Annex 1.SF.1. Coal Dependence: Econometric Analysis and Energy Transition Risks for Coal Producers

A panel regression is used to test for the relationship between income per capita and coal dependence. Time fixed effects are used to capture changes in relative energy prices common to all countries, among other factors. Specifically, the following specification is estimated, relating energy dependence to a third order polynomial in (log) income per capita (gdp):[1]

$$coal\_dep_{it} = \beta_0 + \beta_1 gdp_{it} + \beta_2 (gdp_{it})^2 + \beta_3 (gdp_{it})^3 + \beta_4 X_i + \lambda_t + \varepsilon_{it}$$

where X_i is a vector of control variables, including the share of manufacturing in nominal value added (in deviation from global average), coal reserves per capita (in logs), and hydropower potential (in logs), and λ_t represent time fixed effects, and the indexes *i* and *t* refer to countries and years, respectively.

Two measures of coal dependence are used: (1) the share of coal in total primary energy supply (*relative* coal dependence), and (2) (the log of) coal consumption per capita (*absolute* coal dependence). For the coal share in the energy mix and coal consumption per capita, the conjecture is that of an inverse U-shaped relationship between coal share income and an S-shaped relationship between coal consumption and income.

Results strongly support the presence of an inverse U-shaped relationship between income and the share of coal in the energy mix, with coal attaining its maximum share at an income level of $9600 per capita—that is, when a country reaches upper-middle level income status (Annex Table 1.SF.1.1). For example, specification (1) predicts that, between 1971 and 2017, income per capita contributed to *reductions* in the coal share of 6.4 percentage points in the United States and 5.2 percentage points in Japan, and to *increases* of 12.2 percentage points in India and 11.3 percentage points in China.

Having a larger manufacturing sector modestly increases coal consumption, since manufacturing is coal intensive. However, the decline (rise) of US (China) manufacturing between 1971 and 2018 contributed only to a modest reduction (increase) in the US (China) coal share by 1.2 (2.1) percentage points. Similarly, electricity market deregulation and limits on pollution have had minor effects on coal dependence. A one standard deviation increase in

[1] Coal share (in percentage of total primary energy supply) and coal consumption per capita (in thousands tons of oil equivalent per capita) are from the International Energy Agency; data on real GDP per capita (in 2011 USD) is from the recently revised Maddison Project Database (see Inklaar and others 2018); manufacturing share (as percentage of total value added) is from the UN national accounts database. Hydropower potential, as measured by freshwater resources in billion cubic meters per capita is from the World Bank's Development Indicators. The electricity market regulation index and environmental policy stringency (EPS) indicators are from the Organization for Economic Co-operation and Development, while the average summer and winter temperature are based on data from the World Bank's Climate Change Knowledge Portal.

Annex Table 1.SF.1.1. Determinants of Coal Share and Coal Consumption per Capita

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	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Coal Share	**Coal Share**	**Coal Share**	**Coal Share**	**Coal Consumption per Capita**	**Coal Consumption per Capita**	**Coal Consumption per Capita**
Real GDP p.c. (log)	0.556***	0.325***	-0.592	0.311***	-28.600*	-20.160*	-21.860*
	(-0.110)	(-0.083)	(-0.404)	(-0.083)	(-11.160)	(-9.696)	(-9.618)
Real GDP p.c. (log) Square	-0.030***	-0.019***	0.025	-0.018***	3.430**	2.475*	2.656*
	(-0.007)	(-0.005)	(-0.020)	(-0.005)	(-1.290)	(-1.112)	(-1.105)
Real GDP p.c. (log) Cubic					-0.131**	-0.096*	-0.102*
					(-0.049)	(-0.042)	(-0.042)
Manufacturing Share	0.002*	0.002*	0.003	0.002*	0.055*	0.065**	0.065**
	(-0.001)	(-0.001)	(-0.002)	(-0.001)	(-0.021)	(-0.022)	(-0.022)
Freshwater Resources p.c. (log)		-0.184**	-0.284	-0.148*		-0.459	-0.364
		(-0.066)	(-0.303)	(-0.063)		(-0.727)	(-0.704)
Freshwater Resources p.c. (log) Square		-0.007**	-0.011	-0.005*		-0.018	-0.010
		(-0.003)	(-0.013)	(-0.002)		(-0.027)	(-0.027)
Coal Reserves p.c. (log)		0.041***	0.040***	0.041***		0.368***	0.317***
		(-0.007)	(-0.009)	(-0.007)		(-0.053)	(-0.051)
EPS Market			0.003				
			(-0.006)				
EPS Pollution Limits			-0.009**				
			(-0.003)				
Electricity Market Regulation (log)			0.029*				
			(-0.014)				
Average Summer Temperature (log)				-0.145			-2.591*
				(-0.105)			(-1.098)
Average Winter Temperature (log)				-0.024*			-0.396***
				(-0.012)			(-0.108)
Constant	-2.268***	-1.991**	2.269	-1.029	79.700*	56.990*	74.050*
	(-0.427)	(-0.629)	(-2.748)	(-0.783)	(-31.930)	(-29.080)	(-29.280)
Model	wls fe	ols	ols	ols	wls fe	ols	ols
R^2	0.963	0.45	0.627	0.491	0.375	0.621	0.661
Observations	4729	3119	572	2958	4118	3004	2845
# of countries	114	74	29	72	113	74	72
Coal share maximum	9582.4	6448.1		6357.6			
Static saturation point					34972.2	38665.4	38881.9

Sources: International Energy Agency, World Energy Balances; Maddison Project Database (2018); Organisation for Economic Co-operation and Development, Environmental Policy Strigency Index; Organisation for Economic Co-operation and Development, Indicators of Product Market Regulation; World Bank, Climate Change Knowledge Portal; World Bank, World Development Indicators database; and IMF staff calculations.

Note: Standard errors are in parentheses. Coal consumption per capita is the log of coal consumption per 1 million people. Manufacturing share is in deviation from its global average. All specifications include year fixed effects. EPS = Environmental Policy Stringency; ols = ordinary least squares; wls fe = weighted least squares and country fixed effects.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

electricity market deregulation lowers the coal share by 0.59 percentage point, while the same for limits on pollution lower the coal share by 0.65 percentage point.

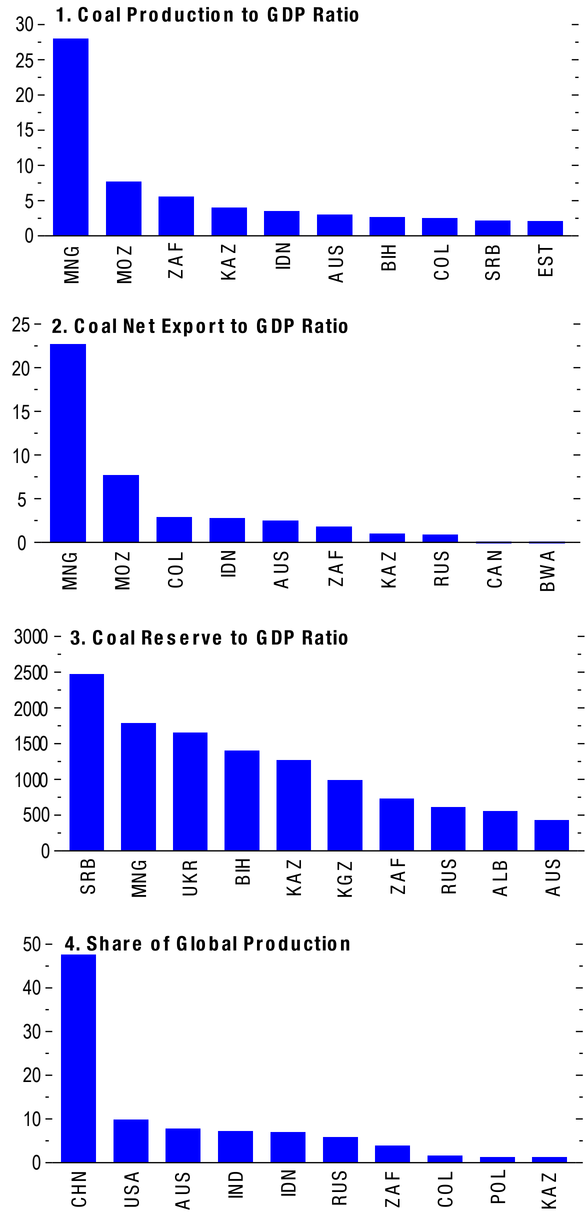
Energy endowments play a quantitatively more important role than manufacturing, however. An increase of hydropower potential of one standard deviation from the mean reduces the share of coal by 4.4 percent while a one standard deviation increases in coal reserves per capita increases the coal share by as much as 11.1 percentage points. For example, all else equal, Norway would increase its coal share by 11.3 percentage points if it had an average hydropower potential, while reductions in coal share of 3.5 percentage points in India, 7.0 percentage points in China, and 15.5 percentage points in the United States would be achieved if they had an average coal reserve per capita.

Weather also plays a large role in the use of coal. A country in the sample experiencing the lowest instead of the highest possible average annual winter temperature since 1971 will see its share of coal increase by 5 percentage points.

Like the relationship between the coal share and income, the relationship between coal consumption per capita and income is highly nonlinear. The preferred specification shows an S-shape relationship with income per capita: at low-income levels, coal consumption growth accelerates, reaches its maximum at the middle-income level, and then levels off. The turning point of absolute coal dependence, after which coal consumption declines, ranges from $35000 to $39000. Furthermore, increasing the average annual winter temperature by 10 percent reduces coal consumption per capita by 4 percent. Hence, warm winters reduce both relative coal dependence and absolute coal dependence.

Annex Figure 1.SF.1.1. The Macroeconomic Relevance of Coal

(Percent)



Sources: British Petroleum, *Statistical Review of World Energy*; International Energy Agency, *World Energy Balance*; World Bank, World Development Indicators database; and IMF staff calculations.

Note: Data labels use International Organization for Standardization (ISO) country codes.

Coal Producers and Risks Associated with Energy Transition

In 2017 total coal production was about 3800 million metric tons, equivalent to $506 billion, or 0.63 percent of global GDP (for comparison the oil expenditure share is about 3 percent). A few coal-exporting countries, such as Mongolia, have a substantial exposure. In general, however, coal exports represent a somewhat modest share of GDP—about 3 percent in Mozambique and Australia and about 1 percent in South Africa, Colombia, and Indonesia (Annex Figure 1.SF.1.1). Even though production is smaller than that of other fossil fuels, the value of coal reserves is multiples of GDP in various countries, which makes the risk of stranded coal assets macro relevant, especially for some major coal-producing countries.[2]

The needs of major coal consumers are typically met domestically.[3] This can raise a political economy hurdle when countries try to introduce policies to curb domestic coal consumption. Indeed, moving away from coal typically lowers demand for the domestically mined product, which could lead to hefty losses for the local mining industry and its workers.[4] Interestingly, in many European countries coal imports have displaced domestic coal production in recent decades. Hence, a large portion of losses from a coal phaseout would not be borne by domestic citizens. This likely paved the way for the European Green Deal.[5]

Looking forward, strong domestic mining interests in large coal consumer and producer countries, especially in Asia, including China and India (Annex 1.SF.2), may complicate and delay the phase-out of coal in major coal consumer-producer countries. In recent US experience, for example, the rapid transition from coal to natural gas—driven by the shale boom—has led to a decline in coal mine employment,[6] a record number of bankruptcies among coal mining firms, and a sharp decline in the Dow Jones US Coal Index. An analog transition in some emerging market coal producers—possibly induced by the introduction of carbon pricing globally or local environmental regulations—may spark financial stability risks associated with the exposure of the banking system to power and mining sector's stranded coal assets.

[2]While there are some infant technologies to replace coking coal with hydrogen, it is uncertain whether these technologies will mature quickly enough to become an affordable and scalable alternative.

[3]In 2017 the top three coal-producing countries (China, United States, India) accounted for about 70 percent and 78 percent of world production and consumption, respectively—with China alone responsible for [47.3] and [51.5] percent of world production and consumption, respectively.

[4]Mining is the most labor-intensive portion of the global coal supply chain, and fuel costs—not capital—accounts for the lion's share of the costs of coal-fired power generation. In fact, fuel costs and fixed capital investment account for about 50–65 percent and 25–40, respectively, of the total costs of coal-fired power generation (McNerney and others 2011).

[5]The European Green Deal is a set of policy initiatives brought forward by the European Commission with the overarching aim of making Europe climate neutral in 2050. Only Poland, the major European coal producer, expressed discontent with these initiatives.

[6]From 2012 to 2016 coal mining employment fell from almost 90,000 to about 50,000 and later stabilized (US Bureau of Labor Statistics).

Annex 1.SF.2. Coal in India

India faces the dual challenge of satisfying increasing energy needs, driven by a growing middle class and social development objectives (for example, universal electricity access), while reducing (both carbon and noncarbon) emissions. Given its size, India's energy policy choices and emissions trajectory matter for meeting global climate mitigation goals.

While India's per capita emissions are about one-tenth that of the United States, in sheer numbers, India accounted for 6.4 percent of global energy consumption and 6.8 percent of global carbon dioxide emissions in 2018. Its share of emissions is expected to exceed 10 percent by 2030 (IEA 2018). India's relatively high carbon intensity is driven by coal's significant use in power generation (see Annex Table 1.SF.2.1), a dirty and inefficient energy source that contributes not only to carbon emissions but also to local pollution. What explains such high reliance on coal? What are India's prospects of moving away from coal?

Annex Table 1.SF.2.1. Electricity Generation, 2018

	Terawatt Hour		Share	
	World	India	World	India
Total Generation	**26,603**	**1,618**	**100**	**100**
Coal	10,123	1,194	38	74
Oil	808	17	3	1
Natural Gas	6,118	71	23	4
Nuclear	2,718	40	10	2
Renewables	6,799	295	26	18
Wind	1,265	58	5	4
Solar Photovoltaic	592	44	2	3
Hydro	4,203	146	16	9
Other Renewables	739	47	3	3

Sources: International Energy Agency, *World Energy Outlook*; and IMF staff calculations.

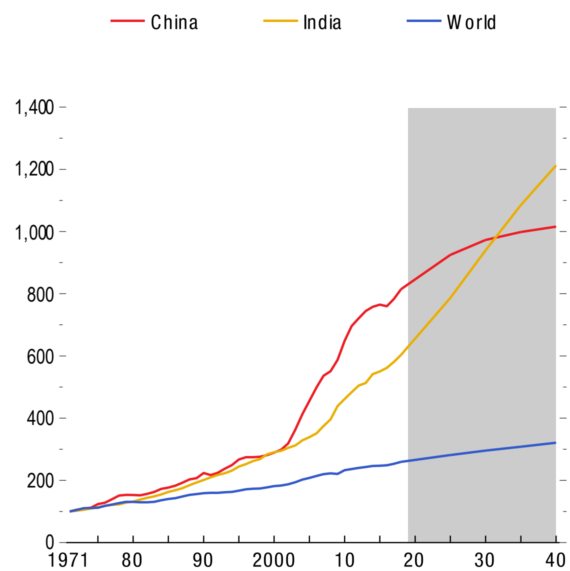
Coal has had such a dominant role in India because it is affordable, available, and reliable, and because the political economy supports the coal sector.

About 70 percent of the coal consumed in India is produced domestically, making India the second-largest hard coal producer after China. Coal is more affordable and reliable than other fuels—such as natural gas, which would need to be imported and requires a huge infrastructure investment in gasification facilities and pipelines. Renewable energy, instead, once installed, has low operating costs and would dispel concerns about energy security. Indeed, in recent years, renewable capacity has increased rapidly, but the upfront investment (per megawatt) remains sizable and has a high import content.

Political economy considerations may also entrench coal in the current economic system (Tongia and Gross 2019). Employment in mining and its footprint on the economy is non-negligible, especially in some regions. Coal accounts for about 44 percent of Indian Railways' revenue and half of its profit, allowing the railway operator to cross-subsidize passenger fares considerably (Tongia and Gross 2018). Furthermore, some coal-producing states (such as Jharkhand, Odisha, West Bengal, Bihar, Chhattisgarh, Telangana, and Madhya Pradesh) need coal levies to partly finance their spending. In addition, further increasing the modest national coal levy may not be feasible, given that electricity prices for households are low and controlled. The direct involvement of India's central government in coal-fired power generation and mining sectors—through controlling stakes in the largest utility firms and coal producers—can also hinder change. This entanglement has encouraged utility firms to reach long-term purchasing agreements with coal producers, which may disincentivize faster expansion of green energy even as renewables' capacity grows.

In addition, the lack of natural gas infrastructure imposes a serious limitation, not only to the use of cleaner gas-fired power plants, but also to the replacement of coal with renewables, given that there would be no backup generation capacity to compensate renewables intermittency.

Annex Figure 1.SF.2.1. Total Energy Consumption and Projections
(Index, 1971 = 100)



Sources: International Energy Agency, *World Energy Outlook and World Energy Balance;* and IMF staff calculations.
Note: Consumption data after 2018 are IEA projections for the Stated Policies Scenario, reflecting the impact of existing policy frameworks and today's announced policy intentions.

Even as India's per capita energy consumption will continue to lag the world average by far, her changing coal usage will play a crucial role in achieving climate mitigation goals. To speed up the transition from coal generation to green energy, India could build on current policies, which have successfully encouraged investment in renewables, and support the development of natural gas infrastructure. Concessionary financing from advanced economies would help stimulate India's green policy adoption and its fairness. The green transition would eventually also reduce financial stability risks associated with Indian banks' exposure to coal assets in the power and mining sector, which could become stranded by the introduction of an international carbon tax or environmental regulations on local emissions. Offering compensation to the mining and power sectors (possibly paid for by raising carbon tax revenue) for the early retirement of old and inefficient coal-fired power plants would reduce the financial stability risks associated with stranded assets during a rapid transition.