted by a coalition of major coal exporters, in analogy to the existing safeguards regime for uranium exports; based on the reasoning that the regulation of commodity exports on the basis of their harmful or unethical end use is a widely accepted principle, and should be extended to coal (A. Martin 2014). Lazarus, Erickson, and Tempest (2015) provide a comprehensive taxonomy of supply-side climate policies.

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Appendix

Country-by-country assessment of production subsidies

Australia

Data on current coal production subsidies in Australia is available from different sources which provide very different estimates: while OECD data suggests an average annual subsidy of 0.1 bn USD (2007-2014) (OECD 2015a), Fulton, Buckley et al. (2015) assume an average direct tax deductions potential that was available from 2005 to 2011 (0.3 bn USD annually), and fuel tax credit scheme available from 2012 to 2013 (0.6 bn USD annually), will both also be available to producers in the future. Additionally, they note that current practice of allowing mining companies to provide less costly financial products as a substitute for rehabilitation bonds, constitute a subsidy to coal mining, which they estimate at 1.5 USD/t or 0.7 bn USD[21], annually. Makhijani and Doukas (2015) report national subsidies to coal production of 0.3 bn USD, almost exclusively from direct spending. The 76% of the subsidies are directed towards remediation, while the rest splits between transportation (20%), R&D (3%) and exploration (1%). Some of the subsidies apply on the regional level for production in New South Wales (46%) and Queensland (20%), the remainder applies to all production sites. For the purpose of the analysis in this paper, I employ the conservative values estimated by Makhijani and Doukas (2015), but add the rehabilitation subsidy noted by Fulton et al. (2015), as this constitutes a major subsidy otherwise not covered. The resulting coal production subsidy level is 2.5 USD/t for New South Wales, 2.1 USD/t for Queensland, and 1.8 USD/t for all other regions[22].

China

The level of subsidies on coal production in China in 2013 is estimated at 5.8 bn USD excluding 0.6-5.8 bn USD of support granted through tax credits, which translate to 1.5 to 3 USD/t of coal produced (Xue et al. 2015). These figures also include financial assistance for state-owned enterprises (SOEs) which account for 92% of coal production in 2013 (Xue et al. 2015). Support is granted as part of an

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[21] According to IEA (2015b), Australia produced 458 Mt of coal in 2013.

[22] According to Queensland Government (2016) coal production in Queensland totaled on average 226 Mt (2012-2015); according to the NSW Department of Industry (2015) coal production in New South Wales totaled 196 Mt in 2013-2014.

industry consolidation and infrastructure improvement plan. While, according to Xue et al. (2015), this subsidy totaled 1.3 bn USD in 2013, ODI (2015a) reports an average support of 6.2 bn USD (2013-2014). For reasons of consistency, I use the figure from Xue et al. (2015). To arrive at figures to be included in this analysis, I further subtract subsidies for coal-bed methane, which is not covered in the model setting, support for R&D, and oversea investments. Furthermore, I employ the conservative estimate on support through tax credits, which gives a total subsidy level of 4.4 bn USD (originating from state level (71%) and regional level (29%) support). The remainder includes direct payments and investments (54%), provision of services below market value (39%), and subsidies in the form of foregone profits (6%). The resulting calculated subsidy level is 1.4 USD/t for producers from Shanxi, Shaanxi and Inter Mongolia, and 0.9 USD/t for producers from all other regions[23].

A sum of1 bn USD of the subsidies is given as compensation for those coal mines that are shut down due to the coal phase-out plan (Xue et al. 2015), other forms of practiced subsidies require local content or give preferential treatment to state-owned enterprises. According to the definition used in section 3.1 these payments clearly constitute a subsidy. This example highlights the fact that the definition of a subsidy is non-indifferent on whether it is used to remove market failures or not. However, a detailed evaluation of the efficiency of each individual subsidy is beyond the scope of this study.

India

Data on coal production subsidies in India is only available from Garg and Bossong (2015). They report total average governmental support of 0.8 bn USD for the period 2013-2014 (ODI 2015b). To a small extent, it takes the form of tax breaks and direct funding for exploration, extraction and equipment, but over 90% originates from investment by SOE Coal India Limited (CIL), which account for around 70% of total coal production in India. Taking into account the state's share and the market share of CIL support translates in a subsidy of 0.9 USD/t of coal produced[24].

Indonesia

Lontho and Beaton (2015) undertake a comprehensive effort in compiling fossil fuel subsidies in Indonesia, but find little data available for the coal sector. OCI (2015) report annual government support to coal mining of 0.9 bn USD in 2013, mainly originating from a difference in royalty taxes between small and big mines, and from untaxed production, accounting for 12-15% of annual production (50-90Mt in 2014, Sanzillo 2015). For the royalty tax reforms are announced, but have not been included in any regulation, so far (PwC 2015, 37), and has been impeded by local resistance (Gatot and Sjahrir 2015; Kannan, Das, and Corazon Aureus 2015). Untaxed production is currently targeted by a new policy requiring producers to obtain "clean and clear" certificates (PwC 2015, 10).

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[23] According to Denjean et al. (2015), in 2013, total coal production in China was 3.7 Gt, with Shanxi, Shaanxi, and Inner Mongolia accounting for 0.96 Gt, 0.493 Gt, and 0.994 Gt, respectively.

[24] According to IEA (2015b), coal production in India totaled 610 Mt in 2013, and 668 Mt in 2014. CIL is a 90% SOE (cf. https://www.coalindia.in/en-us/company/structure.aspx).

For coal produced under the Domestic Market Obligation (DMO) consumers pay a regulated price which is benchmarked against a basket of market-based prices (PwC 2015, 10), including an international reference price. Therefore the case for subsidization via price discrimination cannot be clearly made. Assuming that the two policies equalizing the royalty taxes and preventing unmonitored production remain in their current state and do not become effective, Indonesia exhibits a coal production subsidy of 1.8 USD/t[25].

Poland

As Poland is not a G20 country ODI does not provide a country study and thus no fossil fuel subsidy data base. Therefore, the only source that estimates subsidies to coal production in Poland is OECD (2015a). For 2013 and 2014 the data base reports subsidies of 0.76 bn USD which translate to 5.4 USD/t of coal produced using production figures from IEA (2015b). 98% of the subsidy originates from "stranded cost compensation". However, this compensation is paid to electricity producers to compensate for the termination of long-term power-purchase agreements. In context of the present analysis, this does not constitute a producer subsidy but rather a consumer subsidy as power plants are the consumers of the coal and such subsidies have been excluded in other cases as well. A small fraction of 0.01 bn USD equivalent to a subsidy of 0.1 USD/t remains, which is attributed to free energy supply for mine workers.

Russia

Data on fossil fuel subsidies is available from Ogarenko et al. (2015) and OECD (2015a). For coal production estimates diverge very significantly, with 0.07 bn USD estimated by the former for 2013-2014, while the latter reports an average subsidy level of 0.99 bn USD for 2006-2014, and an extreme increase to levels of 2.29 bn USD to 6.04 bn USD for 2013 and 2014. The two sources report very different subsidy levels for the cost items of "Spending on Exploration and Prospecting for Coal" and another item, "Support for Restructuring and Development of the Coal", is missing in the former database. For reasons of consistency, I base the analysis on data from Ogarenko et al. (2015). Accounting for average annual steam coal production in 2013 and 2014, the resulting subsidy level is 0.4 USD/t. The majority of subsidies is directed towards tax benefits on the regional level (52%), while the rest is used for tax exemptions (33%) and direct spending (14%).

South Africa

Information on coal production subsidies is rarely available for South Africa. Garg and Kitson (2015) report expenditures of 0.04 bn USD to expand coal transportation infrastructure in 2014.

Beside, Eberhard (2015, 180) states that Sasol sells underpriced coal to its Coal-to-Liquids (CtL) plant at rates of 12 USD/t while domestic coal prices are reported to be 20 USD/t (Eberhard 2015, 196). In the COALMOD-World base case data, production cost for South Africa do not account for this subsidy

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[25] According to IEA (2015b), Indonesia has produced 487.7 Mt of coal (total of thermal coal and metallurgic coal) in 2013.

and start at 20 USD/t. Therefore, only subsidies to transport infrastructure which is dedicated to export coal are included in the new analysis, which accounts for 0.5 USD/t.

USA

Data on current coal production subsidies in the US is available from different sources: the reported levels range from 1bn USD in 2013 reported by EIA (2015a) to 6.8bn USD calculated by Fulton, Buckley et al. (2015). Doukas and Whitley (2015) undertake an extensive review of fossil fuel related subsidies in the US and provide a detailed list by subsidy type, jurisdiction, fuel, and fuel chain stage (ODI 2015c) which extends the effort undertaken by OECD (2015a). They calculate national coal production subsidies of 2.1 bn USD. According to their figures, the largest shares of total subsidies originate from relief of royalties (50%), and support for extraction (15%), and remediation (18%). The data allows differentiating between federal subsidies, which apply to all US coal production (44%), and state subsidies that only apply to particular basins (subsidies by the state of Wyoming make up 50% of total subsidy level). Based on this disaggregation, coal production subsidies for the Powder River Basin amount to 3.4USD/t, 1.1USD/t for Appalachia and 1.0USD/t for all other basins[26].

Other producers

No information on subsidies is available for Colombia, and other smaller coal producers like Venezuela and Mozambique.

Country-by-country assessment of coal reserves in operating mines

Australia

Values for Australia are based on information from Geosience Australia (Britt et al. 2015) which report 19816 Mt reserves of black coal in operating mines. Mine level information is available from Australian Mines Atlas[27] but could not be used due to a lack of reporting by some companies.

China

The Statistical Yearbook 2014 (NBSC 2016, Table 8.5) reports ensured reserves by region for 2013, which sum up to a total of 236290 Mt. To arrive at a number on recoverable reserves the figure is corrected by the average recovery factor of 48% obtained from Zhang et al. (2016). Data on reserves in producing mines could not be obtained, as there seems to be no obligation to publish such information to the general public. Therefore, numbers are calculated based on the ratio of reserves reported by BGR (2015) to reserve in operating mines directly obtained from literature (for USA,

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[26] According to EIA (2016), US coal production totaled 984 Mt (short) in 2013 and 1000 Mt (short) in 2014; Wyoming had an average share of 39%, West Virginia (11%) and Kentucky (8%). Federal level subsidies that apply to all production sites account for 44% of the totals, while West Virginia and Kentucky account for 4% and 2%, respectively; the remained stems from Wyoming state support. Furthermore, the calculation takes into account the share of Wyoming of total PRB production (86%) and the share of Kentucky and West Virginia in total Appalachia production (65%).

[27] http://www.australianminesatlas.gov.au/?site=atlas&tool=search.

Colombia, Poland, South Africa, Indonesia, and Australia). The number in brackets is based on the highest ratio obtained in South Africa (69%), while the standard assumption is the average ratio (33%).

Colombia

For Colombia, data on coal reserves in operating mines is obtained from the annual reports of the operating companies which were available for Cerrejon, Calenturitas, and La Jagua from Glencore (2016, 59). The operator Caribbean Resources Corp. provides only resource estimates for its mines Cerro Largo (11.6-21.2 Mt), and La Caypa (47 Mt)[28]. The operator Drummond Company does not provide any data on reserves, instead estimates from the Global Methane Initiative (EPA 2015a, 85) where used for La Loma (485 Mt), and El Descanso (960 Mt). No data was found for La Francia and Jam. In total, 3221 Mt of reserves are estimated in operating mines in Colombia.

India

On the one hand, information on coal reserves in India is readily available from the Coal Directory of India Coal statistics Controller's Organisation (2015), differentiated by depth, quality, and certainty, on a field-wise level. On the other hand, this data carries high uncertainty and measurement is not in line with international standards. Fernandes and Sanzillo (2013) report that reserve estimates for Coal India Limited (CIL), India’s largest, state-owned coal company are 17% overestimated because of categorization based on India ISP code, instead of the international common UNFC code. Cmpdi (2014) provides estimates of category G1 reserves[29] of 19805 Mt of mineable coal in operating mines. This number excludes reserves in captive mining blocks that where allocated to private and public companies. Reserves in these deposits are only available from the Coal Directory of India Coal statistics (2015), reported at 34419 Mt. Applying the same correction factor as for coal from CIL deposits gives a total of 48373 Mt. Currently, the allocation of all these blocks except for four was found illegal and arbitrary by the Indian supreme court in 2014 (Rajagopal 2014). The court ruled that the central government has to re-auction these blocks or has to collect adjustment payments instead. I assume that these blocks remain undistributed as an extreme assumption, resulting in the difference between the high and the low estimate reported for India.

It is worth noting that a significant share (24%) of India’s coal reserves are in low quality coal with an energy content of 4600 Kcal/Kg and below (see Table 2.5, Coal Controller’s Organisation 2015). Assuming that India will pursue modernizing its coal power plant fleet to achieve higher efficiency and lower specific local and global emissions, it will need to rely on higher quality reserves, which would render low quality deposits stranded.

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[28] http://www.caribbeanresources.ca/Properties/Map-of-Properties/default.aspx

[29] Defined as: feasibility study (F1) has been made and economically viable (E1). The balance Mineable Reserve (excluding that of losing mines) as on date will be in this category (cmpdi 2014, 9)

Indonesia

For Indonesia, active mining operations were identified by assessing the Mining Atlas[30] with limited free access. A mine-by-mine assessment was performed based on company annual reports and other publicly available data. Some sources do not distinguish between proven and probable reserves. Total reserves in operating mines are estimated to be 3.5 Gt as of end of 2015.

Kazakhstan

For Kazakhstan no data on reserves in operating mines could be found. The World Energy Council (2013) reports recoverable reserve of hard coal of 21.5 Gt assuming the same ratio between estimated reserves and reserves in operating mines as estimated for Ukraine and Russia (Ukraine: 2500/(15351+16577); Russia: 17700/(49088+97472), resulting in on average 10%). Therefore, reserves in active mines are estimated at 2.2 Gt.

Poland

Saboczyk and Salagua (2013) compare reserve estimates obtained from using the Polish methodology for reserve assessment to estimates based on the JORC code. They report 0.8 Gt of coal in operating mines under valid concessions.

Russia

According to SUEK (2011), the largest Russian coal producers, the company’s proven and probable reserves in operating mines totaled 5.9 Gt by April 2011. The company accounts for 33% of coal production in Russia in 2011 (Tazazanov 2012). For other major Russian coal companies no data on reserves was publicly available. To estimate total reserves, I assume that reserves are evenly distributed among the Russian coal mining companies; therefore I assume that SUEK holds 33% of coal reserves in operating mines. This gives a total estimate of 17.7 Gt.

South Africa

Using data from Wood Mackenzie, SACRM reports reserves of operating mines at 8.9 Gt in 2010, with 95% of this being thermal coal and the remainder metallurgical in operating mines (SACRM 2011): Low initial coal quality requires washing and beneficiation before coal can be marketed, and 21-24% of initial mined run-of-mine coal is discarded (SACRM 2011). Accounting for discard, the remaining steam coal reserves in operating mines are estimated at 6.8 Gt.

Ukraine

Due to a lack of available reserve data from the majority of coal mining companies, a similar approach as in the case of Russia is chosen for Ukraine. DTEK reports commercial coal reserves of 1.7 Gt as of 01.01.2015 (DTEK 2014). The company currently produced 46 Mt of coal in 2014, which accounts for 69% of total production in Ukraine reported by DTEK. Numbers on annual production might be significantly reduced, due to the armed conflict in Ukraine, especially in the largest coal production

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[30] https://mining-atlas.com/operation/php.

region Donetsk. Due to a lack of other sources, this number is used to scale up reserve figures to 2.5 Gt.

USA

Figures on estimated recoverable reserves are reported as 232017 Mt (255755 short Mt) in EIA (2016, Table 15). Figures on reserves in operating mines are given as 17555 Mt (19351 short Mt) in EIA (2016) based on data from EIA (2016, Table 14).

Other small producers

For other, small producers, the original entry for estimated reserves from the COALMOD-World data base (see Mendelevitch et al. forthcoming) is used, as they will not have a major influence on international trade patterns, prices and emissions, due to their insignificant size.

Further results of scenario with high estimate of reserves in operating mines

Table 5: Cumulative production in reference case and scenario with high estimate of reserves in operating mines (in Mt).

	Cumulative production [Mt]				Cumulative production [Mt]		
Country	Reference case	M&E Scenario	Change in	Country	Reference case	M&E Scenario	Change in
AUS	6.4	8.5	33	POL	1.9	0.8	-58
CHN	89.7	83.7	-7	RUS	6.6	10.0	52
COL	4.9	3.2	-35	UKR	1.5	2.1	40
IDN	13.0	6.1	-53	USA	32.3	14.9	-54
IND	30.1	26.9	-11	VEN	0.5	0.5	0
KAZ	3.5	2.2	-37	VNM	0.2	0.2	0
MNG	1.2	1.2	0	ZAF	12.0	6.8	-43
MOZ	0.2	0.2	0	Total	204.0	167.3	-18

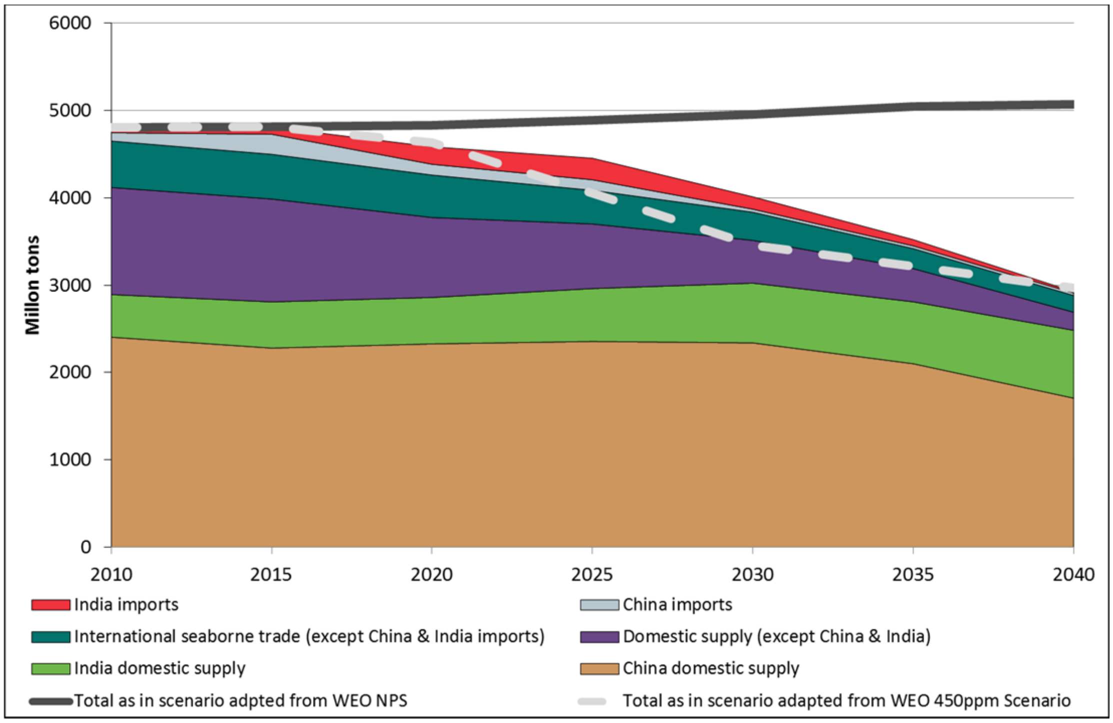

Figure 3: Total supply from imports and domestic production in scenario with high estimate of reserves in operating mines (in Mtpa).

Further details and results of the M&E scenario

Table 6: Cumulative production in reference case and M&E scenario (in Mt).

	Cumulative production [Mt]				Cumulative production [Mt]		
Country	Reference case	M&E Scenario	Change in %	Country	Reference case	M&E Scenario	Change in %
AUS	6447	4000	-38	POL	1916	2505	31
CHN	89723	50113	-44	RUS	6645	3970	-40
COL	4865	3521	-28	UKR	1455	940	-35
IDN	13000	11850	-9	USA	32291	13001	-60
IND	30146	10916	-64	VEN	479	479	0
KAZ	3481	2090	-40	VNM	150	150	0
MNG	1170	1170	0	ZAF	12033	2788	-77
MOZ	212	212	0	Total	204013	107705	-47

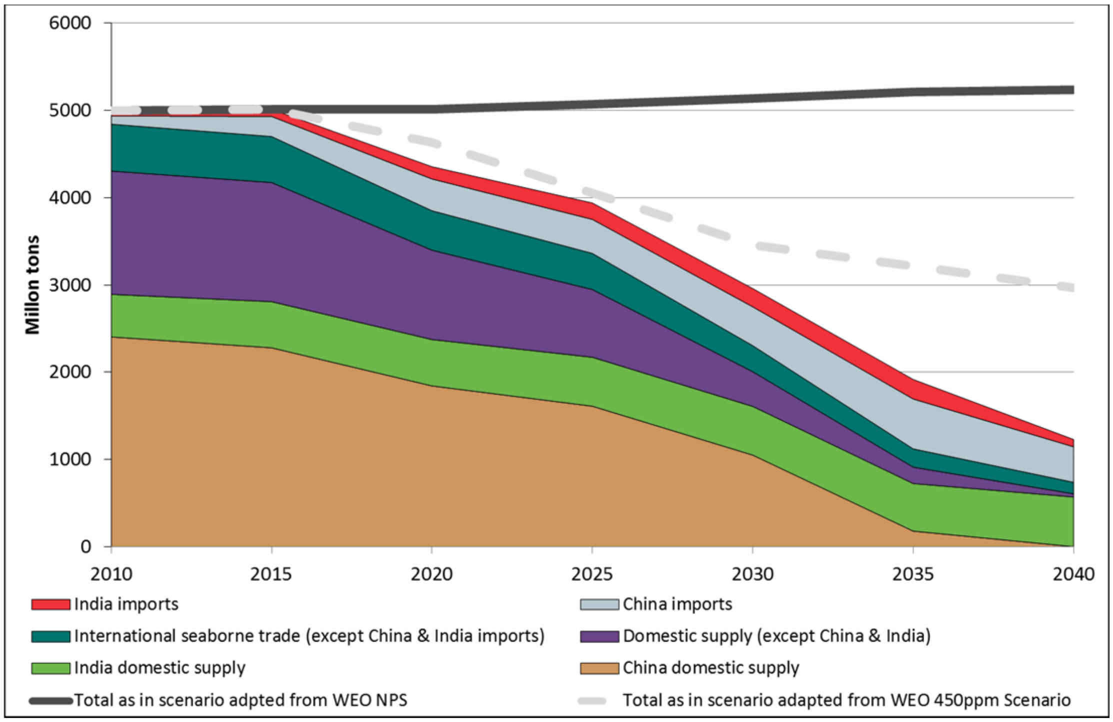

Figure 4: Total supply from imports and domestic production in M&E scenario (in Mtpa).

Conversion between reserves and resources data from McGlade and Ekins (2015) and COALMOD-World

There is no perfect match between the data provided by McGlade and Ekins (2015) (M&E) and data from the COALMOD-World (CMW) dataset. While TIAM-UCL, the model used by M&E, is an energy systems model, CMW is a sectoral model. Additionally, the two models have different time horizons: TIAM-UCL calculates energy use until 2100, with levels of resources unburned reported until 2050.

The two models also have different spatial coverage. While the first has a global coverage of both the demand and the supply of fossil resources, the second is focused on international trade aspects and therefore has no representation of purely self-supplying countries. Therefore, both supply and demand estimates are lower in COALMOD-World as compared to TIAM-UCL.

Moreover, M&E's definition of hard coal also includes coking coal, while CMW is focused on steam coal only, which increases hard coal demand in M&E compared to CMW. Additionally, M&E overestimates the use of lignite compared to hard coal (cf. BGR (2015): hard coal production in 2014: 7.15 Gt, Lignite: 1.05 Gt, compared to 4.9 Gt hard coal and 3.6 Gt lignite calculated by M&E). One explanation for this divergence might be that M&E overestimate the mobility of lignite which is only used for local electricity production due to its low energy content per volume and tonnage ratio, in reality. This might lead to an overestimation of unburned hard coal reserves in M&E. To be consistent with other literature (e.g., Finighan 2016), I use estimates on shares of unburned coal reserves, which comprise hard coal and lignite, for my scenario calculations.

For neither of the issues discussed above there is an easy fix or work-around. As many other measurement errors are also inherent to both model datasets, the results of the scenario should be interpreted as approximate values.

Table 7: Production capacity and reserves in COALMOD-World dataset and M&E scenario.

		Production Cap. in COALMOD-World	Reserves in COALMOD-World	Scenario	M&E Scenario values for coal reserves burned until 2050	Comments
	P_USA_PRB	525	112555	6469	12 Gt for USA	Distribution based on current production levels
	P_USA_Rocky	79	20704	973	same as above	same as above
	P_USA_ILL	115	82887	1419	same as above	same as above
USA	P_USA_APP	336	54572	4140	same as above	same as above
Colombia	P_COL	75	6229	3521	4 Gt for CSA	Distribution ensures usage of Venezuela reserves
Venezuela	P_VEN	10	479	479	same as above	same as above
Poland	P_POL	71	13997	9000	9 Gt for Europe	
Ukraine	P_UKR	45	16271	940	7 Gt for FSU	Distribution based on current production levels
Kazakhstan	P_KAZ	100	28145	2090	same as above	same as above
Russia	P_RUS	190	49078	3970	same as above	same as above
South Africa	P_ZAF	267	48740	2788	3 Gt for Africa	Distribution ensures usage of Mozambique reserves
	P_IND_North	281	35663	6169	62 for India and China	Distribution based on current reserves and ensures usage of Mongolia reserves
	P_IND_Orissa	123	14416	2494	same as above	same as above
	P_IND_West	53	7134	1234	same as above	same as above
India	P_IND_South	58	6755	1169	same as above	same as above
Vietnam	P_VNM	62	150	150	12 Gt for Other developing Asia	Distribution ensures usage of Vietnam reserves
Indonesia	P_IDN	340	13000	11850	same as above	same as above
	P_CHN_SIS	1573	213400	36916	62 for India and China	Distribution based on current reserves and ensures usage of Mongolia reserves
	P_CHN_Northeast	121	15900	2750	same as above	same as above
	P_CHN_HSA	564	4700	4700		used up until 2020, before policy is introduced
China	P_CHN_YG	450	36800	6366	same as above	same as above
	P_AUS_QLD	85	24764	1667	4 for OECD Pacific	Distribution based on current production capacity
Australia	P_AUS_NSW	119	13829	2333	same as above	same as above
Mongolia	P_MNG	17	1170	202	62 for India and China	Distribution based on current reserves and ensures usage of Mongolia reserves
Mozambique	P_MOZ	5	212	212	3 Gt for Africa	Distribution ensures usage of Mozambique reserves

Source: Own calculation based on reserves and production data from Holz et al. (2015), and McGlade and Ekins (2015).