

Enablers for an Ambitious Coal Phase-out

Supplementary Material

Table S1 – Regions in Integrated Assessment Models.

The following regional aggregation was used in Figure 1 (B) of the main paper to show the total installed coal capacity in China+, India+, North America and Europe region.

List of regional aggregation in IAM used in the ENGAGE project and developed for the LIMITS project. For reference please also see: <https://tntcat.iiasa.ac.at/LIMITSDB/dsd?Action=htmlpage&page=about#regiondefs>. Used for Figure 1 in the main paper.

R10NORTH_AM	countries of North America; primarily the United States of America and Canada Canada, Guam, United States of America
R10EUROPE	countries of Eastern and Western Europe (i.e., the EU28), can include Turkey Austria, Belgium, Croatia, Denmark, France, Finland, Spain, Sweden, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Switzerland, Turkey, United Kingdom
R10PAC_OECD	countries of the Pacific OECD Australia, Japan, New Caledonia, New Zealand, Samoa, Solomon Islands, Vanuatu
R10REF_ECON	countries from the Reforming Economies of Eastern Europe and the Former Soviet Union; primarily Russia Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
R10CHINA+	countries of centrally-planned Asia; primarily China China (incl. Hong Kong), Cambodia, Korea (DPR), Laos (PDR), Mongolia, Viet Nam
R10INDIA+	countries of South Asia; primarily India India, Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka,
R10REST_ASIA	other countries of Asia (in not in India+/China+) Afghanistan, Bangladesh, Bhutan, Fiji, Maldives, Nepal, Pakistan, Sri Lanka, Cambodia, Korea (DPR), Laos (PDR), Mongolia, Viet Nam
R10AFRICA	countries of Sub-Saharan Africa Angola, Benin, Botswana, British Indian Ocean Territory, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Cote d'Ivoire, Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Saint Helena, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe
R10MIDDLE_EAST	countries of the Middle East; Iran, Iraq, Israel, Saudi Arabia, Qatar, etc. Iraq, Iran (Islamic Republic), Israel, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, United Arab Emirates
R10LATIN_AM	countries of Latin America and the Caribbean Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua,

	Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela
R10ROWO	Rest of the World - to be used only if decent match with the 10 regions can otherwise not be achieved

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14 Table S2 - Dependent Variables.

Country	Year peak	Capacity peak	Capacity 2021	Retired Capacity Total	Retired Capacity Prematurely	Share retired prematurely	Share retired total	Share 2021 as of peak
Austria	1996	1933	0	1993	522	28.98	100	0
Belgium	1974	2865	0	2865	0	0	100	0
Portugal	1995	2028	0	2028	682	33.62	100	0
Sweden	1990	291	0	291	0	0	100	0
UK	1986	35856.5	6328	29528.5	0	0	82.35	17.64
Denmark	1998	5003	1180	3823	371	7.41	76.41	23.58
Spain	1997	13800.6	3447.7	10352.9	899.7	6.52	75.02	24.98
Canada	1994	18374.2	5679.8	13765.4	495	2.69	74.92	30.91
France	1995	8652	3107	6019	0	0	69.56	35.91
Finland	1994	3722.2	1468.2	2254	78	2.09	60.55	39.44
Slovakia	1976	1285	561	724	0	0	56.34	43.65
Greece	2003	5278	2525	2753	0	0	52.15	47.84
NZ	1983	1000	500	500	250	25	50	50
Romania	1998	7735	5005	2730	1070	13.83	35.29	64.70
Netherlands	2016	6043	4152	3665	1729	28.61	60.64	68.70
		330625.2	227604.8					
US	1994	8	6	132951	5265.8	1.59	40.21	68.84
Italy	2010	9967	6956	4044	735	7.37	40.57	69.79
Hungary	1970	1709	1194	515	0	0	30.13	69.86
Slovenia	2015	1469	1069	535	0	0	36.41	72.77
Germany	2000	52407.6	41122.5	24310.1	3612	6.89	46.38	78.46
Bulgaria	2011	6356	5149	1380	0	0	21.71	81.01
Australia	2009	31004	25137	6407	181	0.58	20.66	81.07
CZ	2004	8857.1	7405.6	2996.5	400	4.51	33.83	83.61
Kosovo	1984	1480	1290	190	0	0	12.83	87.16
Russia	2015	45462.1	41094.1	7779	787	1.73	17.11	90.39
Hong Kong	1997	6610	6110	500	0	0	7.56	92.43
Chile	2019	5189	4941	575	154	2.96	11.08	95.22
Ukraine	1988	22793	21947	846	0	0	3.71	96.28
Uzbekistan	2000	2584	2493	241	0	0	9.32	96.47
Brazil	2013	3278	3177	446	0	0	13.60	96.91
Poland	2011	30661.6	29969.6	5989	225	0.73	19.53	97.74
Turkey	2020	19388.16	19173.16	360	360	1.85	1.85	98.89
Serbia	1991	4437	4405	32	0	0	0.72	99.27
UAE	2021	1200	1200	0	0	0	0	100
Argentina	1983	375	375	0	0	0	0	100
Bangladesh	2020	1845	1845	0	0	0	0	100
Brunei	2019	220	220	0	0	0	0	100
Botswana	2014	732	732	0	0	0	0	100
China	2021	1062837	1062837	107997	82314.9	7.74	10.16	100
Colombia	2018	1633.5	1633.5	0	0	0	0	100
Dominican Republic	2020	1064	1064	0	0	0	0	100
Guadeloupe	2011	102	102	0	0	0	0	100
Guatemala	2016	1010.3	1010.3	0	0	0	0	100
Honduras	2018	105	105	0	0	0	0	100
Croatia	2000	335	335	0	0	0	0	100
Indonesia	2021	39986.6	39986.6	0	0	0	0	100
India	2021	233104.7	233104.7	14436.1	2017.5	0.86	6.19	100

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Ireland	1987	915	915	0	0	0	0	100
Israel	2001	4900	4900	0	0	0	0	100
Japan	2021	50722.98	50722.98	2517.9	468.4	0.92	4.96	100
Kazakhstan	2021	13479	13479	210	0	0	1.55	100
Kyrgyzstan	2017	910	910	195	0	0	21.42	100
Cambodia	2021	705	705	0	0	0	0	100
South Korea	2021	38114	38114	3420	0	0	8.97	100
Laos	2016	1878	1878	0	0	0	0	100
Sri Lanka	2014	900	900	0	0	0	0	100
Morocco	2018	4257	4257	0	0	0	0	100
Moldova	1971	1610	1610	0	0	0	0	100
Madagascar	2011	120	120	0	0	0	0	100
Mexico	2010	5378	5378	0	0	0	0	100
North Macedonia	1988	800	800	0	0	0	0	100
Myanmar	2017	160	160	0	0	0	0	100
Montenegro	1982	225	225	0	0	0	0	100
Mongolia	2021	960	960	0	0	0	0	100
Mauritius	2007	195	195	0	0	0	0	100
Malaysia	2019	13280	13280	0	0	0	0	100
Namibia	1979	120	120	0	0	0	0	100
Pakistan	2021	5118	5118	0	0	0	0	100
Panama	2018	426	426	0	0	0	0	100
Peru	1999	135	135	0	0	0	0	100
Philippines	2020	10557	10557	0	0	0	0	100
North Korea	2018	3700	3700	0	0	0	0	100
Senegal	2021	155	155	0	0	0	0	100
Syria	2010	60	60	0	0	0	0	100
Thailand	2019	5988	5988	825	225	3.75	13.77	100
Tajikistan	2016	400	400	0	0	0	0	100
Taiwan	2019	19082	19082	2200	473	2.47	11.52	100
Vietnam	2021	22717	22717	0	0	0	0	100
South Africa	2021	46274.1	46274.1	0	0	0	0	100
Zambia	2016	330	330	0	0	0	0	100
Zimbabwe	1987	920	920	0	0	0	0	100

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17 Note: This table provides an overview of all variables included in the regression analysis. Peak year indicates
 18 the year in which a country reached maximum coal capacity and the capacity was not substantially
 19 increasing in the following years. For countries where coal capacity is still increasing the last observed year
 20 was included in the analysis. Capacity peak is the capacity in MW in the peak year. As an initial measure we
 21 thus propose to use the share of prematurely retired coal capacity (coal power plants that are bigger than 100 MW and
 22 less than 30-years-old) of the total capacity in the peak year, to which we refer as “**premature.**” Yet countries might
 23 retire many power plants prematurely without substantially decreasing their overall coal stock or, in other words,
 24 without a real trend toward coal phaseout. We thus use **two additional measures** to also account for those trends: (1)
 25 share of retired coal capacity in total capacity in the peak year (based on the year in which a country reached peak
 26 capacity; i.e., after which capacity did not substantially increase) which we refer to as “**retired total**” and (2) share of
 27 peak capacity as a share of the current capacity which we refer to as “**peak versus current**” (calculated to indicate the
 28 retired share in the current capacity).

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30 **Tables S3.**

31 **A. Regression results with the prematurely retired share of coal capacity as the dependent variable.**

DV: share of retired coal of peak capacity	(1)	(2)	(3)	(4)	(5)	(6)
GDPpc	0.000768*** (0.000287)		-0.000311 (0.000231)	0.000462* (0.000276)		
State capacity		26.59*** (3.568)	30.29*** (5.613)		25.81*** (4.340)	28.76*** (9.630)
Coal reserves			-0.918* (0.534)	-1.077** (0.503)	-0.883* (0.509)	-0.772 (0.579)
Coal share % at peak capacity			-0.146* (0.0863)	-0.0292 (0.0973)	-0.139* (0.0803)	-0.263* (0.143)
Liberalization index			2.613* (1.371)	7.060*** (1.425)	2.592** (1.250)	2.867 (2.957)
Federal government			6.304 (8.383)	11.42 (10.61)	4.118 (8.361)	1.471 (14.23)
Climate emergency						0.145 (0.734)
Constant	3.387 (5.075)	-4.451 (2.806)	-11.54 (8.749)	-30.74*** (7.935)	-13.96* (7.573)	-25.37 (54.32)
Observations	72	69	64	68	65	26
R ²	0.183	0.515	0.609	0.400	0.600	0.665
AIC	684.4	621.1	575.0	635.9	582.8	236.6

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33 **B. Regression results with the retired share of coal capacity as the share of peak capacity.**

	(1) Prematurely retired share	(2) Prematurely retired share	(3) Prematurely retired share	(4) Prematurely retired share	(5) Prematurely retired share
Log GDPpc	2.304*** (0.850)		0.0468 (1.210)	2.142** (1.044)	
State capacity		3.337*** (1.141)	3.291* (1.781)		3.334** (1.451)
Oil price			-0.0195 (0.0392)	-0.0325 (0.0315)	-0.0205 (0.0354)
Coal share % at peak capacity			-0.0330 (0.0264)	-0.0273 (0.0228)	-0.0323 (0.0256)
Years since peak			0.0254 (0.0943)	0.0242 (0.0744)	0.0244 (0.0912)
Median age retired			0.00369 (0.0233)	0.0240 (0.0209)	0.00438 (0.0226)
Log NOx emissions			-0.430 (0.516)	-0.192 (0.420)	-0.418 (0.503)
Constant	-19.70*** (7.586)	-0.318 (0.522)	3.007 (10.18)	-15.42* (8.482)	3.380 (3.703)
Observations	72	64	61	68	62
R ²	0.086	0.155	0.191	0.127	0.192
AIC	480.1	428.6	420.5	463.9	424.1

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36 C. Regression results with the retired share of coal capacity as the share of peak capacity.

DV: Share of 2021 capacity of peak capacity	(1)	(2)	(3)	(4)	(5)	(6)
GDPpc	0.000689** (0.000262)		-0.000367* (0.000200)	0.000406 (0.000252)		
State capacity		24.68*** (3.767)	29.90*** (5.836)		24.63*** (4.792)	29.27** (10.88)
Coal reserves			-1.165** (0.525)	-1.325** (0.502)	-1.123** (0.493)	-0.780 (0.638)
Coal share % at peak capacity			-0.150 (0.0936)	-0.0342 (0.100)	-0.143 (0.0877)	-0.284 (0.167)
Liberalization index			2.320 (1.454)	6.637*** (1.426)	2.283* (1.322)	2.273 (3.309)
Federal government			6.367 (9.225)	11.14 (11.14)	3.768 (9.213)	-2.018 (16.40)
Climate emergency						0.202 (0.845)
Constant	1.999 (4.544)	-5.945** (2.695)	-11.16 (8.912)	-29.70*** (7.897)	-13.90* (7.751)	-29.73 (61.13)
Observations	72	69	64	68	65	26
R ²	0.152	0.458	0.562	0.354	0.547	0.623
AIC	685.1	626.7	580.9	639.4	589.4	240.0

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38 D. Regression results including a different set of control variables.

	(1) Prematurely retired share	(2) Prematurely retired share	(3) Prematurely retired share	(4) Prematurely retired share	(5) Prematurely retired share
Log GDPpc	2.304*** (0.850)		0.0468 (1.210)	2.142** (1.044)	
State capacity		3.337*** (1.141)	3.291* (1.781)		3.334** (1.451)
Oil price			-0.0195 (0.0392)	-0.0325 (0.0315)	-0.0205 (0.0354)
Coal share % at peak capacity			-0.0330 (0.0264)	-0.0273 (0.0228)	-0.0323 (0.0256)
Years since peak			0.0254 (0.0943)	0.0242 (0.0744)	0.0244 (0.0912)
Median age retired			0.00369 (0.0233)	0.0240 (0.0209)	0.00438 (0.0226)
Log NOx emissions			-0.430 (0.516)	-0.192 (0.420)	-0.418 (0.503)
Constant	-19.70** (7.586)	-0.318 (0.522)	3.007 (10.18)	-15.42* (8.482)	3.380 (3.703)
Observations	72	64	61	68	62
R ²	0.086	0.155	0.191	0.127	0.192
AIC	480.1	428.6	420.5	463.9	424.1

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40 Table S4.

41 Cases of premature coal retirement identified from the Global Energy Monitor Database (2022). Coding of
42 patterns based on Global Energy Monitor Wiki, media articles, press releases and policy documents.

year	plant_id	Country	Status	capacity_mw	year_retired	plant_age	Pattern
2015	G107010	Germany	retired	820	2021	6	quieting interests (compensation)
2015	G107011	Germany	retired	820	2021	6	quieting interests (compensation)
2014	G110909	Germany	retired	800	2021	7	quieting interests (compensation)
2008	G101407	China	retired	300	2015	7	regulatory enforcement
2008	G101408	China	retired	300	2015	7	regulatory enforcement
2012	G110790	China	retired	330	2020	8	regulatory enforcement
2012	G110791	China	retired	330	2020	8	regulatory enforcement
2012	G110792	China	retired	330	2020	8	regulatory enforcement
2012	G110793	China	retired	330	2020	8	regulatory enforcement
2011	G104255	China	retired	330	2020	9	regulatory enforcement
2011	G104256	China	retired	330	2020	9	regulatory enforcement
2009	G108787	United States	retired	661.5	2018	9	market/price dynamics
2011	G105637	Canada	retired	495	2021	10	market/price dynamics
2007	G102043	China	retired	330	2017	10	market/price dynamics
2007	G102044	China	retired	330	2017	10	market/price dynamics
2006	G104737	China	retired	300	2016	10	regulatory enforcement
2006	G104738	China	retired	300	2016	10	regulatory enforcement
2009	G105612	Russia	retired	330	2020	11	market/price dynamics
2009	G104415	China	retired	350	2020	11	regulatory enforcement; market/price dynamics
2009	G104416	China	retired	350	2020	11	regulatory enforcement; market/price dynamics
2005	G102106	China	retired	300	2018	13	market/price dynamics
2007	G111241	China	retired	300	2020	13	market/price dynamics
2007	G111234	China	retired	300	2020	13	market/price dynamics
2004	G102105	China	retired	300	2018	14	market/price dynamics
2006	G100073	Turkey	retired	360	2021	15	regulatory enforcement
1999	G109849	China	retired	300	2017	18	NA
1999	G110260	China	retired	320	2018	19	NA
1998	G109848	China	retired	300	2017	19	NA
1996	G108205	Spain	retired	317.7	2016	20	market/price dynamics
2000	G111237	China	retired	300	2020	20	market/price dynamics
2000	G111238	China	retired	300	2020	20	market/price dynamics

1985	G110368	Romania	retired	330	2006	21	regulatory enforcement
1983	G110645	Austria	retired	330	2006	23	market/price dynamics
1995	G103753	Netherlands	retired	685	2019	24	quieting interests (compensation)
1997	G106343	Spain	retired	582	2021	24	market/price dynamics
1996	G104152	China	retired	330	2020	24	regulatory enforcement
1992	G109851	China	retired	300	2017	25	NA
1995	G104844	United States	retired	395.4	2020	25	market/price dynamics; regulatory enforcement
1995	G107914	Portugal	retired	341	2021	26	market/price dynamics
1991	G109850	China	retired	300	2017	26	NA
1988	G101018	Netherlands	retired	441	2015	27	regulatory enforcement
1973	G114628	Germany	retired	325	2001	28	market/price dynamics; market/price dynamics
1992	G101062	Italy	retired	660	2020	28	regulatory enforcement
1988	G106536	Netherlands	retired	603	2017	29	regulatory enforcement
1992	G107913	Portugal	retired	341	2021	29	regulatory enforcement; market/price dynamics
1988	G105061	China	retired	330	2017	29	NA

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