

1 **Quantifying the reductions in mortality from air-pollution by cancelling new**  
2 **coal power plants**

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12

13 **Abstract**

14 Deep decarbonization paths to the 1.5°C or 2°C temperature stabilization futures require a rapid reduction  
15 in coal-fired power plants, but many countries are continuing to build new ones. Coal-fired plants are also  
16 a major contributor to air pollution related health impacts. Here, we couple an integrated human-earth  
17 system model (GCAM) with an air quality model (TM5-FASST) to examine regional health co-benefits  
18 from cancelling new coal-fired plants worldwide. Our analysis considers the evolution of pollutants control  
19 based on coal plants vintage and regional policies. We find that cancelling all new proposed projects would  
20 decrease air pollution related premature mortality between 101,388-213,205 deaths (2-5%) in 2030, and  
21 213,414-373,054 (5-8%) in 2050, globally, but heavily concentrated in developing Asia. These health co-  
22 benefits are comparable in magnitude to the values obtained by implementing the Nationally Determined  
23 Contributions (NDCs). Furthermore, we estimate that strengthening the climate target from 2°C to 1.5°C  
24 would avoid 326,351 additional mortalities in 2030, of which 251,011 (75%) are attributable to the  
25 incremental coal plant shutdown.

26

## 1 Introduction

Coal-fired electric power generation plants are one of the largest contributors of global greenhouse gas (GHG) emissions. At global level, in 2010 they represented around 25-30% of total carbon dioxide (CO<sub>2</sub>) emissions [1], and this fraction is even larger in some regions such as China or India. Limiting warming to 1.5°C or 2°C would require all conventional coal-fired power plants to be phased out roughly within the next 30 years [2–4]. Furthermore, none of the existing plans for installation of new coal capacity is consistent with meeting the temperature stabilization targets defined in the Paris Agreement [5–8]. Even implementing projects which have already started would greatly increase the risk of stranding assets [7].

Apart from the GHG mitigation potential, phasing out coal-fired plants would directly reduce air pollution related health impacts, which has been a major driver for historical and ongoing transition from coal power [9,10]. Coal-fired plants are a major source of local air pollutants, particularly sulphur dioxide (SO<sub>2</sub>). At the global level, coal-fired power plants were responsible for 30-45% of total SO<sub>2</sub> emissions in 2010 [11–13], although the share has been decreasing since 2005 (SI, Figure S2). SO<sub>2</sub> is one of the main contributors to the formation of secondary fine particulate matter (PM<sub>2.5</sub>) [14,15], and PM<sub>2.5</sub> is the most hazardous pollutant in terms of human health [16–19] especially in regions such as China [20–22] and India [23,24], due to their high population density.

Existing literature has extensively analysed the importance of incorporating potential health co-benefits in policy design. Several studies have demonstrated that, at a global level, these co-benefits would outweigh the policy cost of mitigation [25–29]. While they show that largest co-benefits would be located in developing Asia, other studies demonstrate that health co-benefits would also play a significant role in developed regions [30,31]. Furthermore, recent studies have analysed sectorial contributions to PM<sub>2.5</sub> and the associated health impacts [32–34]. Reduction of fossil fuel consumption [35], the penetration of cleaner technologies in the power sector [36–38] or the electrification of the vehicle fleet [39] have been proved as effective measures for improving air quality. Moreover, few studies have analysed the air pollution effect in human health specifically contributed from coal-fired power generation [40–43].

However, to our knowledge, this is the first study that shows the benefits of simply cancelling all the new existing projects based on a unit-level database of newly proposed coal-fired power plants worldwide. Specifically, we are asking the following questions: *How large are the health co-benefits from new project cancellation? How large are they compared to the co-benefits obtained from the implementation of the Nationally Determined Contributions (NDCs)? What is the additional impact on*

58 *premature mortality attributable to increased coal-fired power plant retirement in a 1.5°C decarbonization*  
59 *scenario, compared to a 2°C scenario?*

60 Another innovative aspect of this study is that it combines a global dataset of existing and proposed  
61 coal plants [7] with a modelling framework that couples an integrated human-earth system model (Global  
62 Change Analysis Model, GCAM [44]) with an air quality source-receptor model (Fast Scenario Screening  
63 Tool, TM5-FASST [45]). We use GCAM to specify different coal trajectories based on the bottom-up data  
64 and quantify the GHG emission impacts from coal power plants. We use TM5-FASST to evaluate air  
65 pollutants, the concentrations of particulate matter in the atmosphere and the associated premature  
66 mortality.

67 In this framework, we assess health impacts associated to air pollution for five different scenarios  
68 (see section 2.2): first, a baseline scenario where all proposed coal-fired power plants are built and operate  
69 through the lifetime of 50 years (*ContinuedGrowth*); second, a coal cancellation scenario, where no new  
70 coal plants are constructed beyond 2020 (*NoNewCoal*); third, a scenario with the implementation of the  
71 NDCs (*NDC*); fourth, a cost-effective 2°C mitigation scenario where there is an implicit accelerated coal  
72 retirement (2°C); and fifth, a cost-effective 1.5°C mitigation scenario where the coal phase-out is even  
73 faster (1.5°C). We find that cancelling new proposed coal-fired power plants generates significant air  
74 pollution related health co-benefits. This is comparable in magnitude to the co-benefits obtained by  
75 implementing the NDCs, with regional divergences. Moreover, moving from the 2°C to the 1.5°C  
76 decarbonization scenario would generate extra health co-benefits related to faster retirement of coal-fired  
77 plants, mostly in the medium term (2030).

## 78 **2 Methods**

79

### 80 **2.1 Methodology**

81 Our assessments are based on a unit-level database of worldwide newly proposed coal-fired power  
82 plants in different development stages – under construction, permitted, in the permitting process, and in  
83 planning. Data on existing plants are primarily taken from the Global Coal Plant Tracker by Global Energy  
84 Monitor [46]. Information about proposed projects is gathered from various data sources, such as national  
85 and local energy development plans, public notices of project permitting processes (f.e. environmental  
86 impact assessments), coal industry status reports, power company websites, and a variety of news channels.  
87 This aggregated data is validated against other sources and modified at the national level as needed. All  
88 information is updated as of September 2018. More information can be found in Cui et al (2019) [7].

89           This coal data is fed into an integrated human-earth system model – the Global Change Analysis  
90 Model (GCAM) – to estimate the local air pollutant emissions under alternative coal power scenarios.  
91 GCAM is an integrated human-earth system model developed by the Joint Global Change Research  
92 Institute (JGCRI) that represents the interconnections of energy, land-use, economy, water and climate  
93 systems (<https://github.com/JGCRI/gcam-doc>). GCAM is divided into 32 geo-political regions and 384  
94 land subregions and runs in 5-year time steps until the end of the century. As a relevant feature for this  
95 study, the GCAM emissions module tracks the main GHGs and air pollutants, namely carbon dioxide (CO<sub>2</sub>),  
96 methane (CH<sub>4</sub>), nitrogen dioxide (N<sub>2</sub>O), black carbon (BC), organic carbon (OC), carbon monoxide (CO),  
97 non-methane volatile organic compounds (NMVOC), nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>) and  
98 hydrofluorocarbons (HFCs). We use GCAM 5.1 [44,47] in this study. More information can be found in  
99 the SI.

100           The implementation of the coal data into GCAM is detailed in Cui et al (2019) [7]. First, the  
101 generation trajectory for each plant in the database is determined. A coal unit built in a given year is assumed  
102 to continue to operate until the end of an exogenously specified lifetime at a region-specific, constant  
103 capacity factor. Then, unit-level trajectories are aggregated to obtain coal generation pathways for GCAM-  
104 specific regions and model periods. These trajectories are implemented as constraints on the model's output  
105 and are used to quantify the committed emissions.

106           In order to estimate pollutant concentrations, population-weighted exposure, and premature  
107 mortality, we translate the system-wide GHG and air pollutant emissions (estimated from GCAM) to the  
108 TM5-Fast Scenario Screening Tool air quality source-receptor model (TM5-FASST) [45]. TM5-FASST is  
109 an air quality source-receptor model developed by the European Commission's Joint Research Centre (JRC)  
110 in Ispra, Italy. The model is a global reduced form representation of the TM5 full chemistry model,  
111 estimating PM<sub>2.5</sub> and O<sub>3</sub> concentration levels and their impacts in terms of health, agriculture or global  
112 warming. The model uses underlying meteorological and atmospheric information drawn from more  
113 complex chemical transport models to estimate concentrations of PM<sub>2.5</sub> and O<sub>3</sub> in each receptor-region  
114 driven by the emissions of different precursors in different sources (regions). This structure can capture  
115 cross-border health impacts associated with emission reductions in neighbouring regions.

116           For health impacts, TM5-FASST estimates premature mortalities attributable to particulate matter  
117 (PM<sub>2.5</sub>) and ozone (O<sub>3</sub>) based on the exposure-response functions (ERFs) from Burnett et al (2014) [48]  
118 and Jerret et al (2009) [49], respectively (see SI for more details). The model differentiates between different  
119 causes of death, which are ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD),  
120 stroke, lung cancer (LC) and acute lower respiratory airways infections (ALRI).

121 For each cause, variations in mortalities would be determined as a product of the baseline mortality  
122 rates, which are taken from the World Health Organization [50], the exposed population and the attributable  
123 fraction, which is function of the relative risk (RR) of death [51]. For population exposure, we use SSP2  
124 population data, in order to maintain consistency across the models applied in this study. In addition, some  
125 of the causes of death apply only to adults (>30 years) (IHD, stroke, COPD, LC) and ALRI applies only to  
126 infants (<5 years). To estimate the adult-infant proportions we make use of the historical shares from the  
127 United Nations population prospects [52]. For the estimation of future health impacts (as we do in this  
128 study), the used version TM5-FASST does not include any temporal change of population structure, so we  
129 do not capture the effects of population aging over time.

130 Van Dingenen et al (2018) [45] provides a complete documentation of the model, demonstrating  
131 that the simplifications applied (compared to full chemistry models such as TM5), do not compromise the  
132 validity of the output. That study shows that although the outputs would depend on the linearity assumption  
133 for the main exposure metrics, it is a validated tool for analysing differences across predesigned scenarios.  
134 The model is increasingly being used and has been applied in several studies [53–55]. Note that the  
135 combined use of the models allows us to capture the health impacts of both primary and secondary PM<sub>2.5</sub>  
136 [25]. This is essential, particularly for this study, since we need to consider the damages from the set of  
137 pollutants emitted by coal fired power plants (specially SO<sub>2</sub>).

## 138 **2.2 Scenarios**

139 In this study we have modelled five scenarios for estimating the air pollution driven health co-  
140 benefits of coal plant cancellation through different mitigation strategies. The *ContinuedGrowth* is the  
141 baseline scenario, where all coal power projects under development will be completed by 2030, and coal  
142 power plant capacity will continue to grow at the same rate through 2050. The *NoNewCoal* is a coal peaking  
143 scenario, where no new coal plants are built after 2020. We assume that coal electricity generation will be  
144 substituted by generation from non-emitting technologies. The assumed lifetime of the installed coal plants  
145 is 50 years, so they will be gradually phased-out. The scenario does not include any carbon price. In the  
146 *NDC* scenario there is a climate policy where all of the regions apply the Nationally Determined  
147 contributions based on Fawcett et al (2015) [57]. After 2030 in the *NDC* scenario, a conservative approach  
148 is assumed (“Paris Continued ambition” in the aforementioned paper), leading to an increase in global mean  
149 temperature of around 3°C in 2100 that is still increasing. Moreover, the probability of limiting warming to  
150 2°C in this scenario accounts for 8%. For the implementation of the NDCs we establish 32 carbon markets  
151 (for the 32 GCAM regions) and the mitigation will follow a “least-cost” approach. The 2°C and 1.5°C  
152 scenarios are implemented by limiting end-of-century radiative forcing to 2.6 Wm<sup>-2</sup> and 1.9 Wm<sup>-2</sup>.

153 Starting in 2025, emissions reductions are pursued cost-effectively across regions via a single global carbon  
154 price on energy-related emissions. This is different from the regionally differentiated approach in the *NDC*  
155 scenario. Cumulative emissions in the 2°C scenario peak at 900 GtCO<sub>2</sub> in 2070 and decline to 600 GtCO<sub>2</sub>  
156 in 2100. The 1.5°C scenario peaks at 420 in 2050 and declines below zero by 2100. These limits correspond  
157 to cumulative CO<sub>2</sub> emissions that are below the budgets suggested by the IPCC [58].

158 In addition, trajectories of coal plants' future emission factors will directly affect the health co-  
159 benefit calculation. These emissions factors represent the emissions per unit of activity, so they implicitly  
160 capture the potential implementation of air pollution policies and/or the installation of end-of-pipe  
161 technologies. For one set of the scenarios, we apply region, year, fuel, and sector specific emission factors  
162 from the SSP2 (Shared Socioeconomic Pathways) narrative (f.e. *ContinuedGrowth-SSP2*). The SSP2  
163 sectoral specification [53] provides a gradual reduction in emission factors over time due to future  
164 technological developments (i.e. desulphurization) and the implementation of stricter air pollution regional  
165 policies. For the regional evolution of these emission factors, it is assumed that high- and middle-income  
166 countries will implement near-term (2030) pollution control policies, being gradually more stringent up to  
167 2050. The increase in ambition combined with technological improvement, reduces emission factors by  
168 2100. In low-income regions, emission factors equal to the application of near-term policies in high- and  
169 middle-income regions, would be delayed until 2050. Thereafter, emission factors would continuously  
170 decline until 2100.

171 However, this approach lacks the differentiation between coal plants by vintage with specific  
172 emission factors. For example, historical experience to date, particularly for sulphur dioxide emissions,  
173 shows that countries generally set stringent emission limits for new power plants at some point in time.  
174 Additionally, national policies and standards often require existing plants to lower emissions over their  
175 lifetime. SO<sub>2</sub> emissions in particular can potentially drop dramatically over sub-decadal timescales, as seen  
176 historically in Japan [59] and recently in China [60]. Furthermore, the emission factors for new power plants  
177 can be substantially different from the average emission factor of existing plants due to different  
178 regulations. Therefore, we also implement an alternative approach to modelling SO<sub>2</sub> emissions and  
179 calculate the potential health co-benefits. This approach, labelled as "*VintageControl*" (e.g.,  
180 *ContinuedGrowth-VintageControl*), takes advantage of the electric power generation's vintage  
181 representation in GCAM and better matches historical practice (see SI for detailed description). For the  
182 implementation of this approach, we specify a time at which any new coal-fired electric power plants in  
183 must meet a specified standard, which is going to differ across each region (see SI, Table S4). This entails  
184 that the SO<sub>2</sub> emissions per unit of electricity will be reduced, but with substantial different across regions  
185 and periods (see SI, Figure S13 and Figure S14). This has significant implications for SO<sub>2</sub> emissions. At a

186 global level, SO<sub>2</sub> emissions from coal power plants in the baseline scenario account for 20 and 12 Tg in  
187 2030 and 2050 using SSP2 emission factors (31% and 26% of total SO<sub>2</sub> emissions). The implementation of  
188 the *VintageControl* approach reduces those values to 12 Tg (-42%) and 6 Tg (-51%) in the same periods.  
189 Across regions, India shows by far the largest difference between the two approaches. In 2030, India  
190 accounts for around 65% of the total SO<sub>2</sub> emission difference (-5.54 of -8.57 Tg), and, in 2050, this  
191 proportion increases to 85% (-5.15 of -6 Tg).

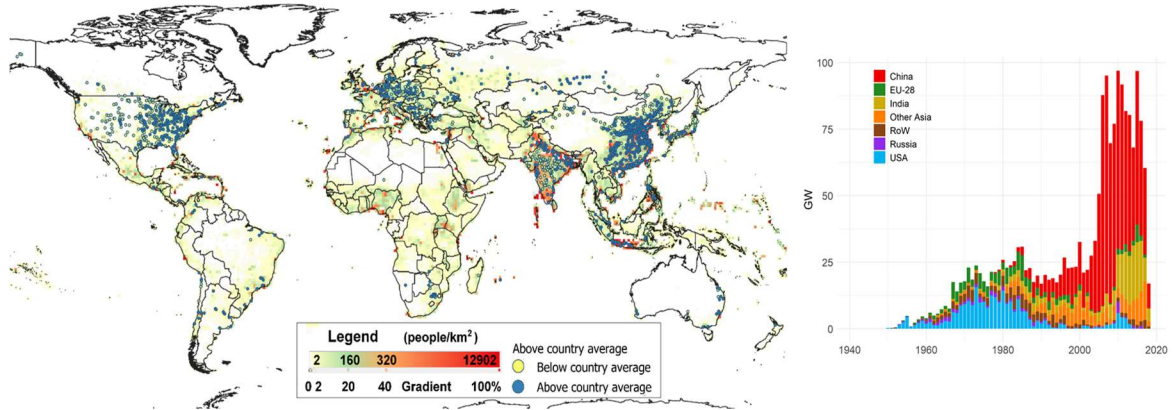
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### 193 **3 Results**

#### 194 **3.1 Proximity of coal plants from densely populated regions**

195 Coal power plants are one of the major sources for SO<sub>2</sub> emissions (SI, Figure S2) so we have  
196 observed that there is a direct relation between SO<sub>2</sub> emissions from the power sector and the location of  
197 coal-fired power plants. This relation is shown in the SI, as gridded SO<sub>2</sub> emissions and, for each cell in the  
198 grid map, SO<sub>2</sub> emissions and the Euclidean distance to a plant (SI, Figures S3 and S4). The distance of the  
199 emission sources (coal-fired power plants) to cities is a key factor for the estimation of health impacts. The  
200 location of the power plants and the transport of the pollutants emitted (largely dependent on prevailing  
201 winds) have direct impacts on total PM<sub>2.5</sub> exposure, which is the most hazardous pollutant for human health  
202 [18,61]. Therefore, we have assessed to which extent existing coal-fired plants are relatively close (less  
203 than 50 km) to high populated/dense nodes (Figure 1). The objective of this assessment is to verify that the  
204 base-year SO<sub>2</sub> emissions patterns used in TM5-FASST are sufficiently robust with respect to the spatial  
205 distributions of existing power plants. Moreover, to verify that plants are relatively close to populated nodes  
206 reduces the inherent uncertainty of the air pollution model (TM5-FASST) in terms of atmospheric and  
207 meteorological assumptions.

208



209

210 **Figure 1: Geolocation of the world coal power plants.** Comparison of the distance of coal-fired power plants to  
 211 high-populated nodes. The green to red gradient shows the gridded population density. The blue and yellow dots  
 212 represent if the plant is above or below the country average density, respectively. Location of the plants is taken from  
 213 World Resource Institute (<http://datasets.wri.org/>). Population data from CIESIN 2017 [62]. The panel in the right  
 214 shows the global coal capacity by vintage year (GW). Data form Cui et al (2019)[7].

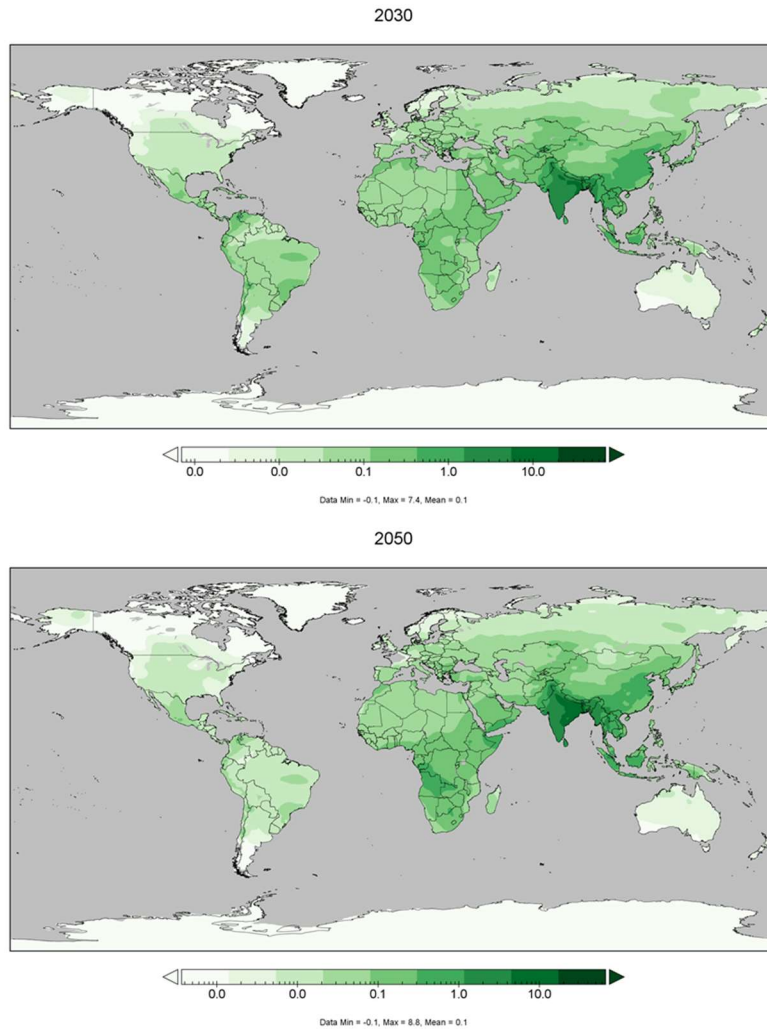
215 In China, 80% of the plants, i.e. 645, are situated (with the 50km radius) in an area where population  
 216 density is above the national average (150 person/km<sup>2</sup>), while the remaining 20% are located in an area  
 217 with a below-average population density. In the USA, 55%, around 235 plants, are situated in an area of  
 218 higher density than the average of the country (36.5 person/km<sup>2</sup>), while 191 plants are situated in an area  
 219 of lower density than the average. In India, on the other hand, only 37% of the plants, i.e. 91 of them, are  
 220 situated in an area of higher density than the average of the country (401 person/km<sup>2</sup>), while 155 plants are  
 221 situated in an area of lower density than the country average. However, given that India's population density  
 222 is significantly higher the world average population density (57 person/km<sup>2</sup>), more than 99% of coal plants  
 223 in India would be located relatively close to areas where the population density is above the world average.  
 224 In the rest of the world, the percentage of the plants close to relatively dense population grids varies  
 225 significantly, ranging from 97% in Poland to 43% in Japan. Additionally, we have compared the plant  
 226 distance to high and low population density areas (25th and 75th percentiles, see the SI, Table S1). Around  
 227 53% of the plants are located relatively close to high-populated nodes at a global level (75th percentile),  
 228 while only the 13% of the plants are close to low density areas (percentile 25<sup>th</sup>).

229

## 230 **3.2 Health impacts from cancelling new projects**

231 In the last decade, SO<sub>2</sub> emissions associated to coal plants have been a major contributor to the  
232 formation of PM<sub>2.5</sub>. This has generated significant health impacts. Between 2010 and 2020, we estimate  
233 that SO<sub>2</sub> emissions from power plants have caused 275,000-305,000 premature mortalities each year at a  
234 global level, which represents around 6-8% of total premature deaths attributable to air pollution. These  
235 premature mortalities would be heavily concentrated in India (100,000-150,000) and China (60,000-  
236 80,000) (SI, Table S2).

237 We find that cancelling all new projects that are currently under development would decrease PM<sub>2.5</sub>  
238 globally due to the replacement of coal by clean energy sources in electricity generation (comparing the  
239 results of “*ContinuedGrowth*” vs “*NoNewCoal*” scenarios). The largest reductions will occur in South and  
240 East Asia, mostly China and India (Figure 2). In each country, PM<sub>2.5</sub> concentration will decrease up to 4%,  
241 and 13%, respectively in 2030, and to 3%, and 24% in 2050. In addition, the large emissions reductions in  
242 these regions make that some contiguous countries (e.g. Pakistan) would present significant cross-border  
243 reductions in PM<sub>2.5</sub> concentration levels (12-15%).



244

245 **Figure 2: Change in anthropogenic PM<sub>2.5</sub> concentrations in 2030 and 2050 (log(µg/m<sup>3</sup>)) between**  
 246 **“ContinuedGrowth” and “NoNewCoal” scenarios, using SSP2 emission factors. PM<sub>2.5</sub> estimations are obtained by**  
 247 **feeding GCAM emissions of PM<sub>2.5</sub> precursors into TM5-FASST. These pollutants are sulphur dioxide (SO<sub>2</sub>), nitrogen**  
 248 **oxides (NO<sub>x</sub>), ammonia (NH<sub>3</sub>), black carbon (BC) and organic carbon (OC).**

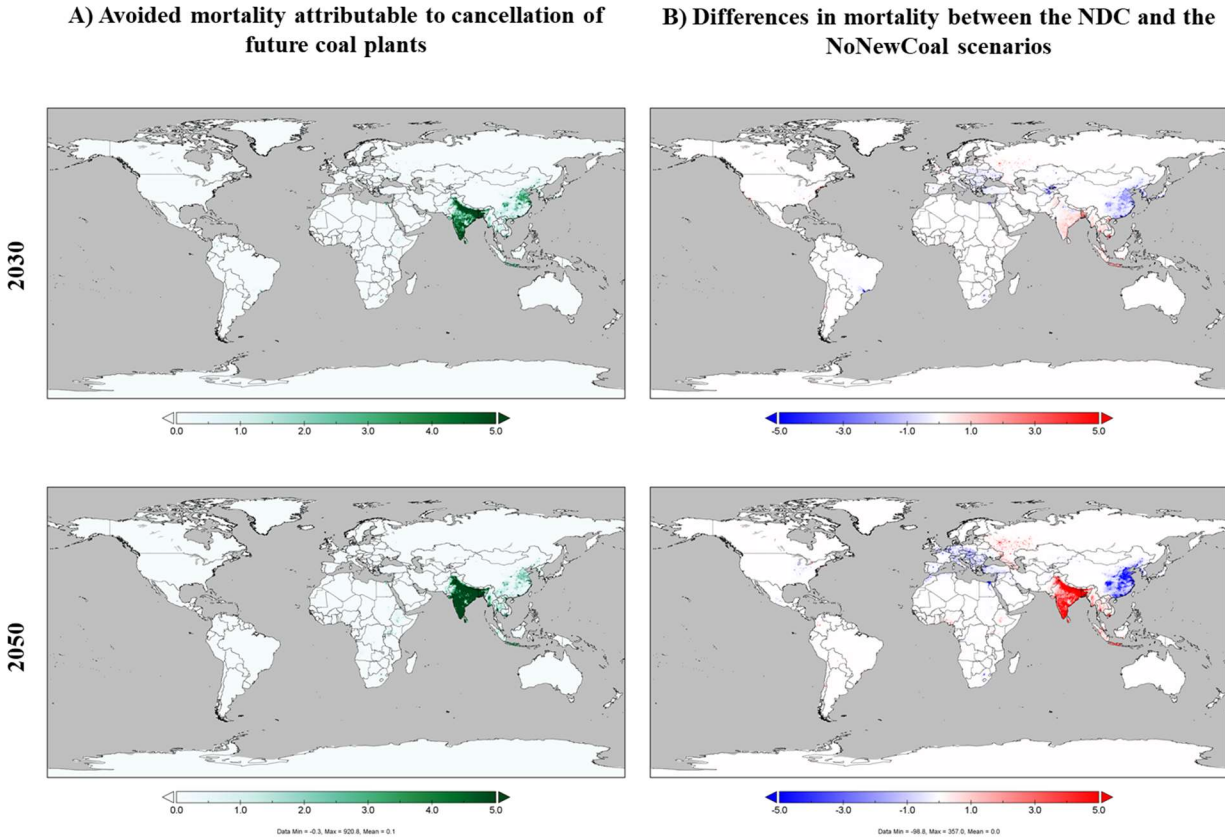
249 These PM<sub>2.5</sub> reductions would decrease premature mortality attributable to air pollution by 213,205  
 250 (5%) and 373,054 (8%) at a global level, in 2030 and 2050, respectively, based on emission factor  
 251 trajectories from the SSP2 narrative. Alternatively, when using the vintage approach to modelling SO<sub>2</sub>  
 252 emissions (*VintageControl*), we have estimated that these values would be reduced to 101,388 (2%) and  
 253 213,414 (5%). By assuming improved control technologies for newer plants, the avoided mortality remains  
 254 significant; on the other hand, if they are not successfully implemented moving forward, the health co-  
 255 benefits from new plants cancellation could be even larger.

256 While air quality improves in many regions across the world, health benefits from cancelling new  
257 coal projects are concentrated in India, China and Southeast Asia due to their high population densities and  
258 the existing coal fleet (Figure 3A). Using SSP2 emission factors, premature mortality will decrease between  
259 3% and 8% in 2030 and around 3% and 17% in 2050, in China and India, respectively. The implementation  
260 of the *VintageControl* approach in the baseline scenario reduces those values, particularly in India, where  
261 they would decrease to 2% and 8% for 2030 and 2050.

262 Moreover, the avoided premature mortality of cancelling new coal-fired power plants in China and  
263 India are comparable to the health benefits obtained by implementing the NDCs. Specifically, premature  
264 mortality associated with air pollution would decrease around 5% and 7% in 2030, and around 8% and 11%  
265 in 2050, in China and India, respectively, if they achieve their NDC targets (see detailed description of the  
266 estimated premature mortalities by region and scenario in SI, Figure S6). The co-benefits obtained from the  
267 implementation of the NDCs are in line with previous studies [25,26], by taking into account projected  
268 population growth by 9% and 26% by 2030 and 2050, respectively.

269 Globally, the no new coal strategy and the economy-wide emission reduction (NDCs) are also  
270 comparable in terms of the resulted air pollution driven health co-benefits. However, the relative effects  
271 between the two tend to vary across regions (Figure 3B). On the one hand, cancellation of coal-fired power  
272 plants would be more effective than the application of the NDCs in India, Indonesia, rest of Southeast Asia  
273 or Eastern Europe. In Indonesia, for example, premature mortality from cancelling coal-fired plants would  
274 decline by 8% in 2030 and 11% in 2050 using SSP2 emission factors; while the application of the NDCs  
275 would only reduce the premature mortality by 3% in 2030 and 2% in 2050. On the other hand, China (and  
276 several other regions, mostly Europe) would obtain larger health co-benefits from the NDCs than no new  
277 coal. This does not imply a choice would need to be made between one strategy or the other, but that regions  
278 can experience differing relative benefits depending on the pathway.

279



280

281 **Figure 3: Avoided premature mortality of cancelling future coal plants (*NoNewCoal*) and implementing the**  
 282 **NDCs, using SSP2 emission factors. A) Comparison of the avoided premature mortality between *NoNewCoal* and**  
 283 ***ContinuedGrowth-SSP2* scenarios for 2030 (top) and 2050 (down). B) Comparison of the avoided premature mortality**  
 284 **between *NoNewCoal* and NDC scenarios (*NDC-NoNewCoal*) for 2030 (top) and 2050 (down). Red indicates that co-**  
 285 **benefits are higher by cancelling all new power plant projects and blue that they would be higher by applying NDCs.**

286 **3.3 Health co-benefits in a context of decarbonization**

287 As demonstrated above, cancelling new coal-fired power plants can effectively reduce the impacts  
 288 of air pollution. Next, we quantify the co-benefits generated by the accelerated coal retirement under deep  
 289 decarbonization scenarios, where different coal retirement pathways are taken (see SI, Figures S7-S10).  
 290 Specifically, we compare air pollution related regional premature mortality of two stringent decarbonization  
 291 scenarios, which are the 2°C and 1.5°C temperature stabilization targets. Then, we examine which share of  
 292 those mortalities corresponds to the rapid phaseout of coal power plants in these scenarios.

293 Strengthening the climate target from the 2°C to the 1.5°C would reduce a significant amount of  
 294 premature mortality. Globally, the reduction of premature mortality driven by reinforcing the temperature  
 295 objective from 2°C to 1.5°C accounts for 326,351 fewer deaths in 2030, of which 251,011 (75%) would be

296 driven by faster retirement of coal-fired power plants in the 1.5°C decarbonization scenario (Table 1).  
 297 However, the additional reduction in mortality driven by faster coal shutdown will disappear in 2050 (SI,  
 298 Table S3), because a large majority of coal power generation without carbon capture and storage (CCS)  
 299 would be phased out by 2050 under both scenarios [3,5,6] (coal plants with CCS will not emit significant  
 300 SO<sub>2</sub> emissions).

Region	2030 Premature mortality			2030 Mortality from coal plants		
	2°C	1.5°C	Diff	2°C	1.5°C	Diff
China	1,300,940	1,203,130	97,810	86,510 (6.65%)	17,980 (1.49%)	68,530
India	1,205,730	1,009,650	196,08	184,310 (15.29%)	49,130 (4.87%)	135,180
Rest of South Asia	331,767	298,811	32,956	25,021 (7.54%)	6,258 (2.09%)	18,763
Russia	199,643	218,410	-18,767	1,098 (0.55%)	269 (0.12%)	829
Western Africa	178,705	179,640	-936	496 (0.28%)	85 (0.05%)	412
Gulf States	131,146	127,914	3,232	644 (0.49%)	130 (0.10%)	513
Eastern Africa	109,310	106,288	3,022	2,253 (2.06%)	472 (0.44%)	1,781
EU-28	93,557	89,021	4,536	2,749 (2.94%)	466 (0.52%)	2,284
Vietnam	53,294	52,542	752	2,745 (5.15%)	468 (0.89%)	2,277
Indonesia	52,822	52,574	248	3,406 (6.45%)	851 (1.62%)	2,555
Egypt	52,674	50,207	2,467	483 (0.92%)	66 (0.13%)	417
Central Asia	50,433	49,110	1,323	556 (1.10%)	66 (0.13%)	490
Ukraine	45,94	44,195	1,745	1,149 (2.50%)	238 (0.54%)	910
USA	45,852	55,749	-9,897	985 (2.15%)	157 (0.28%)	828
Rest of Southeast Asia	32,174	28,794	3,380	4,252 (13.22%)	886 (3.08%)	3,366
Korea	31,119	27,602	3,516	2,146 (6.90%)	439 (1.59%)	1,707
Germany	22,346	22,428	-82	588 (2.63%)	96 (0.43%)	492
Turkey	19,463	16,721	2,742	1,084 (5.57%)	176 (1.05%)	908
Japan	17,011	17,385	-374	1,281 (7.53%)	252 (1.45%)	1,029
<i>Total 19 selected</i>	3,973,923	3,650,172	323,751	321,755 (8.10%)	78,485 (2.15%)	243,270
<i>All other</i>	199,334	196,734	2,600	9,404 (4.72%)	1,663 (0.85%)	7,741
<b>TOTAL</b>	<b>4,173,257</b>	<b>3,846,906</b>	<b>326,351</b>	<b>331,159 (7.94%)</b>	<b>80,148 (2.08%)</b>	<b>251,011</b>

301  
 302 **Table 1: Total premature mortality and share of coal-fired power plants driven premature mortality per region**  
 303 **and scenario in 2030.** Results for 19 selected regions are presented, which account for the largest amount of premature  
 304 mortality and are the most affected by the coal plant retirements. These regions cover more than 93% of the premature  
 305 mortality, so remaining regions are gathered as “Rest of the World (RoW)”. The countries included in the groups are:

306 *Rest of South Asia*: Afghanistan, Bangladesh, Bhutan, Nepal and Pakistan; *Western Africa*: Benin, Burkina Faso,  
307 Cameroon, Cape Verde, Cote d'Ivoire, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia,  
308 Mali, Mauritania, Niger, Nigeria, Republic of Congo, Saint Helena, Sao Tome and Principe, Senegal, Sierra Leone  
309 and Togo; *Gulf States*: Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen;  
310 *Eastern Africa*: Burundi, Central African Republic, Chad, Comoros, Congo, Djibouti, Eritrea, Ethiopia, Kenya,  
311 Madagascar, Mauritius, Reunion, Rwanda, Seychelles, Somalia, South Sudan, Sudan, Tanzania and Uganda; *Central*  
312 *Asia*: Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan; *Rest of Southeast Asia*: Cambodia, Laos and Myanmar.

313           Across regions, China and India each account for around 30-31% and 26-29% of total premature  
314 mortality in 2030, followed by far by Rest of South Asia (7-8%) and Western Africa (4-5%). Although they  
315 have large mitigation potential, the development stage and their high population density make these two  
316 regions account for a substantial amount of the total premature mortality attributable to air pollution (SI,  
317 Figure S11). In terms of premature mortalities associated to coal-fired power plants in 2030 in the 2°C  
318 scenario, India shows the largest amount (184,310; 15%), followed by China (86,510; 7%), Rest of South  
319 Asia (25,021; 8%) and Rest of Southeast Asia (4,252; 13%). Due to the lower temperature target, these  
320 numbers would be greatly reduced in the 1.5°C scenario in 2030, but the regional trends are similar, as  
321 India (49,130; 5%), China (17,980; 1.5%), and Rest of Asia (6,258; 2%) would show the largest premature  
322 mortalities attributable to coal power plants (SI, Figure S12).

323           For certain regions, mortality may increase under the more ambitious 1.5°C target, mainly due to  
324 the potential expansion of biomass used with CCS. Higher biomass consumption would be associated with  
325 additional land conversion, which can result in increases in primary PM<sub>2.5</sub> emissions. However, this effect  
326 is relatively small and only shows in a few countries (Table 1 and SI, Table S3). On the other hand, the  
327 additional health co-benefits driven by faster coal plants shutdown is consistent across countries. In  
328 particular, China and India jointly represent 81% of the total additional reduction of premature mortality in  
329 2030 (68,530 and 135,180 additional avoided deaths), followed by other Asian regions such as Rest of Asia,  
330 Indonesia or Rest of Southeast Asia.

331

## 332 4 Discussion

333 The combined use of integrated models applied in this study is a well-accepted methodology to  
334 analyse the whole-system interactions and implications of different policy strategies. In such a modelling  
335 framework, the socioeconomic, energy, land and environmental assumptions taken will have direct effects  
336 on the results. One of the key assumptions of the scenario analysis is the values of future emission factors,  
337 as they are a key determinant of regional and global emissions levels. Emission factors represent current  
338 and future GHG or air pollutants emissions per unit of activity (produced output or consumed resource).  
339 Thus, these include not only pollutant contents but technological improvements and implicit air quality  
340 regulation that would potentially decrease unitary emissions in the future. Therefore, estimations of future  
341 emission factors would be uncertain as noted in the literature [63,64].

342 In order to analyse the effects of future SO<sub>2</sub> emission factors on the results, we have calculated  
343 health co-benefits attributable to coal phase-out by implementing an alternative approach for SO<sub>2</sub> emission  
344 factors (*VintageControl*, see section 2.2). This approach, by assuming improved control technologies for  
345 newer plants, largely reduces SO<sub>2</sub> emissions in the baseline scenario. As the result, the avoided premature  
346 mortality associated to cancelling new coal projects would be smaller by using the *VintageControl* approach  
347 compared to SSP2 emission factors [65]. Specifically, at a global level, mortality reduction would decrease  
348 from 5% to 2% in 2030, and from 8% to 5% in 2050, when considering the evolution of emissions control  
349 cross coal plants vintages in the baseline. This difference is especially relevant in India, where estimated  
350 avoided premature mortalities decrease from 8% to 2% in 2030 and from 17% to 8% in 2050. These results  
351 demonstrate that coal vintages dynamics would directly impact the results.

352 Apart from the technological developments and the stringency of the proposed air quality policies,  
353 the degree to which air quality policies are effectively implemented will also be a relevant driver. For  
354 example, there exists strong evidence which demonstrates that China has substantially reduced SO<sub>2</sub>  
355 emissions in recent years [60,66], so it seems likely that future emission factors will continue to decrease.  
356 Zheng et al (2018) [60] demonstrate that air pollutant emissions in China have substantially decreased in  
357 recent years due to effective implementation of air quality policies, estimating that SO<sub>2</sub> emissions have  
358 decreased by 62% over 2010-2017. Therefore, future SO<sub>2</sub> emission factors in reality are likely to be  
359 significantly lower than the values assumed in the SSP2 narrative. On the other hand, we note that SO<sub>2</sub>  
360 emissions in India are not aligned with the targets defined in the country's air pollution policies. However,  
361 Indian Government has recently announced a plan for a large-scale installation of flue gas desulphurization  
362 (FGD) units in coal plants by 2022, that would significantly reduce SO<sub>2</sub> emissions [67]. Therefore, future

363 research should focus on baseline regional emission trends for air pollutants in order to better estimate  
364 health co-benefit potential.

## 365 **5 Conclusion**

366 In this research, we quantify the health co-benefits from cancelling new coal-fired power plants in  
367 the context of deep decarbonization. We find that that this measure would result in significant reductions  
368 of PM<sub>2.5</sub> concentrations at a global level, with largest reductions in China and India. These regions also  
369 present the largest health co-benefits due to high population density. In China and India reductions in  
370 premature mortality related to air pollution would account for 47,470 (3%) and 114,590 (8%) in 2030 and  
371 29,840 (3%) and 263,500 (17%) in 2050, respectively.

372 Moreover, strengthening the climate target from the 2°C to the 1.5°C would reduce a significant  
373 amount of premature mortality, especially during the medium-term transition period. While the reduction  
374 of premature mortality related to reinforcing the climate target accounts for 326,351 deaths in 2030, 251,011  
375 (75%) are attributable to the additional retirement of coal-fired power plants. We find that these extra co-  
376 benefits would be heavily focused in India, followed by China and other Asian regions. However, the  
377 additional reduction in mortality driven by faster coal shutdown will disappear in the long run, because the  
378 large majority of coal plants are phased out by 2050 under both the 1.5°C and 2°C scenarios.

379 Phasing out conventional coal plants is necessary for meeting objectives defined in the Paris  
380 Agreement. Mitigating the effects of climate change is a complex undertaking [68], but recent studies have  
381 proved that regional health co-benefits can provide additional incentive to reduce emissions [69]. This study  
382 demonstrates that air quality related health co-benefits from coal plant cancellation are comparable at a  
383 global level to the co-benefits obtained from the implementation of the NDCs. Although end-of-pipe  
384 emission controls can also achieve air pollutant reductions in the near-term, continued air quality  
385 improvement to a higher standard requires energy system transition from fossil fuels to non-emitting  
386 resources (such as renewables) [70]. Therefore, coal plants cancellation would generate greater health  
387 benefits over the long run. Moreover, this work opens avenues for future research. First, a more detailed  
388 analysis of coal retirement, by including variables such as vintage of existing facilities or the investment  
389 needs for alternatives (i.e. costs of CCS retrofits) would allow assessing the economic impacts of such  
390 energy system transformations. Likewise, the monetization of the obtained premature mortality, as done in  
391 previous studies [25,26], would also highlight the magnitude of the potential economic benefits, even  
392 though there exists a scientific debate on the methodologies for monetizing health co-benefits [71]. Finally,  
393 implications of coal power plant cancellation and retirement may also have effects on other Sustainable

394 Development Goals (SDGs) (i.e. water, energy access, employment) which could be incorporated into the  
395 analysis.

396

### 397 **Data Availability**

398 All data used for analysis are available from publicly available sources cited or from the authors upon  
399 reasonable request. Scenarios have been modelled with GCAM, which is an open source human-earth  
400 system model that can be downloaded from a public repository: [https://github.com/JGCRI/gcam-](https://github.com/JGCRI/gcam-core/releases)  
401 [core/releases](https://github.com/JGCRI/gcam-core/releases)

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## 578 **Acknowledgements**

579 The authors acknowledge funding support from Bloomberg Philanthropies. This research is also supported  
580 by Basque Government through the BERC 2018-2021 and the Spanish Government through María de  
581 Maeztu excellence accreditation MDM-2017-0714. Jon Sampedro and Ignacio Cazcarro acknowledge  
582 financial support from the Ministry of the Economy and Competitiveness of Spain (RTI2018-099858-A-  
583 100 and RTI2018-093352-B-I00). Jon Sampedro acknowledge financial support from the Basque  
584 Government (PRE\_2017\_2\_0139). The authors thank Patrick O'Rourke and Brinda Yarlagadda for their  
585 support with data processing. The authors declare no competing interests.

## 586 **Author Contributions**

587 J.S. and R.C. coordinated the research and performed the scenario analysis. J.S. led the writing of the paper.  
588 H.M., N.H. and S.J.S. contributed to the study and scenario design. L.H. and A.S. contributed to data  
589 collection and analysis. I.C. and J.S. designed the geolocation assessment and I.C performed the analysis.  
590 RVD contributed to the TM5-FASST simulations. All the authors contributed to the writing.

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