Air quality, health and toxics impacts of the proposed coal mining and power cluster in Thar, Pakistan

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CREA

Centre for Research on Energy and Clean Air

CREA is an independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions to air pollution.

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Key findings

- Pakistan is already suffering from air pollution levels that are among the highest in the world, reducing life expectancy in the country by more than 2.5 years and increasing the vulnerability of Pakistanis to the COVID-19 pandemic.
- More than 95% of Pakistan's installed coal-based electricity generation capacity (5090 MW) was commissioned during the past 3 years, with more than 6000 MW still in various stages of development. This is happening at a time when coal-based power plants and plans are being scrapped across the globe due to high climate, air pollution and economic impacts.
- A massive cluster of coal mines and power plants, with a total of 9 power plants and a total capacity of 3,700 megawatts is being proposed in the Thar region alone out of which 660 megawatts has already been commissioned at Thar Block II power station. The proposed plants would constitute one of the largest air pollutant, mercury and CO_2 emissions hotspots in South Asia.
- The air pollutant emissions from the plants and mines would expose an estimated 100,000 people to exceedances of the World Health Organization guideline for 24-hour average SO_2 concentrations and 3,000 people to exceedances of the guidelines for 24-hour average $PM_{2.5}$ concentrations.
- The power plants and mines would be responsible for a projected 29,000 (95% confidence interval: 22,000-37,000) air pollution-related deaths over an operating life of 30 years. Other health impacts include 40,000 asthma emergency room visits, 19,900 new cases of asthma in children, 32,000 preterm births, 20 million days of work absence (sick leave) and 57,000 years lived with disability related to chronic obstructive pulmonary disease, diabetes and stroke.
- The plants would emit an estimated 1,400 kg of mercury per year, of which one fifth would be deposited into land ecosystems in the region. Most of the deposition takes place onto cropland, increasing the mercury concentrations in crops. The levels of mercury deposition are potentially dangerous in an area with 100,000 inhabitants.

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Introduction

Pakistan is the second most polluted country in the world after Bangladesh when ranked by population weighted $PM_{2.5}$ concentration according to 2019 World Air Quality Report by IQAir (2019). The report highlighted that four of the 15 most polluted cities in 2019 were in Pakistan. High pollution levels make air pollution the leading environmental risk factor for mortality in Pakistan, accounting for more than 9% of deaths (128,000) in 2017 alone (SoGA, 2019). The Status of Global Air report (Health Effects Institute 2019) in 2019 estimates that the "loss in life expectancy at birth due to air pollution exposure in Pakistan stands at 2 years and 8 months."

The contribution of different sources of pollution varies from geography to geography, but globally major contributing sources to the air pollution problem are majorly categorised as:

- Burning of fossil fuels in transportation sector;
- Burning of fossil fuels (i.e., coal and oil) in energy/electricity production/industries
- Biomass burning for cooking/heating purposes
- Agricultural biomass burning
- Dust/pollution emissions from construction actor
- Municipal waste burning

We have seen across the globe that areas impacted by air pollution have achieved improvements by majorly reducing the emission of harmful pollutants across sectors either by shifting to better and more cleaner options or by strengthening the emission standards and norms. Air quality improvements through coordinated actions on emission reduction and aggressive shift towards renewable energy across geographies such as The United States, EU and China are examples of how improvements in air quality can be achieved. India is adopting similar measures as well where emission standards for polluting industries have been strengthened and a national clean air action plan to reduce pollution levels in a time bound manner has been formulated.

On the contrary we are observing an addition of more pollution sources in the form of fossil fuel burning capacity in Pakistan through coal based power plant additions. This becomes even more critical when the country lacks stringent emission standards for controlling emissions from coal based power plants similar to the standards which exist in EU, US, China as well as have been notified in 2015 in India as well. As of January 2020, Pakistan has 5090 MW coal based power generation capacity out of which 4900 MW has been added over the past three years (Shearer et al 2020).

Table 1. Operational coal based power plants in Pakistan

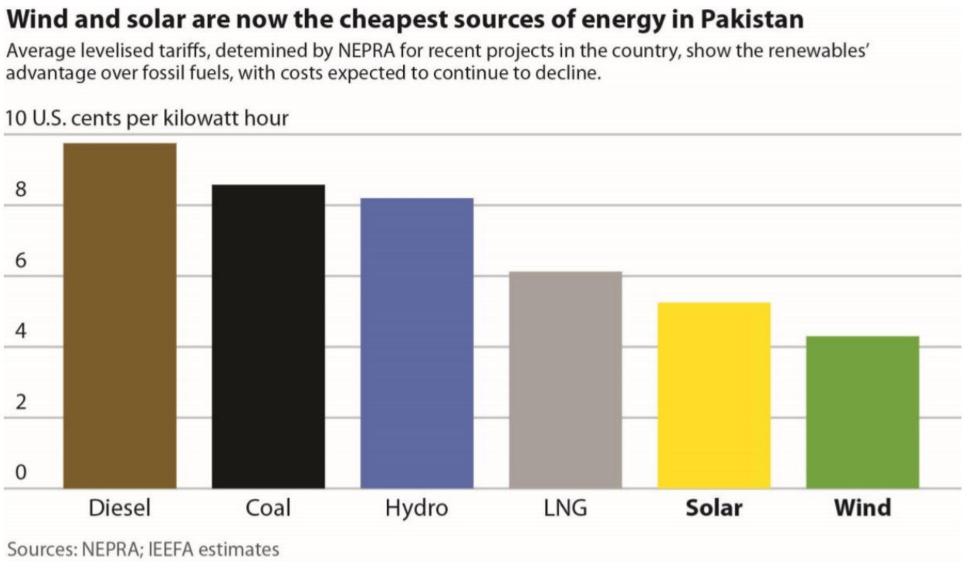
Region	Power Station Name	Year of Commissioning	Capacity (MW)
Balochistan	Hubco power station	2019	1320
Punjab	Faisalabad Sitara Chemical power plant	2016	40
	Maple Leaf power station	2017	40
	Muzaffargarh sugar mill power station	2017	120
	Sahiwal power station	2017	1320
Sindh	Fauji Fertilizer power station	2017	120
	Lakhra power station	1995-96	150
	Port Qasim EPC power station	2017-18	1320
	Thar Block II power station	2019	660
Grand Total			5090

Apart from the operational coal capacity there is an additional capacity of more than 6000 MW in various stages of development which will further deteriorate the air quality and health through emission of hazardous pollutants.

Table 2. Coal based Power plants in various stages of development in Pakistan

Region	Power Station Name	Announced	Construction	Permitted	Pre-Permit	Grand Total
Balochistan	Gwadar power station				300	300
Punjab	Grange Holdings power station	163				163
	Sheikhupura power station	55				55
Sindh	Jamshoro power station		660	660		1320

	Port Qasim Datang power station			700		700
	Port Qasim Lucky power station		660			660
	Siddiqsons power station			330		330
	ThalNova power station				330	330
	Thar Block VI power station				700	700
	Thar Energy Limited power station		330			330
	Thar SSRL power station			1320		1320
Grand Total		218	1650	3010	1330	6208



We have also seen that the problems with rising capacity charges (Kiani, 2020) and overcapacity scenario have put the Pakistan government in a very tough situation especially now when the demand for electricity is going to be much more less than even projected earlier and the renewable energy landscape is changing very fast making it more affordable and quick to adapt compared to any other source of energy. Renewable energy including wind and solar is now the cheapest form of new electricity generation in Pakistan (IEEFA 2018) and has the potential to fuel the future growth in demand (Unwin, 2019).

The growth of capacity charges for coal based power generation in Pakistan has been termed unsustainable by the Government as the charges are expected to go up from 600 bn Rupees to 1.5 trillion in a few years if the coal capacity increases as planned (Kiani, 2020).

Thar Block-II Power station started supplying the electricity to the National Grid in April 2019 with multiple other power stations still in pipeline at various stages of development (Jabri, 2019). The information on environmental and public health impact of the operational and upcoming power plants in the region has not been discussed at a comprehensive scale primarily due to little data availability in the public domain. In Sindh, where the Tharparkar (Thar) district is located, the provincial EPA has also largely been unable to provide ambient air quality reports routinely in a transparent manner (SEPA, 2020). The Environment Quality Standards (SEQS) for ambient air in the region are much more relaxed (SEPA, 2016) as compared with the National (NEQS) or WHO recommended standards, i.e., while the NEQS sets the $PM_{2.5}$ limit for 24-hour mean at 35 µg/m^3, the SEQS sets it at 75 µg/m^3.

At a time when coal is becoming the fuel of the past globally due to associated pollution and climate change hazards as well as unfavourable economic conditions due to availability of more affordable and cleaner renewable energy sources, it becomes hard to understand why Pakistan still needs to develop the proposed coal infrastructure.

With an already existing wide understanding around Coal based electricity not being economically sustainable compared to renewable energy, in the current report we look at how the operational and under construction coal cluster in Thar will add to the already hazardous air pollution levels. The study will also estimate the health impacts of additional coal capacity in the region in terms of premature deaths and disabilities caused due to pollutants emitted from operation of coal based power plants and mines in the Thar region.

Results:

Emissions

Environmental Impact Assessment (EIA) reports were available for the Block II, Thar Energy Limited (TEL) and Block VI power stations. As these projects encompass the two different technologies planned to be used in the cluster, Circulating Fluidized Bed and sub-critical pulverized coal boilers, and all of them reported similar targeted emissions control performance, emissions data from these EIAs was generalized to the other projects.

Annual emissions were calculated from the emissions rates in grams per second, given in the EIAs. For plants for which EIAs were not available, emissions rates were estimated based on the most similar plant with an EIA, scaled by plant capacity. In both scenarios, all plants were assumed to run at 7,000 full-load hours per year, the low end of the assumptions used in the EIAs - operating rates up to 7,400 hours were assumed but were deemed unrealistic. Stack height and other properties affecting plume rise were generalized from values given in the three EIAs.

The emissions estimates assume that the plants fully and properly operate their emissions controls. If there are gaps in operation & maintenance or enforcement, the emissions and impacts could be considerably higher.

Dust emissions from the mines were calculated using emission factors developed by the European Monitoring and Evaluation Programme (EMEP) of the Convention on Long-range Transboundary Air Pollution (CLRTAP) for lignite mining. Annual lignite production at each mine was projected based on estimated coal consumption of plants using coal from the mine - these values are generally lower than the production volumes assumed in the mine EIAs, but the intention was to model the impacts of coal mining associated with the studied power plants.

Multiple issues were found with the emission data provided in the EIAs.

- The mercury (Hg) emissions for block VI are massively under-reported - actual emissions should be about 200 times higher. Apparently the consultant that prepared the EIA is not aware that only a tiny fraction of mercury in the plant flue gas is bound to fly ash, and hence assumes that mercury will be almost fully captured by the fly ash controls. In reality, the emission control technologies the plant will incorporate capture 20% of the mercury, at most (UNEP 2017). The other EIAs fail to provide any information whatsoever about mercury emissions into the air, one of the key environmental and public health impacts of coal-fired power plants.
- The TEL EIA shows that air pollution levels in the area violate both the Sindh standards and the IFC guidelines (not to mention the WHO guideline) for PM10. This means that the IFC emission limits for degraded airshed should be applied. Yet both the Block VI and TEL EIAs give the reader the impression that the projects intend to follow IFC guidelines.
- However, the air quality data provided in the EIAs themselves makes it clear that the air quality in the project area is in violation of the Sindh Ambient Air Quality Standard, the IFC guideline and the World Health Organization guideline for annual average PM_{10} concentrations. This means that if the projects intend to follow the IFC guidelines, they should adopt the values for degraded airshed, which are significantly stricter than the applied values. Hence the EIAs mislead the public about the emission control technology they intend to adopt.

- All of the EIAs neglect to model the combined air quality impacts of the lignite mines and the power plants that they are fueling. The Block II power station EIA in fact acknowledges that the air quality impact of the mine dominates in the vicinity of the block but states that the impact is excluded, with no justification given.

The existence of such elementary errors and omissions in the cornerstone data used in the EIAs makes it appear that the reports have not been independently reviewed by the regulator, raising serious questions about the level of regulatory oversight.

Table 3. Power projects included in the study.

Plant	Parent	Capacity (MW)	Status	Technology	Linkage
Thar Block II power station	CMEC, HBL Bank, Sindh Engro Coal Mining Company	2x330	Operation	Subcritical pulverized	Block II
Thar Energy Limited power station	Hubco (60%), Fauji Foundation (30%), CMEC (10%)	1x330	Construction	CFB	Block II
Thar SSRL power station	State Power Investment Corporation	2x660	Planned	Subcritical	Block I
Thar Block VI power station	Beijing Jingneng Power Company (73%), PowerChina (15%), Oracle Coalfields (12%)	2x350	Planned	CFB	Block VI
Siddiqsons power station	Siddiqsons Group	1x330	Planned	Supercritical	Block II
ThalNova power station	Hubco (37%), Thal Limited (31.5%), CMEC (10%), Other (20.5%)	1x330	Planned	CFB	Block II

Table 4. Characteristics of the modeled stacks.

Plant	Lat	Lon	Stack Height, m	Inner Dia, m	Flue Gas Temperature, C	Flue gas flow rate, m3/s
Thar Block II	24.8125	70.3941	200	5.8	170	20.8
Thar Energy Limited	24.8100	70.4000	210	7.1	130	13.7
Thar SSRL	24.7035	70.2395	210	10.0	170	20.8
Thar Block VI	24.8246	70.3190	210	7.1	130	13.7
Siddiqsons	24.7836	70.3671	210	7.1	130	20.8
ThalNova	24.8200	70.3900	210	7.1	130	13.7

Table 5. Modeled power plant emissions (tonnes per year, except mercury kilograms per year).

Plant	SO_2	NO_x	TSP	PM_{10}	$PM_{2.5}$	Hg
Thar Block II	12331	8042	514	347	154	329
Thar Energy Limited	6205	4118	249	168	75	164
Thar SSRL	24661	16083	1028	694	308	657
Thar Block VI	13513	7565	1082	730	325	329
Siddiqsons	5578	3638	232	157	70	149
ThalNova	6757	3783	541	365	162	164

Table 6. Modeled lignite mines (latitude and longitude refer to the center of the mine pit; emissions given in tonnes per year).

Name	Lat	Lon	Output, Mt/a	TSP	PM10	PM2.5
Block I	24.67	70.33	6.57	538.9	256.3	39.4
Block II	24.77	70.40	8.06	660.8	314.3	48.4
Block VI	24.74	70.31	3.29	269.5	128.2	19.7

Air quality and health

This case study provides a detailed analysis of the air quality, toxic and health impacts of the coal mine and power plant cluster in the Thar region, combining best available emissions data for the projects with detailed atmospheric modeling and existing epidemiological data and literature.

The air quality impacts of emissions from the plants were modeled using the CALPUFF dispersion model, which uses detailed hourly data on wind and other atmospheric conditions to track the transport, chemical transformation and deposition of pollutants, and is widely used to assess the short and long range impacts of emissions from industrial point sources and area sources. The model predicts the increases in hourly, daily and annual pollutant concentrations caused by emissions from the studied source.

Emissions from the power plant contribute to ambient concentrations of $PM_{2.5}$, NO_2 and SO_2, causing increases in the risk of both acute and chronic diseases and symptoms.

Table 7. Projected annual health impacts associated with the emissions from the Thar power plants and mines.

Cause	Pollutant	High emissions	
deaths	Total	618	(467 - 778)
of which due to:			
chronic obstructive pulmonary disease	$PM_{2.5}$	121	(46 - 214)
diabetes	$PM_{2.5}$	2	(1 - 3)
ischaemic heart disease	$PM_{2.5}$	262	(220 - 304)
lower respiratory infections	$PM_{2.5}$	57	(23 - 96)
lower respiratory infections in children	$PM_{2.5}$	19	(14 - 27)
lung cancer	$PM_{2.5}$	14	(7 - 22)
stroke	$PM_{2.5}$	100	(43 - 164)
all causes	NO2	6	(3 - 13)
asthma emergency room visits, adults	$PM_{2.5}$	534	(534 - 797)
asthma emergency room visits, children	$PM_{2.5}$	605	(204 - 803)
new cases of asthma in children	NO_2	103	(27 - 206)
preterm births	$PM_{2.5}$	1,090	(528 - 1,158)
work absence (sick leave days)	$PM_{2.5}$	483,217	(411,091 - 554,855)
years lived with disability, chronic obstructive pulmonary disease	$PM_{2.5}$	934	(346 - 1,743)
years lived with disability, diabetes	$PM_{2.5}$	51	(17 - 116)
years lived with disability, stroke	$PM_{2.5}$	229	(77 - 451)

Table 8. Projected cumulative health impacts associated with the emissions from the Thar power plants and mines, over 30 years of operation.

Outcome	Pollutant	High emissions	
deaths	Total	29,352	(22,169 - 37,006)
of which due to:			
chronic obstructive pulmonary disease	$PM_{2.5}$	5,726	(2,156 - 10,122)
diabetes	$PM_{2.5}$	88	(38 - 160)
ischaemic heart disease	$PM_{2.5}$	12,458	(10,465 - 14,485)
lower respiratory infections in adults	$PM_{2.5}$	2,680	(1,065 - 4,539)
lower respiratory infections in children	$PM_{2.5}$	286	(203 - 403)
lung cancer	$PM_{2.5}$	663	(346 - 1,052)
stroke	$PM_{2.5}$	4,752	(2,062 - 7,796)
all causes	NO_2	271	(144 - 603)
asthma emergency room visits, adults	$PM_{2.5}$	22,568	(22,568 - 33,684)
asthma emergency room visits, children	$PM_{2.5}$	16,947	(5,706 - 22,485)
new cases of asthma in children	$PM_{2.5}$	2,959	(774 - 5,894)
preterm births	$PM_{2.5}$	29,276	(14,179 - 31,087)
work absence (sick leave days), million	$PM_{2.5}$	20.5	(17.4 - 23.5)
years lived with disability, chronic obstructive pulmonary disease	$PM_{2.5}$	44,164	(16,361 - 82,398)
years lived with disability, diabetes	$PM_{2.5}$	2,396	(785 - 5,490)
years lived with disability, stroke	$PM_{2.5}$	10,873	(3,672 - 21,444)

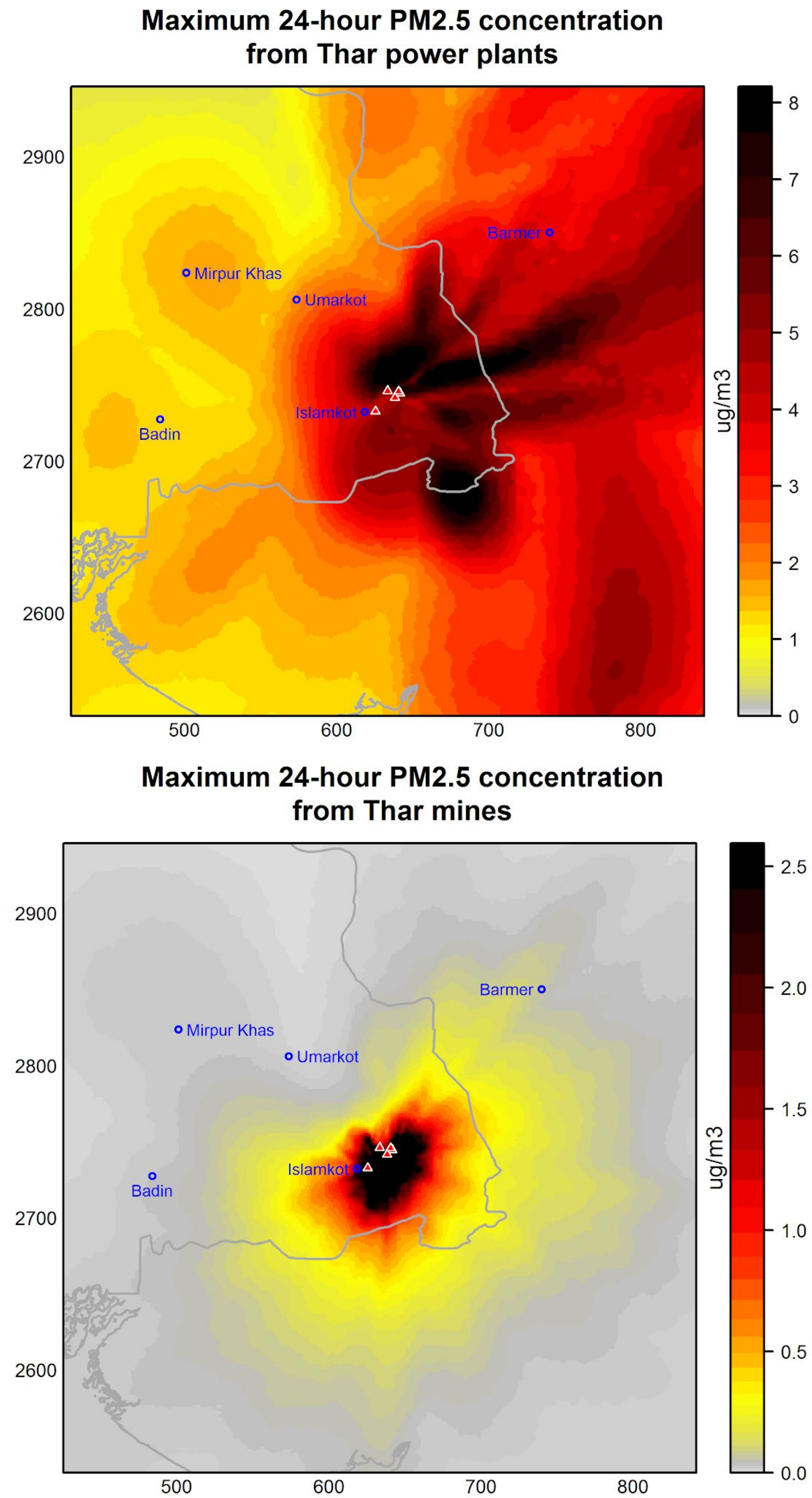


Figure 2. Projected contributions from the Thar power plants and mines to ambient $PM_{2.5}$ levels.

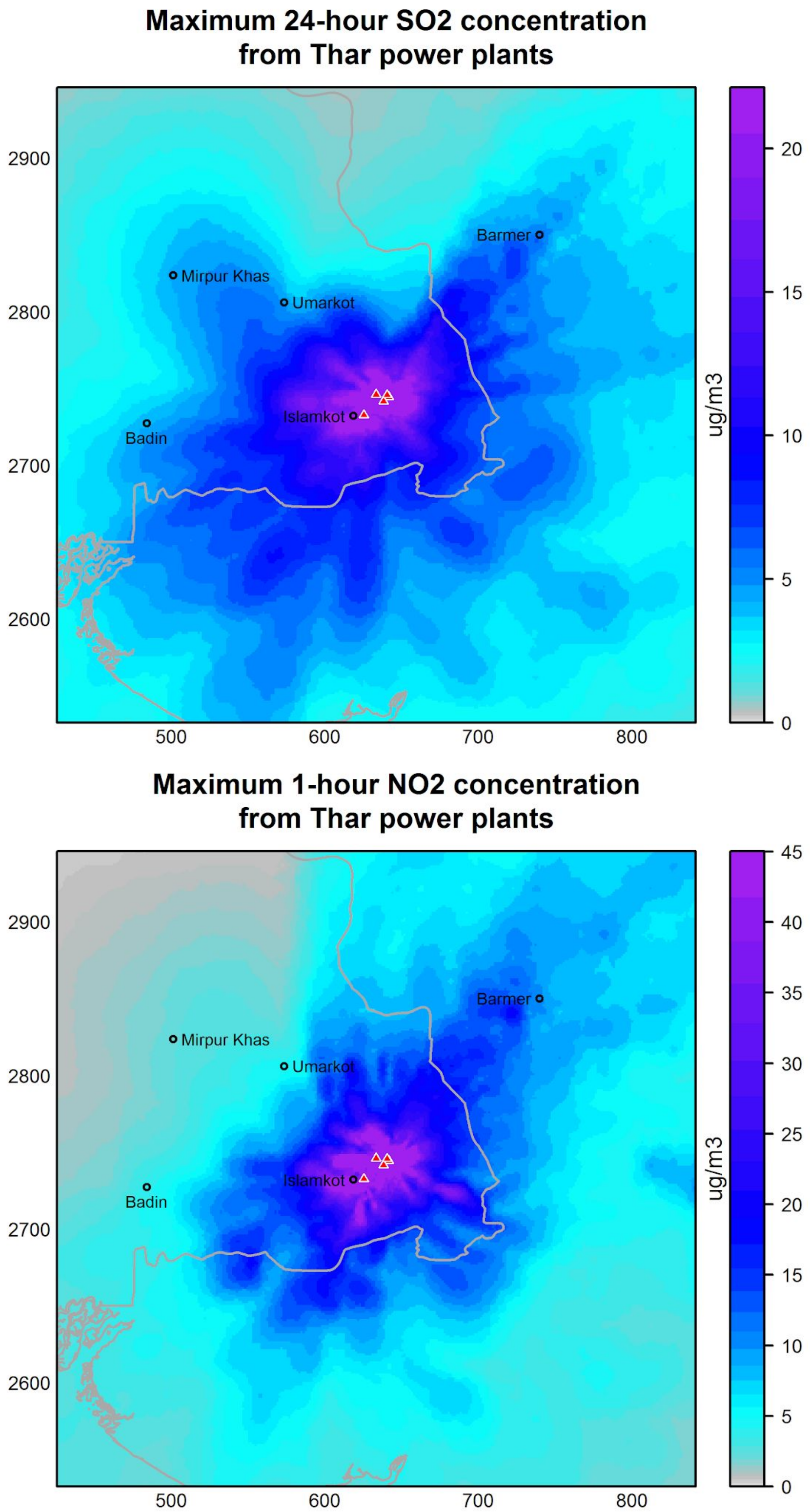


Figure 3. Projected contributions from the Thar power plants to ambient SO_2 and NO_2 levels.

Toxic deposition

The Thar power plant and mining cluster would emit approximately 1400 kg of mercury and 5,000 tonnes of heavy metal-containing particulate matter (coal dust and fly ash) per year.

Approximately one fifth (22%) of the mercury emitted by the plants is estimated to be deposited into land and freshwater ecosystems in the region, amounting to approximately 320 kg per year. Mercury deposition rates as low as 125 mg/ha/year can lead to accumulation of unsafe levels of mercury in fish (Swain et al 1992). The plants are estimated to cause mercury deposition above 125mg/ha/yr in an area of 1,300 km^2 to the northeast of the plants, with a population of approximately 100,000 people (Figure 4).

While actual mercury uptake and biomagnification depends very strongly on local chemistry, hydrology and biology, the predicted mercury deposition rates are a cause for serious concern and an assessment of the impacts and of measures to reduce mercury emissions is needed urgently.

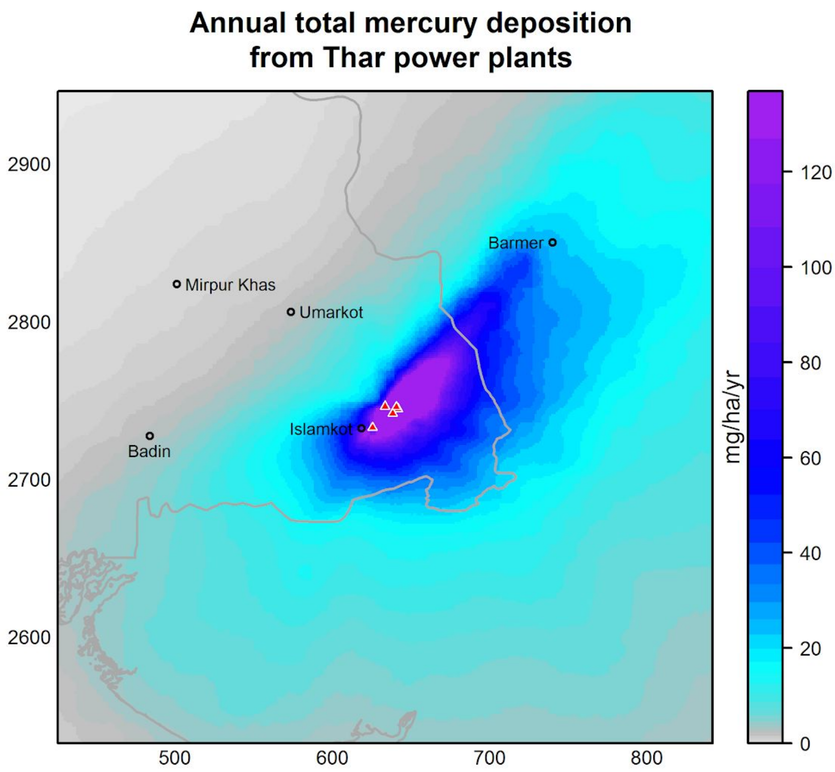


Figure 4. Projected mercury deposition from the Thar power plants.

Materials and methods

Since none of the EIAs contained information on mercury emissions into the air or mercury content in coal, the UNEP/AMAP (2013) default value of 0.1 g Hg/metric tonne, and UNEP (2017) default capture efficiency of 20% was used.

Dust emissions from lignite mining were estimated based on EMEP/EEA (2016) default emission factors. Dust emissions were doubled from the default rate during the dry season from mid-Dec to mid-Jun. Mines were modeled as area sources, spanning 1.5x1.5km around the central point. In reality, most of the dust will be emitted from a much smaller area with active mining operations at any given time, meaning that the assumption results in conservative projection of peak local concentrations.

Short-term air quality impacts were modeled assuming all plants running at full capacity, while annual average impacts were modeled with the assumed average capacity factor of 79.9%.

Atmospheric dispersion modeling was carried out using version 7 (June 2015) of the CALPUFF modeling system. Meteorological and geophysical data for the simulations was generated with the TAPM model, developed by Australia's national science agency CSIRO. A set of nested grids with a 50x50 grid size and 30km, 10km and 5km horizontal resolutions and 12 vertical levels was used, centered on the power plant cluster.

The CALPUFF model performs a detailed simulation of the rise of the plume from the power plant stack, through which the emissions are discharged; the characteristics of the modeled stacks are given in Table 4.

For emissions from main boilers of the power plants, 30% of emitted fly ash was assumed to be $PM_{2.5}$, and 37.5% PM_{10}, in line with the U.S. EPA AP-42 default value for electrostatic precipitators. Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA chemistry module within CALPUFF, and required atmospheric chemistry parameters (monthly average ozone, ammonia and H_2O_2 levels) for the modeling domain were imported into the model from baseline simulations using the Geos-Chem atmospheric model (Koplitz et al 2017). The CALPUFF results were reprocessed using the POSTUTIL utility to repartition different nitrogen species (NO, NO_2, NO_3 and HNO_3) based on background ammonia concentrations.

Health impact assessment follows the methodology of the CREA study "Quantifying the Economic Costs of Air Pollution from Fossil Fuels" (Myllyvirta 2020). The health impacts resulting from the increase in $PM_{2.5}$ concentrations were evaluated by assessing the resulting population exposure, based on high-resolution gridded population data for 2020 from CIESIN (2017), and then applying the risk model developed by Burnett et al (2018) based on a comprehensive meta-analysis of available studies on the long-term mortality risk from PM2.5. Deaths from long-term NO2 exposure were quantified following the recommendations from the WHO HRAPIE project (WHO 2013). Deaths of small children from lower respiratory infections linked to PM2.5 pollution from fossil fuels was assessed using the Global Burden of Disease risk function for lower respiratory diseases (GBD 2017).

For all mortality results, the required country-specific data on baseline death rates and years of life lost was taken from the Global Burden of Disease project results for 2017 (GBD 2017).

As the concentration-response relationships used include non-linear functions and no-harm thresholds, information on baseline air pollutant concentrations is needed for the health impact assessment. This data was obtained from van Donkelaar et al (2016) for $PM_{2.5}$ and Larkin et al (2017) for NO_2.

Projections of future health impacts take into account projected population growth on the national level, and for mortality impacts, on projected changes in age-specific death rates based on UNPD (2019) medium variant. Importantly, use of age-specific death rates captures the impact of expected improvements in population health status and health services, which results in lower mortality for children, while increasing the susceptibility of the adult population to non-communicable diseases associated with air pollution.

Deposition results were differentiated by land use type using the European Space Agency global land use map for the year 2015 at 300m resolution (ESA 2018). Land use codes 10-30 were mapped as cropland; codes 50-100 were mapped as forest and code 170 as mangrove.

Table 9: Input parameters and data used in estimating health impacts.

Age group	Effect	Pollutant	Concentration - response function	Concentration change	No-risk threshold	Reference	Incidence data
1-18	New asthma cases	NO_2	1.26 (1.10 - 1.37)	10 ppb	2 ppb	Achakulwisut et al 2019	Achakulwisut et al 2019
0-17	Asthma emergency room visits	$PM_{2.5}$	1.03 (1.01–1.04)	10 ug/m3	6 ug/m3	Zheng et al 2015	Anenberg et al 2018
18-99	Asthma emergency room visits	$PM_{2.5}$	1.02 (1.02–1.03)	10 ug/m3	6 ug/m3	Zheng et al 2015	Anenberg et al 2018
Newborn	Preterm birth	$PM_{2.5}$	1.15 (1.07, 1.16)	10 ug/m3	8.8 ug/m3	Trasande et al 2016	Chawanpaiboon et al 2019
25-99	Deaths from non-communicable diseases and lower respiratory infections	$PM_{2.5}$	non-linear		2.4 ug/m3	Burnett et al 2018	IHME 2018
0-4	Deaths from lower respiratory infections	$PM_{2.5}$	non-linear		5.8 ug/m3	IHME 2018	IHME 2018
25-99	Deaths from lower respiratory infections	$PM_{2.5}$	non-linear		5.8 ug/m3	IHME 2018	IHME 2018
25-99	Disability caused by diabetes, stroke and chronic respiratory disease	$PM_{2.5}$	non-linear		2.4 ug/m3	IHME 2018	IHME 2018
30-99	Premature deaths	NO_2	1.037 (1.021-1.080)[1]	10 ug/m3	20 ug/m3	WHO HRAPIE 2013	IHME 2018

Numeric values in the column “Concentration-response function” refer to relative risk corresponding to the increase in concentrations given in the column “concentration change”. “Non-linear” indicates the use of a non-linear concentration-response function given in the reference. No-harm threshold refers to a concentration below which the health impact is not quantified, generally due to lack of evidence in the studies on which the function is based on.

[1] Central and low values for NO_2 are scaled down by 1/3 to remove possible overlap with $PM_{2.5}$ impacts, as indicated by WHO (2013).

Recommendations

- Stringent emission standards should be developed and enforced to control PM, SO_2, NO_2 and Hg pollution emission as well as to reduce the usage of water by operational coal based power plants, similar to other countries such as those in force in the EU and China, and being implemented in India.

- It is essential to fully assess and take into account the cost of air pollution and other external impacts when making decisions about future power generation. Meeting growth in electricity demand by renewable energy development would greatly reduce these costs.

- The planned addition of a large amount of coal-fired capacity would worsen Pakistan's already hazardous air quality, while adding to the indebtedness of the power sector and increasing capacity charges for untitled power from these coal based plants. In order to reduce such negative impacts on public health and the economy, the coal based plants in early stages of development should be cancelled and currently operational plants should be used at optimal capacity to be able to meet electricity demand more economically.

About CREA

Centre for Research on Energy and Clean Air (CREA) is a new independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions to air pollution. CREA uses scientific data, research and evidence to support the efforts of governments, companies and campaigning organizations worldwide in their efforts to move towards clean energy and clean air, believing that effective research and communication are the key to successful policies, investment decisions and advocacy efforts. CREA was founded in December 2019 in Helsinki and has staff in several Asian and European countries.

References

Achakulwisut P, Brauer M, Hystad P & Anenberg SC 2019: Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: estimates from global datasets. Lancet 3(4):E166-E178.

Anenberg SC, Henze DK, Tinney V, Kinney PL, Raich W, Fann N, Malley CS, Roman H, Lamsal L, Duncan B, Martin RV, van Donkelaar A, Brauer M, Doherty R, Jonson JE, Davila Y, Sudo K & Kuylenstierna JCI 2018: Estimates of the Global Burden of Ambient PM2.5, Ozone, and NO2 on Asthma Incidence and Emergency Room Visits. Environmental Health Perspectives 126:10. https://doi.org/10.1289/EHP3766.

Burnett R et al 2018: Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. Proceedings of the National Academy of Sciences 115(38):9592-9597. https://doi.org/10.1073/pnas.1803222115.

Center for International Earth Science Information Network (CIESIN), Columbia University, 2017. Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 10. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4DZ068D.

Chawanpaiboon S, Vogel JP, Moller AB, Lumbiganon P, Petzold M, Hogan D, Landoulsi S, Jampathong N, Kongwattanakul K, Laopaiboon M, Lewis C, Rattanakanokchai S, Teng DN, Thinkhamrop J, Watananirun K, Zhang J, Zhou W & Gülmezoglu AM 2019: Global, regional, and national estimates of levels of preterm birth in 2014: a systematic review and modelling analysis. Lancet Glob Health 7(1):e37-e46. https://doi.org/10.1016/S2214-109X(18)30451-0.

Shearer C, Myllyvirta L, Yu A, Aitken G, Mathew-Shah N, Dallos G & Nace T 2020: Boom and Bust 2020: TRACKING THE GLOBAL COAL PLANT PIPELINE. https://endcoal.org/wp-content/uploads/2020/03/BoomAndBust_2020_English.pdf

EMEP/EEA 2016: Air pollutant emission inventory guidebook 2016. CLRTAP & European Environment Agency.

European Environment Agency (EEA) 2014: Costs of air pollution from European industrial facilities 2008–2012 — an updated assessment. EEA Technical report No 20/2014. https://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012

European Space Agency (ESA), 2018. Land Cover Maps – v2.0.7. http://maps.elie.ucl.ac.be/CCI/viewer/download.php

Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2017 (GBD 2017) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2018. http://ghdx.healthdata.org/gbd-results-tool.

Health Effects Institute (HEI) 2019: State of Global Air 2019 (SoGA 2019). https://www.stateofglobalair.org/sites/default/files/soga_2019_pakistan.pdf

Huscher J, Myllyvirta L and Gierens R 2017: Modellbasiertes Health Impact Assessment zu grenzüberschreitenden Auswirkungen von Luftschadstoffemissionen europäischer Kohlekraftwerke. Umweltmedizin - Hygiene - Arbeitsmedizin Band 22, Nr. 2 (2017) https://www.ecomed-umweltmedizin.de/leseproben/self/umweltmedizin--hygiene--arbeitsmedizin-band-22-nr-2-2017-.pdf

Kiani K 2020: Pakistan urges China to soften terms for power deals. Dawn. https://www.dawn.com/news/1549299/pakistan-urges-china-to-soften-terms-for-power-deals (accessed on 10 May 2020)

Koplitz S, Jacob DJ, Sulprizio MP, Myllyvirta L & Reid C 2017: Burden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia. Environmental Science & Technology. http://dx.doi.org/10.1021/acs.est.6b03731.

Institute for Energy Economics and Financial Analysis (IEEFA) 2018: Pakistan's Power Future Renewable Energy Provides a More Diverse, Secure and Cost-Effective Alternative. http://ieefa.org/wp-content/uploads/2018/11/Pakistans-Power-Future_December-2018.pdf

Institute for Health Metrics and Evaluation (IHME) 2018: Global Burden of Disease Study 2017 (GBD 2017) Results. Seattle, United States. http://ghdx.healthdata.org/gbd-results-tool.

IQAir 2019: 2019 World Air Quality Report, Regions & City PM2.5 Ranking. https://www.iqair.com/world-most-polluted-cities

Unwin J 2019: What does Pakistan's energy mix look like and what is its future? Power Technology. https://www.power-technology.com/features/pakistan-energy-mix/ (accessed on 10 May 2020)

Larkin A, Geddes JA, Martin RV, Xiao Q, Liu Y, Marshall JD, Brauer M & Hystad P 2017: Global Land Use Regression Model for Nitrogen Dioxide Air Pollution. Environmental Science & Technology 51(12):6957-6964. https://dx.doi.org/10.1021/acs.est.7b01148.

Myllyvirta L 2020: "Quantifying the Economic Costs of Air Pollution from Fossil Fuels". Centre for Research on Energy and Clean Air. https://energyandcleanair.org/publications/costs-of-air-pollution-from-fossil-fuels/

Jabri P 2019: Block-II of Thar Coal Power project starts generating 660 MW. Business Recorder. https://www.brecorder.com/2019/04/11/487932/block-ii-of-thar-coal-power-project-starts-generating-660-mw/ (accessed on 10 May 2020)

Sindh Environmental Protection Agency (SEPA), Government of Pakistan 2020: Air Quality Monitoring Reports. http://epasindh.gov.pk/aqm.htm (accessed on 10 May 2020)

Sindh Environmental Protection Agency (SEPA), Government of Pakistan 2016: Sindh Environmental Industrial Waste Water, Effluent, Domestic Sewerage, Industrial Air Emissions and Ambient Air, Noise for Vehicles, Air Emissions for Vehicles and Drinking Water Quality Standards, 2015. http://epasindh.gov.pk/Rules/SEQS%202016.pdf (accessed on 10 May 2020)

Swain EB, Engstrom DR, Brigham ME, Henning TA & Brezonik PL 1992: Increasing Rates of Atmospheric Mercury Deposition in Midcontinental North America. Science 257:784-787.

Trasande L, Malecha P, & Attina TM 2016: Particulate Matter Exposure and Preterm Birth: Estimates of U.S. Attributable Burden and Economic Costs. Environmental Health Perspectives 124:12. https://doi.org/10.1289/ehp.1510810.

United Nations, Department of Economic and Social Affairs, Population Division (UNPD) 2019: World Population Prospects 2019, Online Edition. Rev. 1.

United Nations Environment Programme and Arctic Monitoring and Assessment Programme (UNEP/AMAP) 2013: Technical Background Report for the Global Mercury Assessment 2013. http://hdl.handle.net/11374/732.

United Nations Environment Programme (UNEP) 2017: Toolkit for Identification and Quantification of Mercury Releases. UN Environment Chemicals Branch, Geneva, Switzerland.

U.S. EPA 1998: AP-42: Compilation of Air Pollutant Emission Factors, Ed. 2, Fifth Edition, Volume I. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors.

van Donkelaar A, Martin RV, Brauer M, Hsu NC, Kahn, Levy RC, Lyapustin A, Sayer AM, & Winker, Global Estimates of Fine Particulate Matter using a Combined Geophysical-Statistical Method with Information from Satellites, Models, and Monitors, Environ. Sci. Technol, https://doi.org/10.1021/acs.est.5b05833.

World Health Organization (WHO) 2013: Health risks of air pollution in Europe-HRAPIE project. http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf?ua=.

Zhang H, Feng X, Larssen T, Qiu G & Vogt RD 2010. In Inland China, Rice, Rather than Fish, Is the Major Pathway for Methylmercury Exposure. Environ Health Perspect. 118(9): 1183–1188. https://dx.doi.org/10.1289%2Fehp.1001915.

Zheng X, Ding H, Jiang L, Chen S, Zheng J, Qiu M, Zhou X, Chen Q & Guan W 2015: Association between air pollutants and asthma emergency room visits and hospital admissions in time series studies: a systematic review and meta-analysis. PloSOne 10(9):e0138146, PMID:26382947, https://doi.org/10.1371/journal.pone.0138146.