Assessing the air quality, toxic and health impacts of the Lamu coal-fired power plants

Lauri Myllyvirta[1] & Clifford Chuwah[2]

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Summary

The proposed Lamu coal-fired power plant would be a major point source of air pollution in Kenya with potentially significant impacts on the surrounding communities and ecosystems.

This case study provides a detailed analysis of the air quality and health impacts of the proposed Lamu coal-fired plant, combining detailed atmospheric modeling with existing epidemiological data and literature. The impacts were modeled over a 1500km x 1500km domain covering Kenya and parts of the surrounding areas.

The emissions from the planned Lamu power plant would

- Elevate the levels of toxic particles and NO_2 in the air over Lamu and beyond, increasing the risk of diseases such as stroke, lung cancer, heart and respiratory diseases in adults, as well as respiratory infections in children. This leads to premature deaths from these causes. SO_2, NOx and dust emissions contribute to toxic particle exposure.
- Cause acid rain, which can affect crops and soils.
- Cause fallout of toxic heavy metals such as arsenic, nickel, chrome, lead and mercury.

The planned Lamu coal-fired power plant is more likely to result in approximately 26 (present day) and 41 (2030) premature deaths per year due to exposure to $PM_{2.5}$ and NO_2, including deaths of infants due to an increased risk of respiratory infections. The would be a projected 20 low birth weight births per year associated with the pollution from the plant. Over an operating life of 40 years, this would translate to approximately 1,600 premature deaths and 800 low birth weight births.

There is a risk of acid rain and deposition of heavy metals being a significant issues up to 50km to the north and 20km to the west from the Lamu plant.

[1] Coal and Air Pollution specialist, Greenpeace.
[2] Air Quality Scientist, Greenpeace Research Laboratories
[3] Greenpeace Research Laboratories, Innovations Centre Phase 2, Rennes Drive, University of Exeter, Exeter EX4 4RN, UK

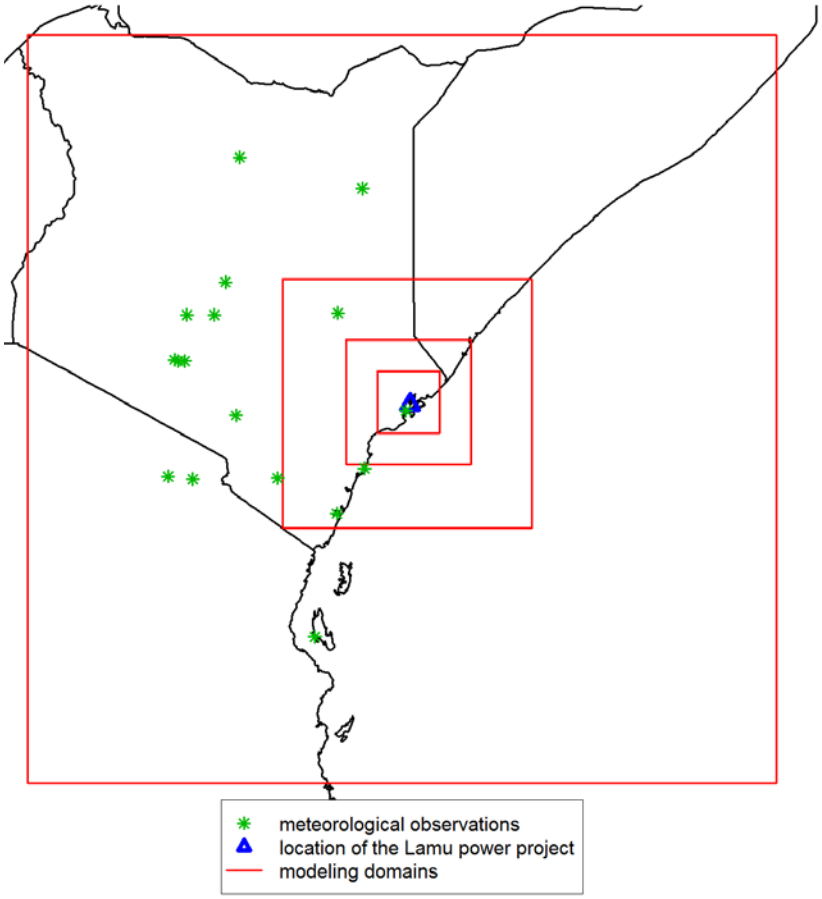

Figure 1 CALPUFF modeling domains (red), location of study area (blue triangle and location of different meteorological observations (green asterisk).

Air pollutant emissions

Annual emissions were calculated from emission rates at full operation given in the EIA, assuming 80% capacity utilization. The basic data on the location and stack characteristics of the plant were similarly obtained from the EIA and are shown in table 2 below. The emission data shown in Tables 1 and 2 were used as the basis of modeling the plants' air quality impacts using the CALMET-CALPUFF modeling system. The modelling domains used is shown in Figure 1 above.

Units	Flue gas concentrations (mg/Nm^3)			Annual emissions (t)			
	SO_2	NO_x	Dust	SO_2	NO_x	Dust	Mercury (kg)
Lamu	343	450	42	8671	11376	1062	11.4

Table 1 Estimated air pollutant emissions from the power plan

Plants	Capacity, MW	Steam condition	Latitude	Longitude	Stack height, m	Stack inner diameter, m	Flue gas velocity, m/s	Flue gas temperature, K
Lamu	3x350	Subcritical	2.09°S	40.90°E	210	5.3	18.6	413

Table 2 Basic data on the case study power generating units.

The emission limits applied to the project are alarmingly weak in international comparison (Figure 1). For example, the plant would be allowed to emit 5-10 times as much key air pollutants as a new coal-fired power plants in China and the EU.

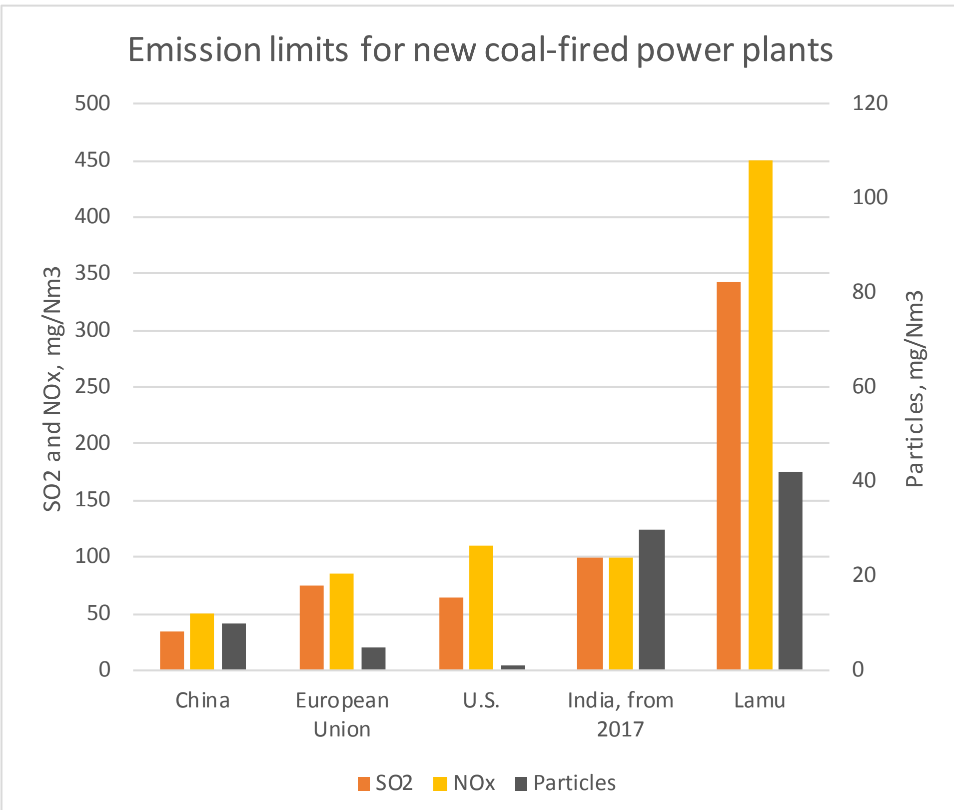

Figure 2 Emission limits applied in the Lamu project compared with emission standards in selected jurisdictions.

Impacts on air quality

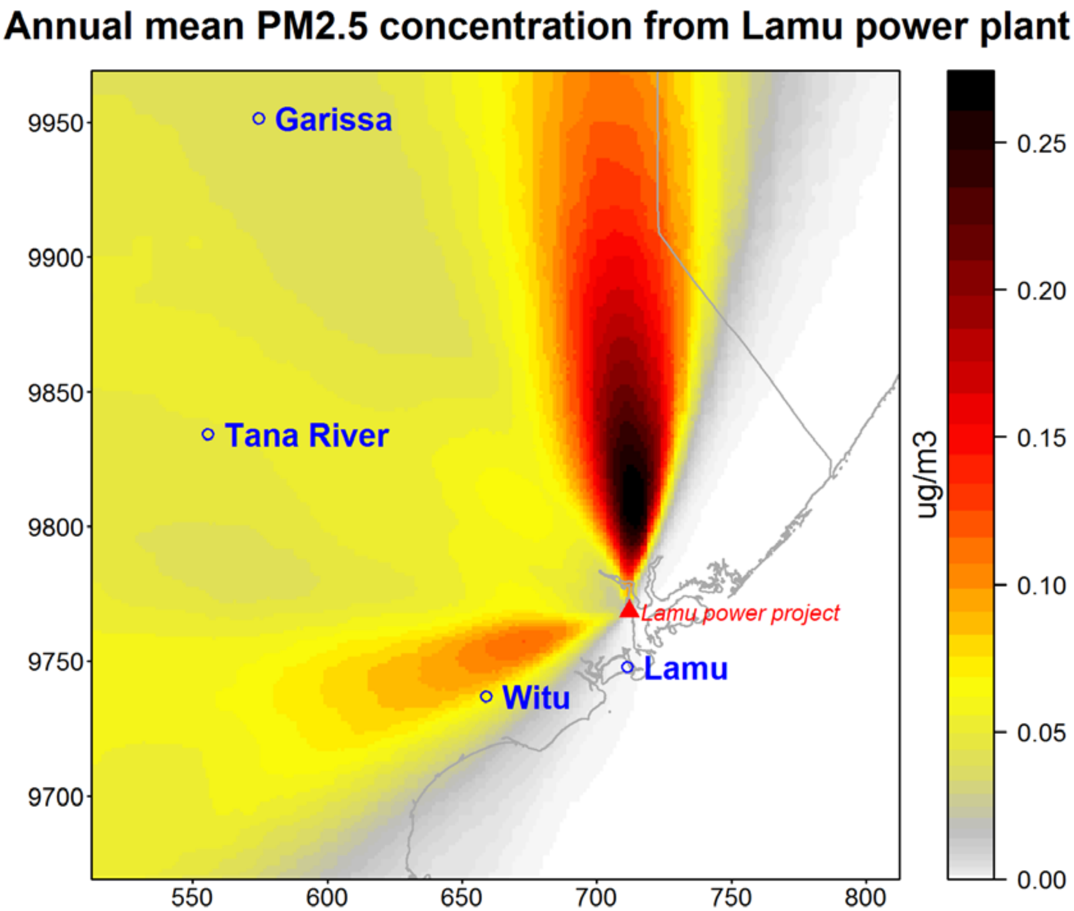

Figure 3 Projected annual average $PM_{2.5}$ concentration attributable to emissions from the Lamu power plant ($\mu g/m^3$)

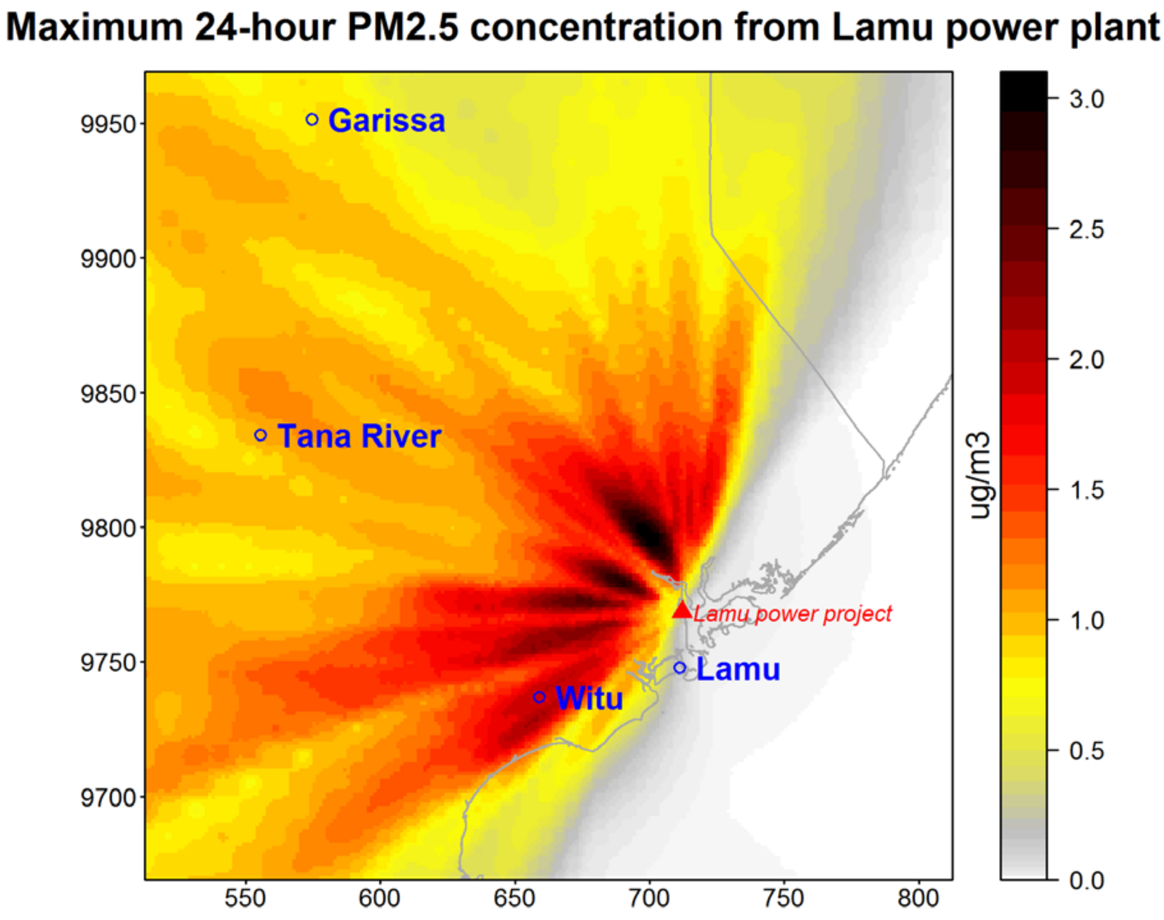

Figure 4 Projected 24-hour maximum $PM_{2.5}$ concentration attributable to emissions from the Lamu power plant ($\mu g/m^3$)

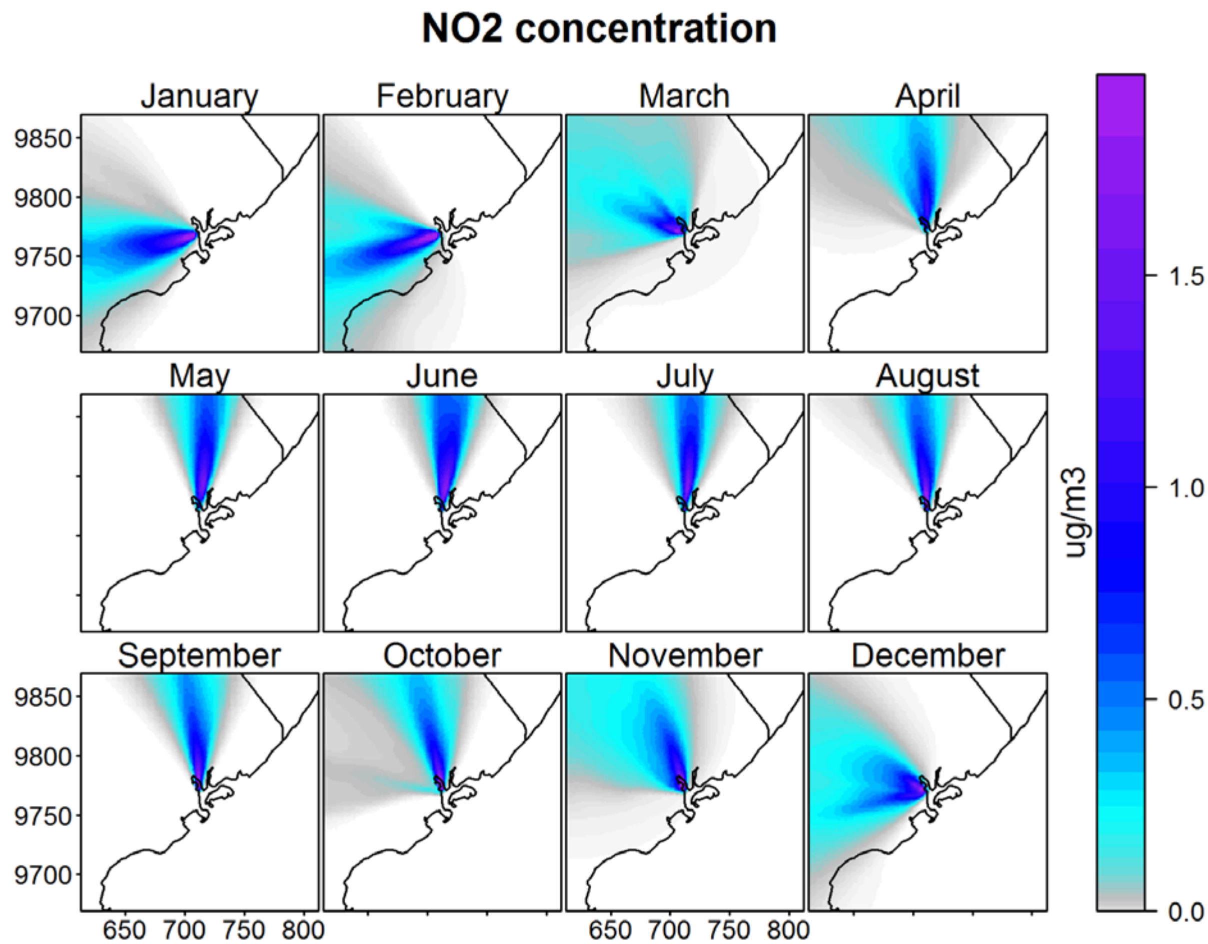

Figure 5 Projected monthly average NO_2 concentrations caused by emissions from the Lamu power plant (µg/m^3)

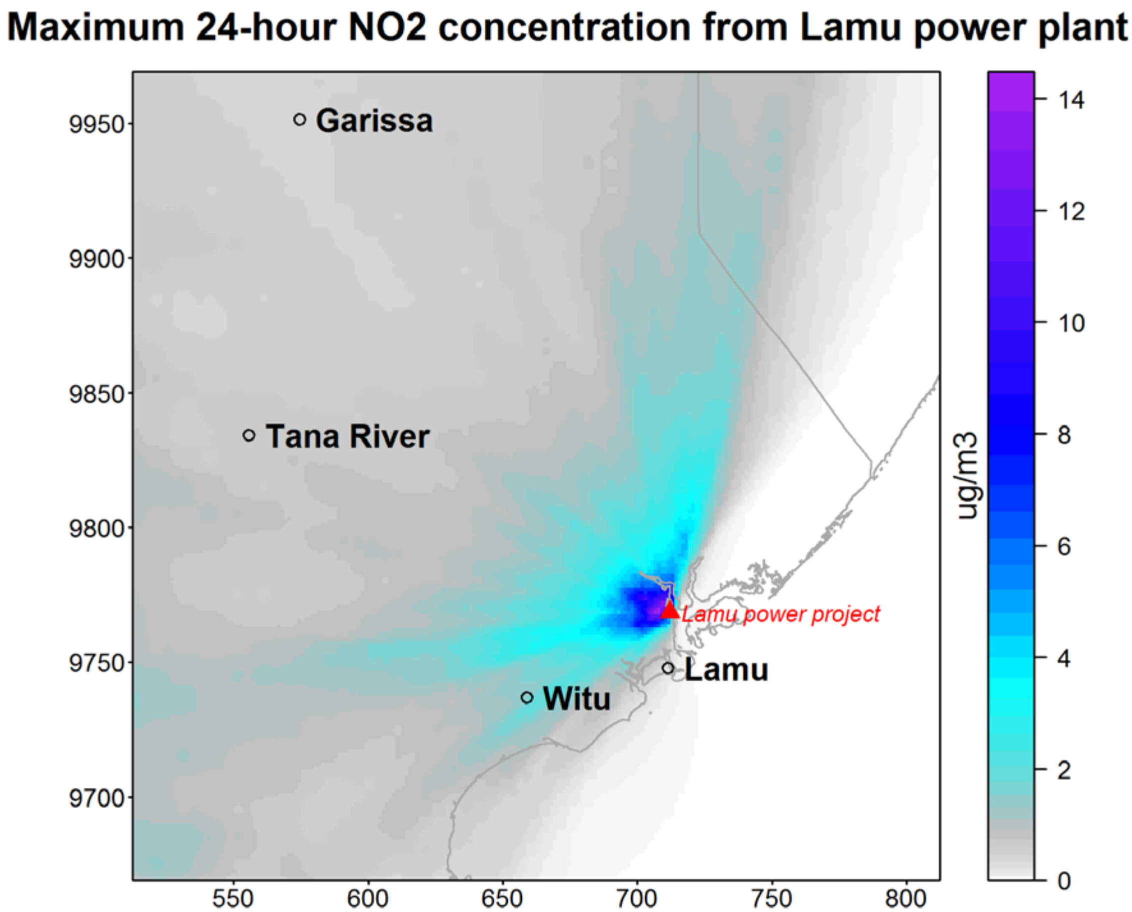

Figure 6 Projected 24-hour maximum NO_2 concentrations caused by emissions from the Lamu power plant (µg/m^3)

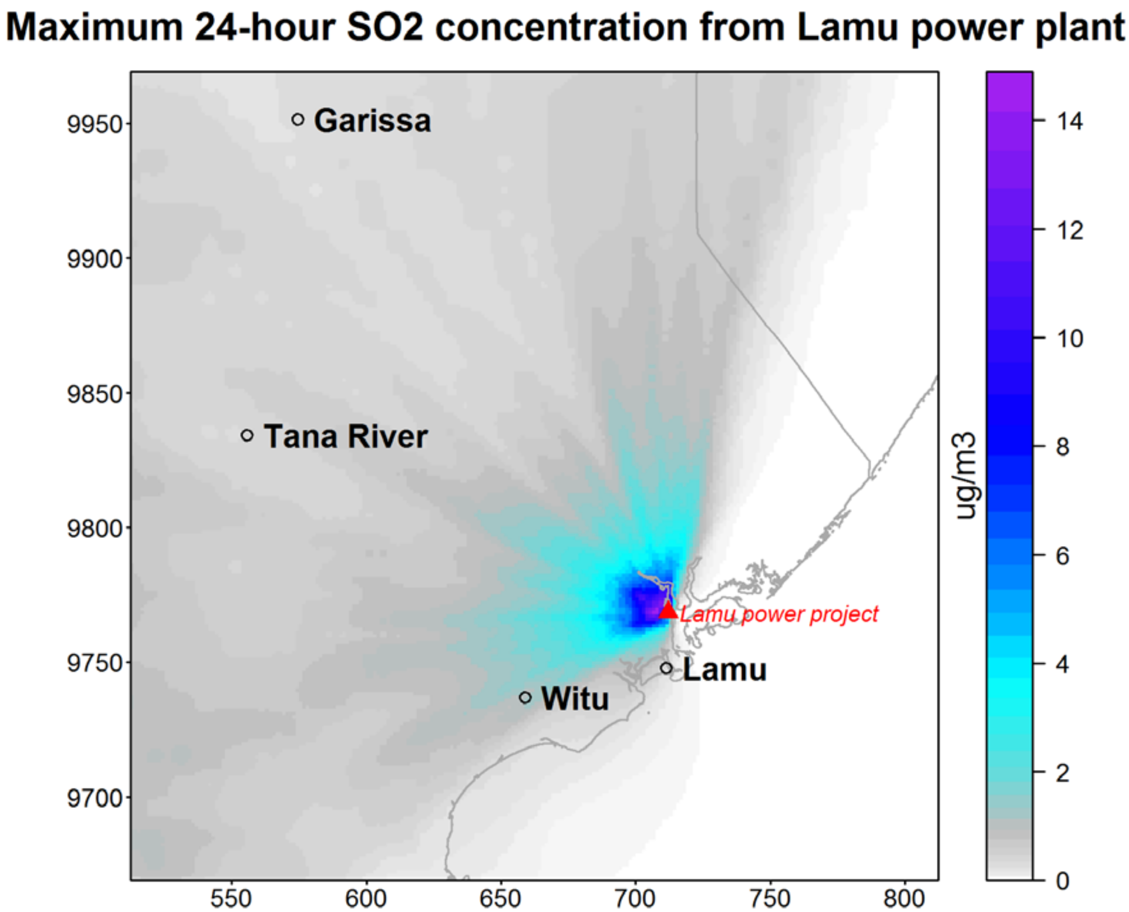

Figure 7 Projected 24-hour maximum SO_2 concentrations caused by emissions from the Lamu power plant (µg/m^3)

The results are shown here for the projected situation if the planned new units (3 x 350MW) are built and operated. These units would introduce a major new source of air pollution in the region. The emissions affect $PM_{2.5}$ pollution levels as far as Garissa in the Northwest and Tana River in the west (Figure 2 and Figure 3). A significant impact on the monthly level of NO_2 is seen in the North and west regions (Figure 4) from Lamu, with maximum 24 hour concentration levels of NO_2 and SO_2 at the most affected locations reaching around 15µg/m^3, higher than current background concentrations, as reported in the EIA (Figure 5 and Figure 6). Largest projected daily increases of $PM_{2.5}$ levels are 3µg/m^3, also higher than average $PM_{2.5}$ levels reported in the EIA. Emissions from the planned Lamu power plant are likely to affect pollution levels most significantly in cities and towns to the north and west of the power plant. The highest estimated daily SO_2 and NO_2 levels are in Garissa and Voi (Figure 7).

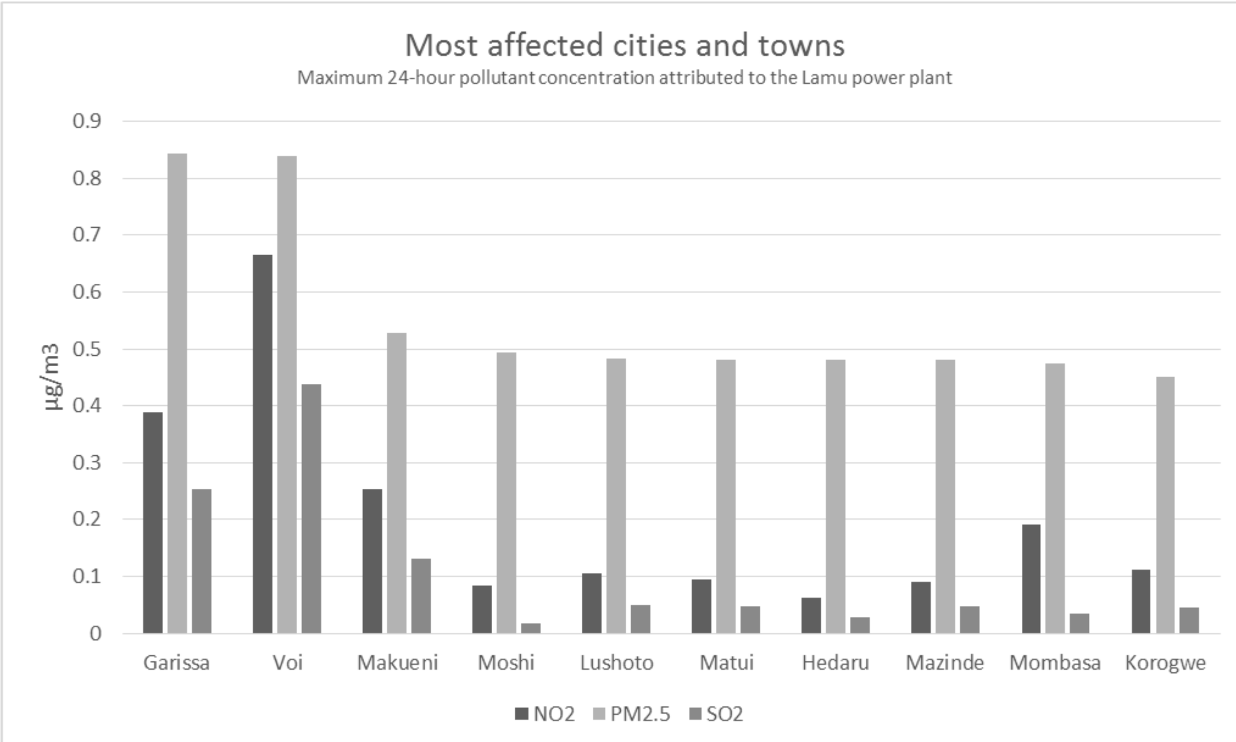

Figure 8 most affected cities and towns.

Toxic fallout

The pollution emissions from coal-fired power plants lead to deposition of toxic heavy metals and fly ash, as well as acid rain (figure 9 and figure 10).

Most intense acid and fly ash deposition would take place in the areas up to 50km to the north and 20km to the west of the plant, with most affected areas receiving an estimated 10kg of SO2-equivalent per hectare and 2kg of fly ash per hectare per year.

Total fly ash deposition on land is predicted at 500 tonnes per year. As an indicative estimate, based on USGS analysis of 41 South African coal samples[4], 500 tonnes of fly ash could be expected to contain around 3 to 10 kg of arsenic, 50 to 130 kg of chromium, 20 to 40 kg of copper, 80 to 270 kg of manganese, 20 to 90 kg of nickel, and 7 to 40 kg of lead[5].

Total acid deposition on land is projected at 800 tonnes SO_2 equivalent. Acid deposition could affect agricultural yields or increase input costs for farmers who have to neutralize the deposition. Acid rain also damages property and culturally important buildings.

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[4] USGS 2011: World Coal Quality Inventory v1.1. http://energy.usgs.gov/Coal/AssessmentsandData/WorldCoalQualityInventory.aspx

[5] These rough estimates are calculated using the 10th and 90th percentiles of values in USGS coal samples, and assuming an enrichment factor of 1 from ash in unburned coal to fly ash emitted from the stack, in line e.g. with the empirical results of Linak et al 2000. http://www.tandfonline.com/doi/pdf/10.1080/10473289.2000.10464171

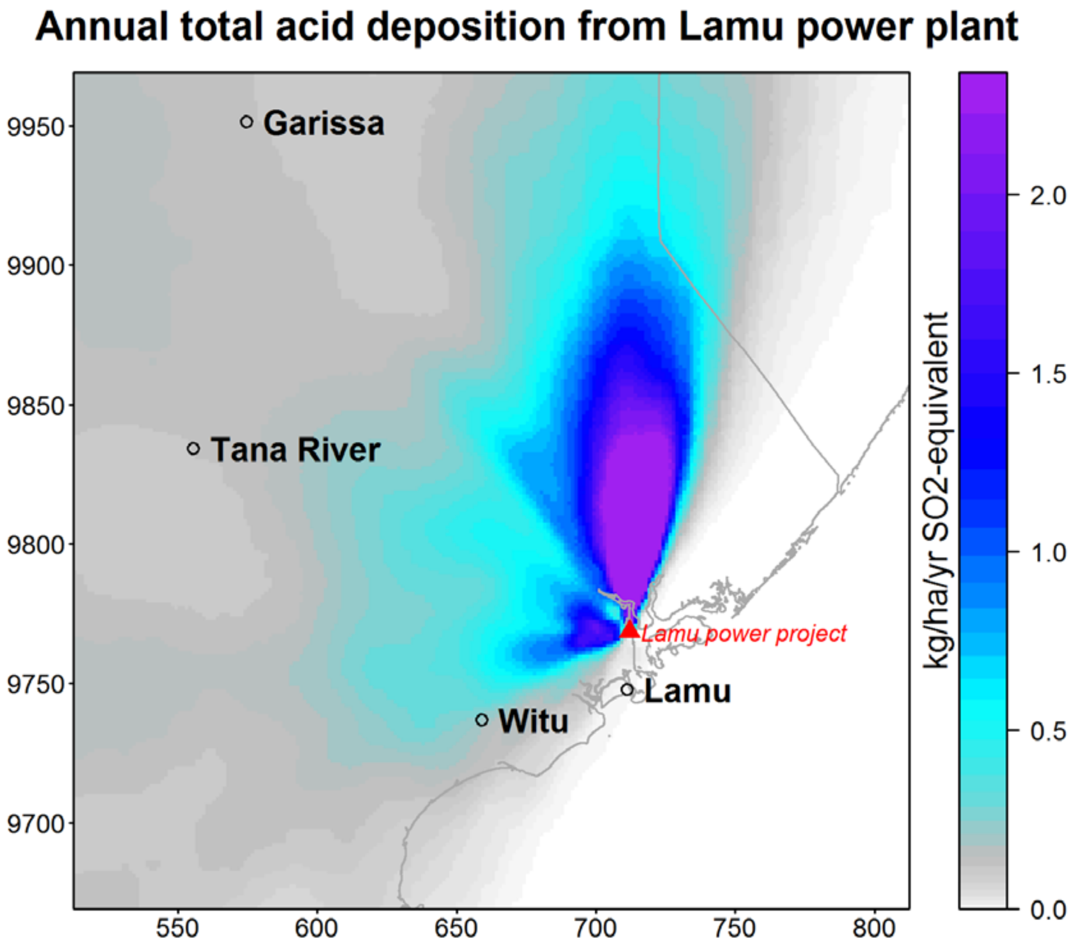

Figure 9 Projected acid deposition (SO_2 equivalent) from the Lamu *power plant (kg/ha/year)*

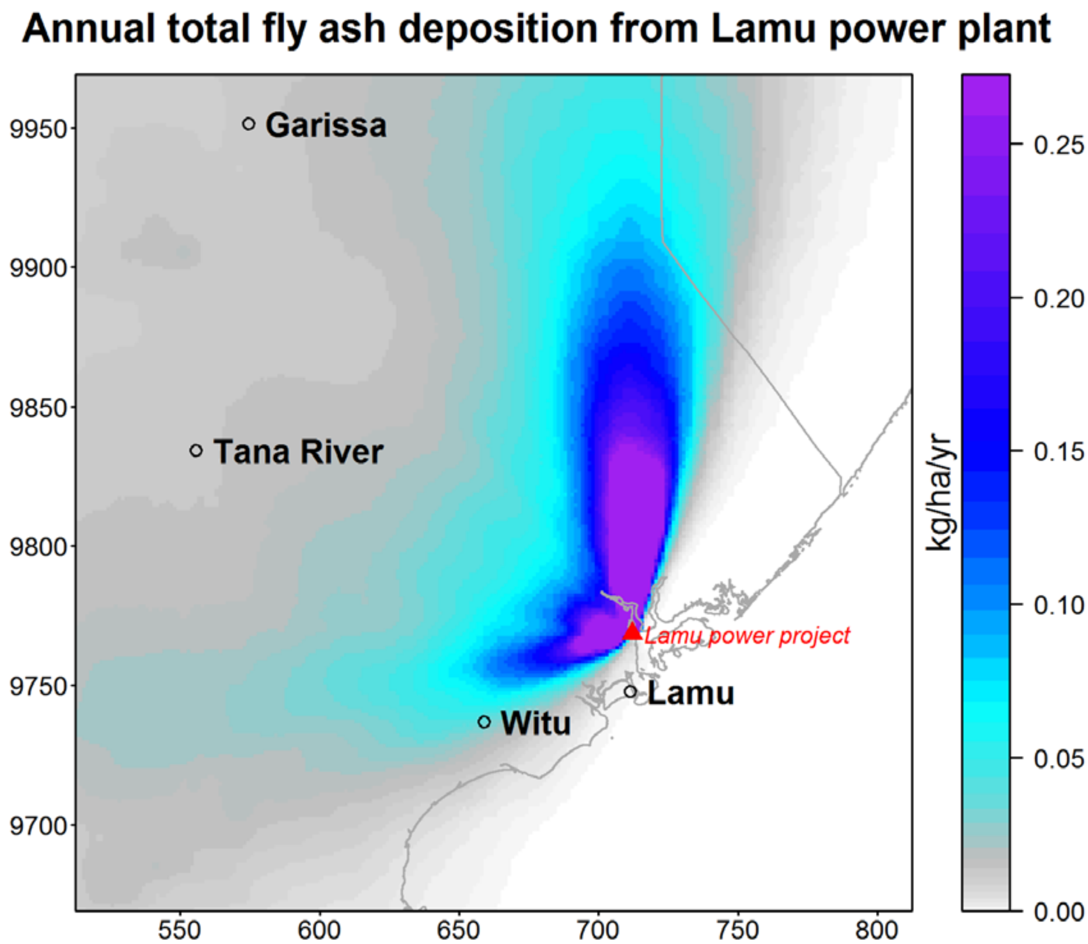

Figure 10 Projected fly ash deposition from the Lamu power plant (kg/ha/year)

Health impacts

The planned Lamu coal-fired power plant is more likely to result in approximately 26 (present day) and 41 (2030) premature deaths per year due to exposure to both $PM_{2.5}$ and NO_2 respectively (Table 3). There is a risk of acid rain and fly ash fallout being significant issues up to 50km from the Lamu plant in the in the north and northwestern regions.

If the power plant gets built, it can be expected to operate for decades. It's therefore important to take into account the future population growth and change in population age structure. The health impacts were projected to 2030 assuming no change in emissions but projected increase in population and change in rates of death from different causes, which reflect factors such as improved health care and aging population.

	Outcome	Present day population		2030 population	
$PM_{2.5}$, premature deaths	Chronic diseases in adults	22	*(14-29)*	38	*(24-50)*
	Lower Respiratory Infections in children	3	*(1-8)*	3	*(1-7)*
NO_2, premature deaths	All causes	1	(0-1)	1	*(1-2)*
Premature deaths	**Total**	**26**	*(15-38)*	**41**	*(26-58)*
$PM_{2.5}$	Low birth weight births	20	*(6-35)*		

Table 3 Present day and projected premature deaths and other health impacts caused by emissions from the studied power plants, cases per year.

Assuming a 40-year lifetime, and applying the projected health impacts for 2030, the proposed power plant would be responsible for a total of 1,600 premature deaths (95% confidence interval: 1,000-2,200) and 800 low birth weight births over its entire operating life.

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Appendix: Materials and methods

Atmospheric dispersion modeling for the case studies was carried out using version 7 (June 2015) of the CALPUFF modeling system. CALPUFF is an advanced non-steady-state meteorological and air quality modeling system adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts.

Meteorological data for the simulations comes from two sources: 17 hourly surface meteorological observation stations for which data was available through U.S. NCDC under the World Meteorological Organization agreement on sharing meteorological data, and three-dimensional meteorology generated in the TAPM modeling system, developed by Australia's national science agency CSIRO. TAPM uses as its inputs global weather data from the GASP model of the Australian Bureau of Meteorology, combined with higher-resolution terrain data. TAPM outputs were converted into formats accepted by CALPUFF's meteorological preprocessor, CALMET, using the CALTAPM utility, and the meteorological data were then prepared for CALPUFF execution using CALMET. CALMET generates a set of time-varying micrometeorological parameters (hourly 3-dimensional temperature fields, and hourly gridded stability class, surface friction velocity, mixing height, Monin-Obukhov length, convective velocity scale, air density, short-wave solar radiation, surface relative humidity and temperature, precipitation code, and precipitation rate) for input to CALPUFF.

Terrain height and land-use data were also prepared using the TAPM system and global datasets made available by 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.

To 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. Particles larger than 10 microns were modeled with a mean aerodynamic diameter of 15 microns. Reported annual emissions were converted into average emission rates, which were then applied throughout the year.

Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA II 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 global atmospheric model with nested grid for Africa (Marais 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.

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 2010 from NASA SEDAC[6], and then applying the health impact assessment methodology of the Harvard-Greenpeace coal-

[6] http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-count-future-estimates

health study (Koplitz et al., 2017). In addition, premature deaths from NO_2 exposure were assessed based on Mills et al. (2016), and Health risks of air pollution in Europe (in the case of all PM2.5-causes) and increase in low birth weight births based on Dadwand et al (2013). Baseline death rates in Kenya from different causes were obtained from WHO Global Health Estimates (2014), birth rates and incidence of low birth weight from World Bank (undated).

Risk ratio for 10µg/m^3 increase in $PM_{2.5}$ exposure	Central	95% CI, low	95% CI, high	Reference
Lower respiratory infections	1.12	1.03	1.3	Mehta et al 2011
Low birth weight	1.100	1.030	1.180	Dadwand et al 2013

Risk ratio for 10µg/m^3 increase in daily NO_2 exposure	Central	95% CI, low	95% CI, high	Reference
Deaths, all causes	1.0060	1.0033	1.0087	Mills et al 2016

Risk ratio for 10µg/m^3 increase in daily $PM_{2.5}$ exposure	Central	95% CI, low	95% CI, high	Reference
Deaths, all causes	1.062	1.04	1.083	WHO, 2013

Table 4 Risk ratios from different studies used for health impact assessment.