Final Report
Reducing Air Pollution in Lahore: Model on Direct Air Capture

Decision Analysis – DISC 321 – S1

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# Executive summary

The project aims to explore the feasibility of installing direct air capture (DAC) technology to absorb and store carbon dioxide in order to mitigate the high levels of air pollution and carbon dioxide in Lahore, Pakistan. By lowering atmospheric carbon dioxide levels, the project's principal goal is to lessen air pollution and improve the air quality index (AQI). Simulation and risk under uncertainty models were used to estimate the number of deaths that can be avoided, as well as improvement in other health parameters such as heart diseases, respiratory infections, blindness and vision loss, etc. The cost of running a DAC plant for a year has also been included as part of the project's secondary research process. Electricity requirements, health information on air contaminants, AQI/weather information, and probability distributions for input parameters like atmospheric pressure and wind speed are among the model's inputs. In order to further develop and apply this technology, the project plans to work with academic and governmental organisations. The long-term objective is to reduce the carbon footprint in other cities and fulfil the WHO's recommended standards. The project will aim to set goals and make recommendations for the use of DAC technology.

# Introduction to Direct Air Capture (DAC)

Using a chemical procedure, Direct Air Capture (DAC) technology removes carbon dioxide from the atmosphere. Through high-powered fans, air is drawn into a processing facility where the $CO_2$ is separated through a series of chemical reaction, the air contacts with a liquid solvent such as potassium hydroxide (KOH). This forms a carbon dioxide rich solution which is then further processed through a series of reactions to purify carbon dioxide. Then the $CO_2$ is permanently stored in underground reservoirs through secure geologic sequestration or can be used to make new products such as building materials, food processing and to produce low carbon fuels.

Carbon dioxide is the main contributor to global warming; it has been increasing at an alarming rate. Carbon dioxide global average set a record in 2021: 414.72 parts per million. Moreover, this has significant effect on the ocean as it has absorbed enough carbon dioxide to lower its pH level by 0.1 units, increasing the acidity in ocean water by 30%. Thus, government and environmental bodies needs to take instant action to implement policies to lessen the effect of carbon dioxide and decrease its emissions. In this time, DAC is a very suitable solution to this alarming situation.

1PointFive is the main organization that provides the DAC facilities. Currently there are 18 direct air capture plants operating worldwide capturing 0.01 million tons of carbon dioxide per year. Another direct air capture plant is in the development stage in United States expected to capture 1 million tons carbon dioxide per year. Additionally, 1PointFive has just completed the initial front-end engineering and design phase on the largest DAC facility in the world. It is expected to capture 500,00 tons of carbon dioxide per year but has the capacity to reach up to 1 million metric tons per year.

Compared to conventional carbon capture and storage (CCS) systems, which collect carbon dioxide from industrial point sources, DAC technology has a number of benefits. DAC is a flexible tool for lowering atmospheric carbon dioxide levels because, in contrast to CCS systems, it can directly capture carbon dioxide from the air, independent of its source. Furthermore, DAC systems are dependable for carbon dioxide capture because they can run independently of the energy supply. DAC technology's limited scale, high expense, and energy intensity have all prevented widespread adoption. However, as technology and research progress, DAC systems are becoming more effective and economical. Lahore, Pakistan has been on the map due to increased air pollution and subsequent adverse health issues in the population. The construction of DAC plants in Lahore may help to lessen the amount of carbon dioxide in the atmosphere and to lessen its negative effects on the ecosystem and human health.

## Problem Statement

The need to discover a practical solution to lower the high levels of atmospheric carbon dioxide in Lahore, Pakistan. Over 11 million people live in Lahore, a significant metropolis in Pakistan, which is also the location of numerous businesses, transportation hubs, and power plants. These activities generate a substantial amount of carbon dioxide, a greenhouse gas that has detrimental effects on both the environment and human health. Emissions of carbon dioxide are one of the main sources of air pollution. Lahore’s air quality worsened to 97.4 micrograms of PM2, an increase of 10.9 micrograms from 2021, making Lahore the most polluted city in the world. Air quality worsens in the month of December and January, increasing the air quality index above 200, categorizing the Lahore region as extremely hazardous.

To discover a solution that will significantly lower Lahore's atmospheric carbon dioxide levels while minimizing any negative effects on the environment and public health. Plants that use DAC might be able to address this issue. Even at low concentrations, DAC technology can directly collect carbon dioxide from the atmosphere and run without an external energy source. DAC plants can successfully lower carbon dioxide levels in Lahore while supporting other moderation efforts.

## Aims of the Project

Considering Lahore has been at the receiving end of multiple reports and articles consisting of its deteriorating environment, the project's main goal is to lower the amount of carbon dioxide in the air over Lahore by using DAC technology to capture and store carbon dioxide, and thereby reduce air pollution and improve AQI. Rise in carbon dioxide results in an increase in pollution which ultimately causes various health diseases like cancer to its inhabitants. By doing this, the effects of carbon dioxide on the environment and public health in the metropolis will be lessened. Lahore has a bad reputation for such environmental hazards, and its ‘reputation’ might also improve through this initiative. The construction of DAC plants will support additional mitigation initiatives, such as lowering emissions from motor vehicles, factories, and the promotion of environmentally friendly policies and EV’s. This can have a bigger effect on the environment by reducing carbon dioxide levels using a multifaceted strategy, which could ultimately lower the carbon footprint of the area.

By offering a dependable and affordable means of carbon capture, the installation of DAC plants can encourage sustainable development. The model aims to justify the installation of these DAC plants in terms of reducing air pollution and its adverse effects on health. To advance research and development, the project aims to collaborate with academic and government organisations in the future, to further improve and implement this technology. In the long run, this will contribute to the technology’s availability, affordability and increase its efficacy. Ultimately, the wider goal is to ensure the minimization of carbon footprint in other cities and reach WHO’s specified guidelines as well as reach Pakistan’s own goal of reducing $CO_2$ emissions by 20% in this decade. With the model applied in Lahore, it can serve as a point of reference to other cities, ultimately moving towards the solution to the pollution crisis of the whole country.

## Current Approach

To mitigate the current pollution crisis, there are a number of measure being taken by relevant authorities. Firstly, in order to reduce emissions from private cars, the Lahore government has put in place a number of initiatives to promote public transportation, including the Bus Rapid Transit System (BRTS) and Metro Bus Service. Dedicated bus lanes, part of the BRTS system, serve to lessen traffic congestion and increase the speed and effectiveness of public transportation. Contrarily, because the Metro Bus Service runs on a specific elevated route, there is less traffic, and the service is more dependable. The Lahore government wants to reduce the number of private cars on the road, which is a major source of carbon dioxide emissions, by promoting public transportation, such as the introduction of electric buses. Hence, by this efficient network not only it is able to make the lives of the citizens easier, but also reduce the amount of carbon dioxide emitted in the environment.

Secondly, an alternate method is used by the government in the energy sector to improve the current pollution fiasco. A large number of Lahore's power plants have switched from using furnace oil to natural gas, which is a cleaner fuel and produces fewer greenhouse gases. Additionally, natural gas is a more dependable and economical fuel, which lowers the total cost of producing electricity. The Lahore government has also taken steps to promote the use of energy-saving technologies, such as efficient air conditioning systems and LED lighting, which further cut down on energy use and carbon dioxide pollution.

Thirdly, to lessen the dependence on fossil fuels and cut carbon dioxide emissions, the Lahore government is promoting renewable energy, such as solar and wind energy. In order to promote the use of renewable energy, the government has put in place a number of regulations and incentives, such as net metering, which enables customers to transfer any extra electricity produced by solar panels back to the grid. To boost the proportion of renewable energy in the city's energy mix, the government also plans to build a number of solar parks and wind farms. Hence, incentivising the use of renewable energy sources can cut down some of the emission however, it is to be remembered that renewable energy resources are not widely available in Pakistan which makes their use costly. Which means there is still a high price barrier which limits their usage.

Reforestation is also a classical approach used by the government to curb the ever growing pollution issue. To expand the city's green cover, which can help absorb carbon dioxide from the air, the Lahore government has launched a number of afforestation projects.

Numerous trees have been planted by the government in parks, on the sides of roadways, and in other public areas. The government has also put policies in place to stop deforestation and the encroachment of current forests and habitats for animals. Additionally, to decrease emissions from stationary sources, the government has put in place air pollution control measures like closing polluting industries and setting up air quality monitoring sites. The government has also put in place steps to control vehicle emissions, such as mandating the use of fuels that comply with Euro-II standards and submitting all vehicles to regular emissions testing. The government has also taken action to reduce dust emissions, such as mandating dust control practices at construction locations. Hence, these important corrective actions are timely and much needed, which could eventually help Lahore combat the pollution problem.

Although these preventive measures have contributed to a certain degree in the reduction of carbon dioxide emissions in Lahore, they might not be enough to bring about the intended reductions. The pollution levels are rising each year and $CO_2$ emissions also increasing. Therefore, adding DAC plants can be a useful method to complement these actions and get the city's carbon dioxide levels down significantly. DAC technology is a flexible tool for lowering atmospheric carbon dioxide levels because it has the capacity to directly capture carbon dioxide from the air, independent of its source.

## Methodology

The main research method is secondary research since the data required cannot be directly collected. Additionally, the data needs to be collected from various periods of time, therefore, it cannot be done due to the limited time frame of this project. The required data was collected from credible sources, established and credible authorities, such as Punjab government, US consulate, global health organizations etc.. Simulation and Risk under Uncertainty are the main models used to prove the feasibility of installing DAC's in Lahore. This research project is applied research, using primarily quantitative methods. However, some aspects of qualitative data were also used to justify and back up qualitative techniques.

## ORCA (DAC) by Climeworks

The ORCA is the latest in DAC technology, claiming an efficiency level of 90%, and the best available in the wide array of technologies. It has been implemented in various countries, for businesses, as well as government authorities. The biggest plant is in Iceland, that captures 36,000 tons of $CO_2$ each year. This project has selected the ORCA to derive the feasibility of implementing DAC in Lahore, since it is the best in its field, with the maximum efficiency as well as its better scalability. The plant can be designed to fit anywhere and be used on a rooftop of a small building or even scaled to a huge plant on acres. Therefore, it remains that the best option available and befitting Lahore's requirements is the ORCA.

## Data Collection

Data collection is essential to the development of accurate and reliable models. Collecting data from reputable sources, such as government agencies, academic institutions, and research organizations, ensures that the data is up-to-date and comprehensive. However, the type of data collected is also crucial to the development of the model. For the model, data pertaining to the costs associated with operating a DAC plant, energy costs, and other operations expenses were collected from the official ORCA website, which manufactures the DAC plants.

Health data related to respiratory and cardiovascular diseases associated with air pollution, including morbidity and mortality rates, were also gathered. Information such as the concentration of air pollutants in the air, including particulate matter ($PM_{2.5}$ and $PM_{10}$), nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$), ozone ($O_3$), and carbon monoxide (CO), and data on the sources and patterns of air pollution, including industrial emissions, transportation, and other anthropogenic activities were also included. Furthermore, Air Quality Index (AQI) data was also gathered. Historical levels of AQI in the region or city where the DAC plant will be located, including data on air pollution concentration and impacts on public health, were collected. Along with this, information from regulatory and policy frameworks governing air quality and pollution control in the region or city was gathered.

This data is vital to developing a model that is not only effective but also outlines the environmental and health impacts associated with air pollution. Without this data, it would be impossible to accurately assess the situation and create effective measurements and plans to reduce air pollution. Additionally, it is important that the data collected is up-to-date, comprehensive, and relevant to the specific context and objectives of the model. It is with this data that the model described above can be developed and monitored in order to mitigate the effects of air pollution.

# Assumptions

## Health Data

Since direct sources for verifiable latest data regarding the respiratory and cardiovascular diseases associated with air pollution were not available for the year 2022, hence, past data (2016-2019) and its rates are being used to replicate the current trends of the diseases in Lahore. It is assumed that the percentage number of cases remains same over the years, therefore it can be applied to more recent years after being adjusted for AQI. Average yearly Air Quality indices over these years were compared with health data to analyze the effect of air quality improvement on public health percentages and assumed that this correlation remains constant.

## $CO_2$

The data of $CO_2$ levels for Lahore was not available, since it is not actively monitored. However, the per capita emissions in Lahore were calculated through reliable publications. Multiplying the population of Lahore with the per capita emissions allowed the approximation of yearly emissions for $CO_2$. Air pollutants other than $CO_2$ tend to linger and may be concentrated in some areas rather than the others, however, $CO_2$ itself spreads out and over time becomes constant in the atmosphere, therefore, it was not required to identify areas with higher air pollution and therefore build a model that calculated areas best suited for the DAC plant. Climeworks also states that it is not necessary to install these plants in areas of high emissions or air pollution, since results are the same everywhere, given the machine's requirements are met

## AQI

$CO_2$ does not directly affect the AQI levels. However, it indirectly increases AQI levels, since it is a heat trapping gas and damages the ozone layer while also contributing to the increase of climate change and global warming. It contributes to the formation of the other air pollutants as well. AQI is calculated by averaging all data points of all pollutants individually, and then selecting the highest average and displaying the AQI level of the highest pollutant. Since the major air pollutant in Pakistan is $PM_{2.5}$, AQI is also calculated through averages of $PM_{2.5.}$ Reliable and Valid data of $CO_2$ levels, $PM_{2.5}$, and other air pollutants was collected from the monitoring stations at Mount Luau, Hawaii, and a regression analysis was run to gauge the effect of reducing $CO_2$ on $PM_{2.5}$. It was assumed that this correlation between $CO_2$ and $PM_{2.5}$ remains same everywhere.

### Efficiency

The company claims efficiency levels of 0.9 for the ORCA machine. However, outside the weather requirements, for example, above 86ºF or below 41ºF, the machine's efficiency would be affected, but it was not specified by how much. Therefore, it was assumed that the percentage change in weather conditions would be affect the efficiency levels by the same percentage. For example, if the temperature levels reached 100ºF, meaning approximately a 16% change, then the total efficiency would also be reduced by 16%.

### Adverse health effects' costs to society

Measuring the adverse health effects due to air pollution in terms of monetary value proved to be extremely difficult. It is not feasible for this project to measure the monetary cost of one death due to air pollution, since it cannot be gauged what each person contributed to the GDP. Additionally, ethical considerations become blurry when a monetary value is assigned to a person's death, hence, published research on air pollution was used that approximated that the cost of health affects in terms of monetary value to Pakistan was 1.1% of its GDP. Therefore, it was assumed that with the changing GDP and population, this percentage remains same and the GDP cost reduced due to air pollution was gauged through this.

## The Model

To formulate the model, @Risk in Excel was used to estimate the number of deaths that can be prevented as well as the improvement in health parameters, by using DAC technology to capture carbon from the air, the cost of operating a DAC plant for a year, the amount of carbon that can be captured, and the impact of DAC technology on AQI.

### Define the input parameters

*Electricity requirement of the plants:*

| Pakistan Requirements: Electricity & Area | | | | | |
|---|---|---|---|---|---|
| 4000 | tonnes of CO2 | 0.42 Acre Area | 0.9 | Efficiency of ORCA | by Climeworks |
| 1000 | kW | 22.11 | Rs/kwh | industrial use | B3 customer |
| 2.2 | kW | 420 | Rs | fixed charge | |

The data has been compiled through the official website of the ORCA DAC. As it has been confined to a single-sized plant of 0.42 acres, the overall electricity requirement of all the plants will be the same. Electricity/Energy costs for Lahore Pakistan, from official government websites, were also used.

*Health data on air pollutants and related diseases*

| | Public Health Data | | | | | |
|---|---|---|---|---|---|---|
| | Parameter 1 | Parameter 2 | Parameter 3 | Parameter 4 | Parameter 5 | Parameter 6 |
| | Deaths | Respiratory infections | Trachea, bronchus, lung cancers | Ischaemic heart disease | Chronic Obstructive pulmonary disease | Blindness and vision loss |
| Number of Cases | 10907.4 | 29520 | 2631 | 80958 | 36205 | 64147.7414 |
| % change if AQI reduced | 0.07794329 | 0.0761862 | 0.041164702 | 0.054783757 | 0.003550147 | 0.0854101 |

This has been accumulated through several verified websites. Diseases that are caused by air pollutants and the number of cases in the past years 2016-2020 have been used.

*Air Quality Index (AQI) / Weather data*

| AQI, CO2, PM 2.5 and Health Correlations | | | |
|---|---|---|---|
| Deaths per 1000 | 0.98 | Correlation between PM 2.5 & CO2 | 0.4 |
| Change in AQI | 0.221061793 | Change in AQI | 1 |
| Overall change in health | 0.127495795 | Overall change in health | 0.576742787 |

This has been collected through verified websites. The data includes all the details of the weather, including humidity, wind speed, temperature, etc., for the year 2022 in Lahore. At the same time, the AQI $PM_{2.5}$ data has been compiled by the hour for 2022 in Lahore.

## Probability distributions for input parameter

Firstly, the DAC ORCA requirements were identified through their official website:

| Climeworks Orca machine Requirements | | | | |
|---|---|---|---|---|
| | | Lower limit | Upper limit | Unit |
| CO2 | Above 400 ppm | - | - | - |
| Temperature | 41°F and 86°F | 41 | 86 | F |
| Wind speed | between 1-3 m/s. | 0 | 31 | mph |
| Atmospheric pressure | 14.7 psi | 29 | 30 | in |
| Humidty | 10-90% | 10 | 90 | % |

*Atmospheric Pressure*

After that, the weather conditions data for Lahore was prepared. For the atmospheric pressure in the weather for each month, a uniform distribution with the minimum, most likely, and maximum values was chosen after distribution fitting and the best fit selected. Since atmospheric pressure tends to remain same throughout the year, the same formula was used for all months. **=RiskUniform(28.3,30)**

*Wind Speed*

Since the windspeed varied throughout the year, the Risk Exponential function has been used to better gauge the best-fit value of the wind speed for each month. Wind speed tended to vary across different months, therefore different formula was used for each month, but the distribution remained the same. **=RiskExpon(0.9,RiskShift(9) ,RiskStatic(9))**

*Temperature*

Since the temperature had a normal distribution, Risk normal was applied with the minimum, most likely, and maximum values for the deduction of the best-fit value. Temperature tended to vary across different months, therefore different formula was used for each month, but the distribution remained the same. **=RiskNormal(54.3,5.43,RiskStatic(54.3))**

*Humidity*

For the humidity variation in the temperature, we can use a triangular distribution with the minimum, most likely, and maximum values based on the available weather data. Humidity tended to vary across different months, therefore different formula was used for each month, but the distribution remained the same. **=RiskTriang(59.13,65.7,100)**

The probability distributions made it possible to gauge the practical efficiency levels of the machine after simulating the weather conditions in Lahore each month This encouraged more accurate and practical results to be generated.

## RISK Output parameters

*Amount of carbon captured by the DAC plant in a year*

After running simulation, the number of tones that the plant is able to capture throughout the year can be deduced. Several input parameters need to be considered, which include pressure, windspeed, temperature, humidity, and overall efficiency, which change throughout the year according to the former parameters mentioned. Therefore, this becomes a RISK output.

*Public Health improvement by using DAC technology*

After running the simulation, the effect of carbon reduction in the atmosphere is linked with the effect on the AQI and $PM_{2.5}$, which are directly related to the pollutants causing those diseases. Hence the number of deaths along with the number of diseases that will be reduced was predicted. All these health parameters were also part of the RISK output.

## Other Output parameters

*Change in AQI due to DAC technology*

$CO_2$ directly cannot affect AQI and is not a pollutant. In calculating AQI, $CO_2$ is not taken into consideration directly. To gauge the effect of $CO_2$ on the atmosphere and the diseases, regression was run, and a correlation significance value was found between $PM_{2.5}$ (a pollutant that directly affects the AQI) with $CO_2$. Hence using the correlation significance value, the change in AQI was calculated.

*The total cost of operating the DAC plant for a year*

To calculate the total cost of operating the DAC plant for a year, the company states the running cost as dependent on the tones of $CO_2$ removed, plus the power consumption. After collecting the per kWh cost of electricity, the operational cost for the plant throughout the year was calculated, therefore, the cost of improving health parameters was also calculated, for example, how much it costs to save one life.

# Results & Analysis

## Output

*<u>Total CO2 Removed</u>*

| | Simulation T | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 20 | 40 | 60 | 80 | 100 |
| CO2 removed | Total CO2 removed | Energy consumed | Cost | Initial AQI | Average yearly AQI | AQI reduction |
| Unit/Year | /Year | kWh | PKR | US AQI Index | US AQI Index | US AQI Index |
| 3419.257004 | 3419.257004 | 3419257.004 | Rs 75,610,860.36 | 172.0339902 | 188.4761824 | 0.040871952 |

Output Cell

The output in this cell depicts the total CO2 removed using Climeworks orca machine after incorporating the impact of pressure, wind speed, humdity percentage, and temperature on the efficiency of machine.

Formula = CO2 removed per unit per year multiplied by the values in simtable that shows the units of climeworks orca machine.

For instance, 3419.257004 total tons of CO2 will be removed for one plant in one year.

*<u>Improvement in Public Health</u>*

| | Public Health Data | | | | | |
|---|---|---|---|---|---|---|
| | Parameter 1 | Parameter 2 | Parameter 3 | Parameter 4 | Parameter 5 | Parameter 6 |
| | Deaths | Respiratory infections | Trachea, bronchus, lung cancers | Ischaemic heart disease | Chronic Obstructive pulmonary disease | Blindness and vision loss |
| Number of Cases | 10907.4 | 29520 | 2631 | 80958 | 36205 | 64147.7414 |
| % change if AQI reduced | 0.07794329 | 0.0761862 | 0.041164702 | 0.054783757 | 0.003550147 | 0.0854101 |

| Improvement in Public Health (in terms of reduction in cases) | | | | | |
|---|---|---|---|---|---|
| Parameter 1 | Parameter 2 | Parameter 3 | Parameter 4 | Parameter 5 | Parameter 6 |
| # | # | # | # | # | # |
| 0.184360926 | 0.4877099 | 0.023486307 | 0.961790506 | 0.027873002 | 1.188117808 |
| % | % | % | % | % | % |
| 0.001690% | 0.001652% | 0.000893% | 0.001188% | 0.000077% | 0.001852% |

In terms of, Deaths reduced, respiratory infections, asthma reduced, Trachea, bronchus and lung cancer reduced, Ischaemic heart disease reduced, Chronic Obstructuve pulmonary diseases reduced, and Blindness and vision loss reduced.

Parameter 1 (Deaths Reduced) cell formula = RiskOutput ("Deaths reduced")+AQI% reduction*Number of cases of death*percentage change in death if AQI is reduced.

This cell depicts the decrease in number of deaths if the calculated AQI percentage is reduced. To calculate this, the Percentage reduction AQI after removing CO2 is multiplied by the number of cases of death multiplied by the percentage change in number of deaths if AQI is reduced by 1%. Similarly relevant cells are selected to apply the same formula to identify the decreases in respiratory infections, asthma reduced, Trachea, bronchus and lung cancer reduced, Ischaemic heart disease reduced, Chronic Obstructive pulmonary diseases reduced, and Blindness and vision loss reduced.

## Other Important Outputs

*AQI Reduction*

| Average yearly AQI | AQI reduction | AQI % reduction |
|---|---|---|
| US AQI Index | US AQI Index | % |
| 210.44979 | 0.046256838 | 0.0002198 |

This cell calculates the reduction in average yearly AQI achieved. It multiplies the correlation coefficient with the total tons of $CO_2$ removed and divides by the total tons of $CO_2$ emitted annually.

*Improvement in Public Health & Resultant Savings*

| Cost of Air pollution | Improvement in public health | Monetary savings in public health |
|---|---|---|
| PKR | % | PKR |
| Rs 456,619,218,000.00 | 0.01% | Rs 34,027,517.01 |

The cost of air pollution is calculated through GDP & percentage monetary loss due to air pollution. Improvement in Public health is calculated by the sum of the percentage reduction in the 6 parameters of public health. Savings in public health is calculated by multiplying both.

*Operating Cost of the Plant for 1 year*

| Energy consumed | Cost |
|---|---|
| kWh | PKR |
| 3527983.585 | Rs 78,014,805.06 |

The operating cost of the plant for 1 year is calculated by multiplying kWh consumed per ton of $CO_2$ removed with the cost of 1 unit of kWh and adding power consumption and its cost. Therefore, it is observed that to remove 3419 tons of $CO_2$ a year, it costs approximately Rs. 78,014,805.

# Analysis

In all instances after running @Risk for 11 simulations, the decrease in AQI casued the reduction in blindness and vision loss to be the highest. After blindness and vision loss, reduction in Ischaemic heart disease is the greatest. Thus, results shows that number of people with blindness and vision loss will be significantly reduced. The following order lists the health diseases in ascedning order with the highest reduction in cases.

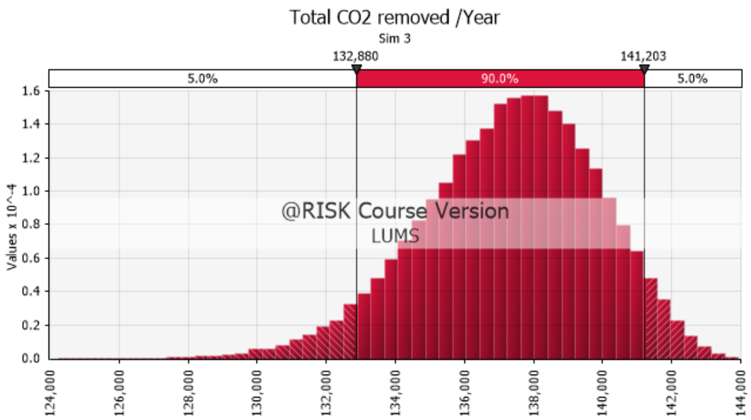
1. Blindness and Vision losses
2. Ischaemic heart disease
3. Respiratory infections, asthma
4. Deaths
5. Chronic Obstructive pulmonary diseases
6. Trachea, bronchus, and lung cancer

| | | |
|---|---|---|
| 1 machine | Rs 74,707,299.42 | Rs 410,124,835.43 |
| death reduced | 0.182157463 | 1 |

These cells depict; in order to reduce the number of deaths by 1, approximately, Rs 410 million would need to be invested in the ORCA machine. Though, the cost of reducing one death is very high, ethical and humanity considerations strongly asserts that human life does not have a cost associated with it. The indirect benefit that reduction in CO2 and eventually reducing even one case of death are enormous in long-term economic growth. High mortality rate has a negative effect on GDP per capita. According to bounding strategy the effect of reducing mortality by 10% is increasing the GDP per capita by 9.6 percnetage points over a period of 25 years (Rosen, 2012). Though, the initial cost of planting the climeworks orca machine is high, the benefits that it will yield are higher in the long-term.

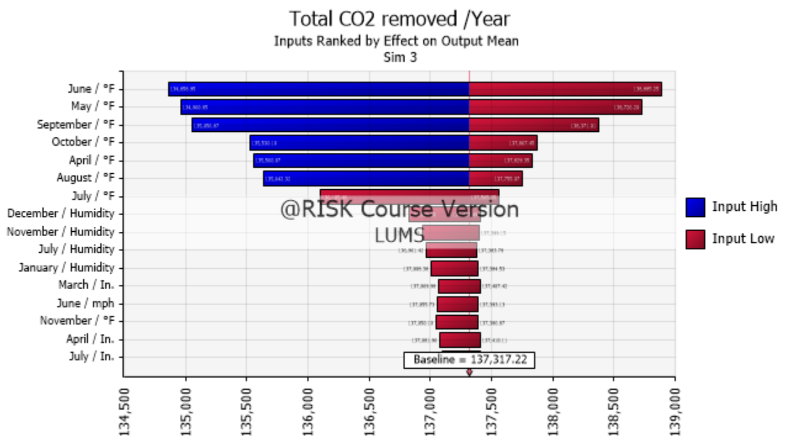
## Graph Output Report

The following graphs are for simulation 3 with 40 units of machines.

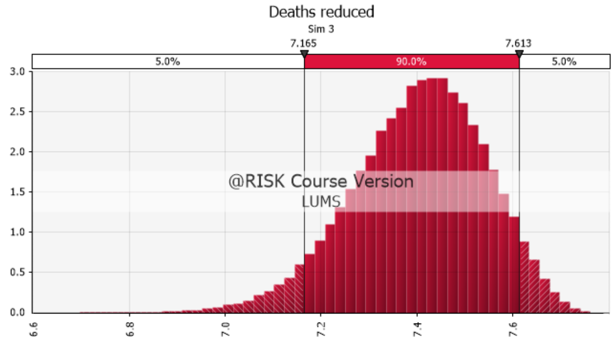



This graph depicts that with 40 units of machines there is a 90% chance that 132,800 to 141,203 tons of $CO_2$ will be removed per year.

Tornado Diagram

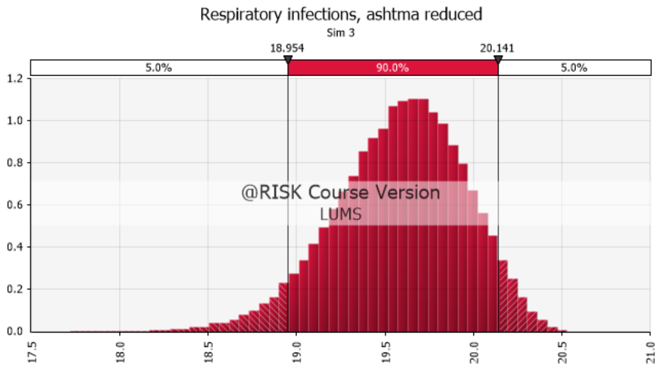


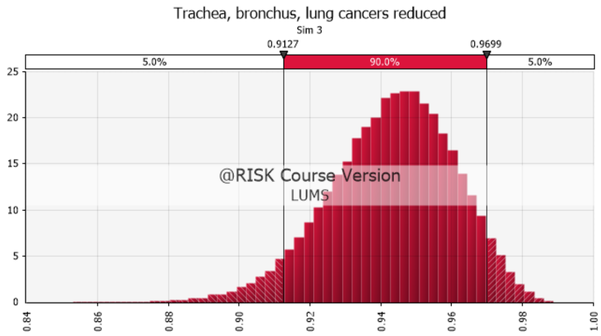

This shows that in, June, May, September, October, April, August and July the variance in tons of $CO_2$ removed is high as the temperatures are high in these months consequently, affecting efficiency. However, in the winter season months, December, November and January, the variance in $CO_2$ removed is low since temperatures are low and humidity high which does not significantly impact the efficiency. Similar effect of summer and winter months are depicted in the tornado diagrams of all other health parameters.




This graph depicts the cases of deaths reduced as a result of installing 40 units. There is a 90% chance that 7.165 to 7.613 people will be saved.

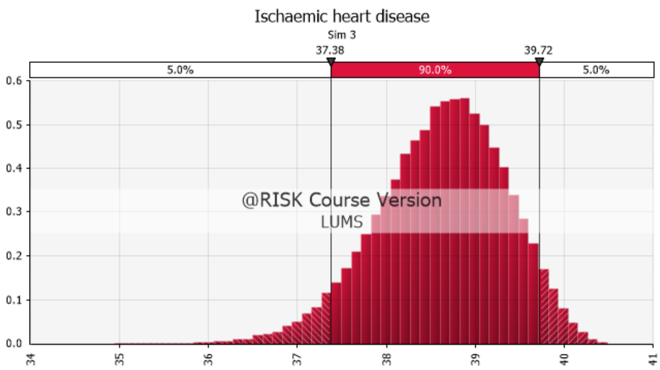
This graph depicts the cases of Respiratory infections and asthma reduced as a result of installing 40 units. There is a 90% chance that the number of people having respiratory and asthma infections will be reduced by 18.954 to 20.141 cases.

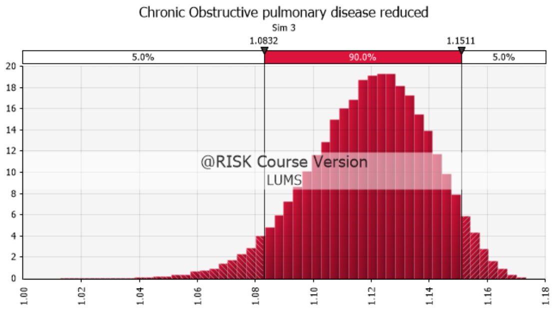



This graph depicts the cases of Trachea, bronchus, lung cancers reduced if 40 units are installed. There is a 90% chance that the number of people having Trachea, bronchus, lung cancers will be reduced by 0.9127 to 0.9699 cases

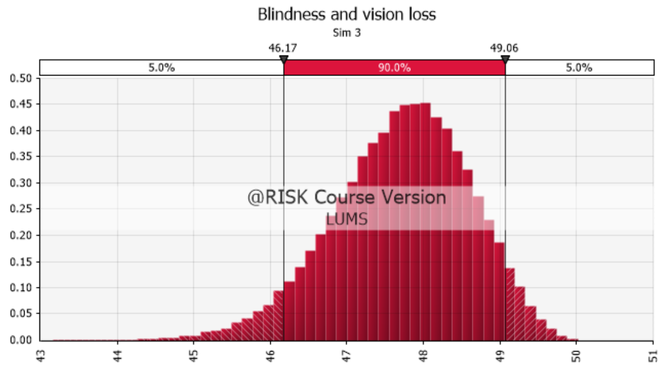
This graph depicts the cases of Ischaemic heart disease reduced if 40 units are installed. There is a 90% chance that the number of people having Ischaemic heart disease will be reduced by 37.38 to 39.27 cases.






This graph depicts the cases of Chronic Obstructive pulmonary disease reduced if 40 units are installed. There is a 90% chance that the number of people having Chronic Obstructive pulmonary disease will be reduced by 1.0832 to 1.511 cases.

This graph depicts the cases of Blindness and Vision loss reduced if 40 units are installed. There is a 90% chance that the number of people having Blindness and Vision loss will be reduced by 46.17 to 49.06 cases.




Summary Statistics

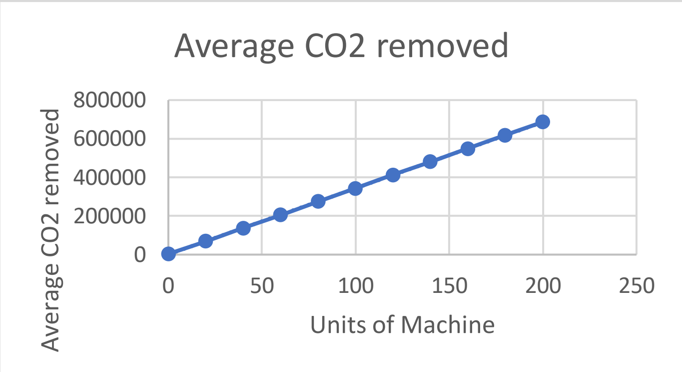
| Output Cell | Minimum | Maximum | Mean | Std Dev | 5% | 95% |
|---|---|---|---|---|---|---|
| Total CO2 removed /Year | 124,226.71 | 143,939.82 | 137,317.22 | 2,538.20 | 132,880.34 | 141,202.89 |
| Parameter 1 reduced | 6.69811 | 7.76101 | 7.40393 | 0.13686 | 7.16470 | 7.61344 |
| Parameter 2 reduced | 17.7192 | 20.5310 | 19.5864 | 0.3620 | 18.9535 | 20.1406 |
| Parameter 3 reduced | 0.853293 | 0.988699 | 0.943209 | 0.017434 | 0.912733 | 0.969899 |
| Parameter 4 reduced | 34.9433 | 40.4883 | 38.6255 | 0.7140 | 37.3774 | 39.7185 |
| Parameter 5 reduced | 1.012668 | 1.173365 | 1.119379 | 0.020691 | 1.083210 | 1.151054 |
| Parameter 6 reduced | 43.1661 | 50.0160 | 47.7148 | 0.8820 | 46.1730 | 49.0649 |

- For 40 units of machines planted, the average amount of CO2 removed per year will be 143,939.82 tons, the respective minimum and maximum amount of CO2 removed per year will be 124,226.71 and 143,939.82. This tells us that at the least 124,000 tons of $CO_2$ will be removed each year.
- The average cases of deaths reduced will be 7.40393 with the minimum and maximum number of deaths respectively are 6.69811 and 7.7610.

- The average cases of respiratory and asthma infection cases reduced are 19.5864 with the minimum and maximum number of respiratory and asthma infection cases reduced are 17.7192 and 20.5310 respectively.
- The average cases of Trachea, bronchus, lung cancer cases reduced are 0.943209 with the minimum and maximum number of Trachea, bronchus, lung cancer cases reduced are 0.853293 and 0.988699 respectively.
- The average cases of ischemic heart disease cases reduced are 38.6255 with the minimum and maximum number of ischemic heart disease cases reduced are 34.9433and 40.4883 respectively.
- The average cases of Chronic Obstructive pulmonary disease cases reduced are 1.119379 with the minimum and maximum number of Chronic Obstructive pulmonary disease cases reduced are 1.012668 and 1.173365 respectively.
- The average cases of Blindness and Vision loss cases reduced are 47.7148 with the minimum and maximum number of Blindness and Vision loss cases reduced are 43.1661 and 50.0160 respectively.

<u>If 40 units (Simulation 3) of the ORCA are installed: -</u>

- There is a 100% probability that there will be minimum reduction of 6.870 cases of deaths.
- There is a 100% probability that there will be minimum reduction of 18.185 cases of Respiratory and asthma infections.
- There is a 100% probability that there will be minimum of 127,400 tons of CO2 will be removed.
- There is a 100% probability that there will be minimum reduction of 0.8760 cases of Trachea bronchus and lung cancer.
- There is a 100% probability that there will be minimum reduction of 1.0400 cases of Chronic Obstructive Pulmonary disease.
- There is a 100% probability that there will be minimum reduction of 35.85 cases of ischemic heart diseases.
- There is a 100% probability that there will be minimum reduction of 44.30 cases of blindness and vision loss.
- the above-mentioned statistics and graphs clearly show with increase of units of machines the amount of CO2 removed will increase and eventually the reduction in health diseases caused by pollution will increase.



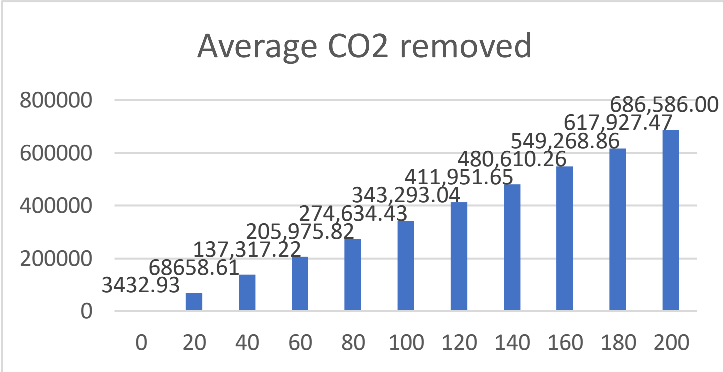




Figure 1 Figure 2

Figure 1 and 2 shows that as the number of units increases the amount of CO2 removed also increases. CO2 Removed with x as number of units = y = 3425.1x + 1092.3

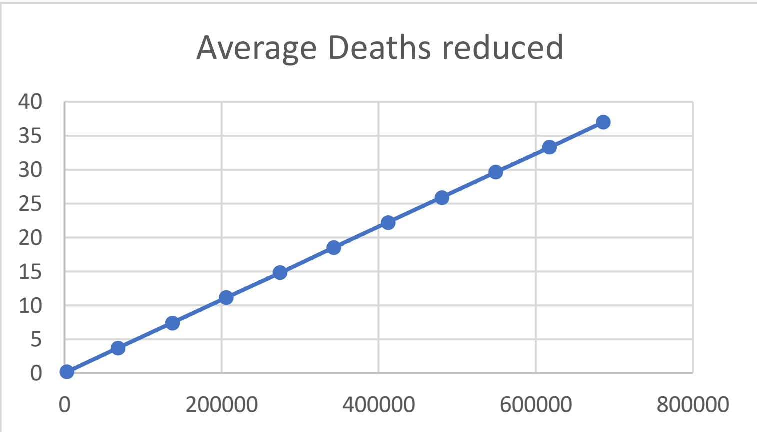



Figure 3

Average deaths reduced where x is the amount of CO2 removed = $y = 5E\text{-}05x^1$

These figures depict that as the amount of CO2 removed increases the improvement in public health increases with the same amount. The following equations will show the relevant reductions in cases where X is the amount of CO2 removed.

| | |
|---|---|
| Average deaths reduced: | $\underline{y = 5E\text{-}05x^1}$ |
| Average Respiratory and Asthma cases reduced: | $\underline{y = 4E\text{-}17x^2 + 0.0001x + 1E\text{-}06}$ |
| Average Trachea, Bronchus and Lung cancer cases reduced: | $\underline{y = 2E\text{-}17x^2 + 7E\text{-}06x + 4E\text{-}07}$ |
| Average ischemic heart diseases cases reduced: | $\underline{y = -5E\text{-}16x^2 + 0.0003x - 4E\text{-}05}$ |
| Average Chronic Pulmonary Disease cases reduced: | $\underline{y = -5E\text{-}17x^2 + 8E\text{-}06x - 1E\text{-}06}$ |
| Average Blindness and Vision Loss cases reduced: | $\underline{y = 2E\text{-}16x^2 + 0.0003x + 3E\text{-}05}$ |

This Model analyzed the feasibility of using Climeworks Orca machine to capture $CO_2$ from Lahore's air. It has become the need of the hour as the pollution levels reach *hazardous* every year in winters. Considering that the efficiency of $CO_2$ capture rate is highly dependent on external uncontrollable factors, this model considers all those factors. This model depicts that the Climeworks Orca Machines will successfully remove $CO_2$ and improve public health linked with pollution, after incorporating the effects of external factors in the efficiency of the machines. This strong correlation between average $CO_2$ removed and improvement in public health is depicted in Figure 1 – Figure 10 by the linear lines with constant rate of change for each health parameter.

## Recommendations

Based on the dynamic research conducted and varying situations analyzed, investment in DAC technology seems imperative for Pakistan. The Climework Orca Machine has shown promising results. Since the technology is new, Lahore can become an example for the country as well as the global community on how it used the rising technology to curb the threat of climate change. The results have served to be consequential for the betterment of health in highly polluted areas such as Lahore. With just 40 units, approximately 7.3 lives can be saved, around 37 cases of heart disease can be curbed, around 20 cases of asthma can be avoided, and chronic illnesses like lung cancer can be made less probable. Pakistan also enjoys ample space for the installation of these plants making Lahore an optimal location. The technology has high scalability and does not require any complex inputs. While the objective is to remove CO2 from the atmosphere, the plant also promises many unmeasurable benefits, such as the protection of the ozone layer. This, too, directly impacts health positively as eye diseases and cataract cases drastically go down. The DAC plant, due to its effectiveness, is a far greater tool for carbon removal compared to afforestation. Consequently, Pakistan will be able to achieve the United Nations Sustainable Development Goal 7 at a faster rate compared to countries that are slow to adopt the technology. While the cost may come as a challenge, it can not be ignored that such success will make Pakistan eligible for receiving foreign aid for the respective cause. More importantly, the hidden and unmeasured positive impacts on the GDP through the preservation of life and health serve to justify the cost. Ultimately Pakistan stands in a position where one technology can help improve a spectrum of issues. The promise for this technology to grow comes with an equal promise for conditions in Pakistan to improve as a consequence.

# Limitations

While the results derived are promising and can prove to be consequential for the future of DAC deployment, the research team surely faces some limitations. First of all, the project is highly focused on developing a model that can be used with varying data to reach an accurate result. Emphasis on the accuracy of the data has been relatively less and thus the current data set may not produce an outcome of the highest degree of accuracy. Additionally, the DAC technology is new, and thus data for it is less reliable and subject to the varying conditions the DAC has operated in. Data on its website is a bold exaggeration as such results can only be achieved in perfectly suitable conditions, which is not the case when it comes to implementation. The technology is also very new and thus has not reached maximum efficiency. This makes updates in design and functionality a common feature. Consequently, this model only helps generate results based on the current technology available. It is not flexible to major changes and will need to be calibrated accordingly. Lastly, many assumptions in data collection were made, as previously discussed. The cost of a life, the relation between CO2 and PM2.5, and the weather conditions' effect on efficiency are all subject to error, which of course, will result in minor inaccuracies. With that said, the percentage error can be reduced drastically with greater investments by the government in the collection of relevant data. The model, if coupled with accurate data, guarantees a highly conclusive recommendation.

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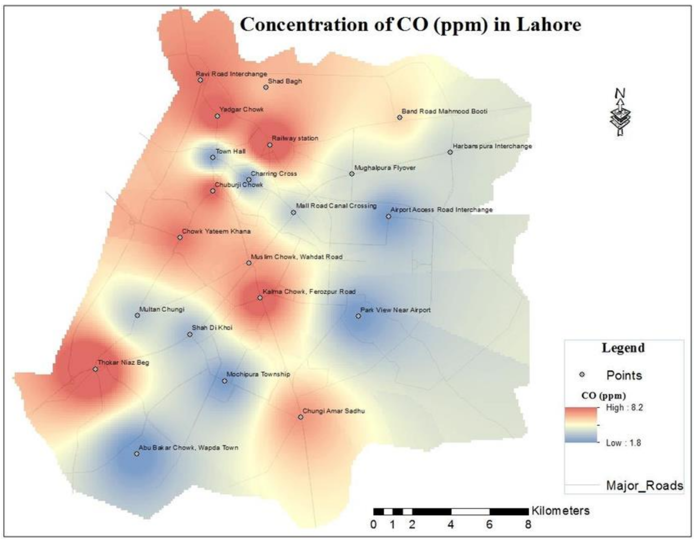
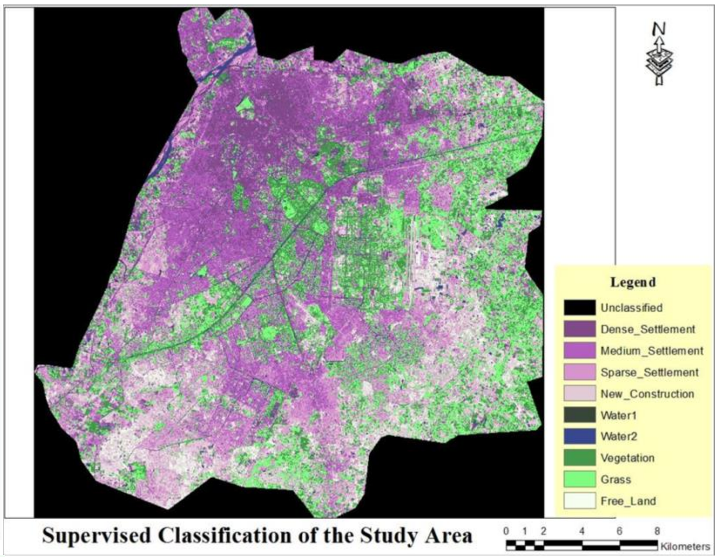
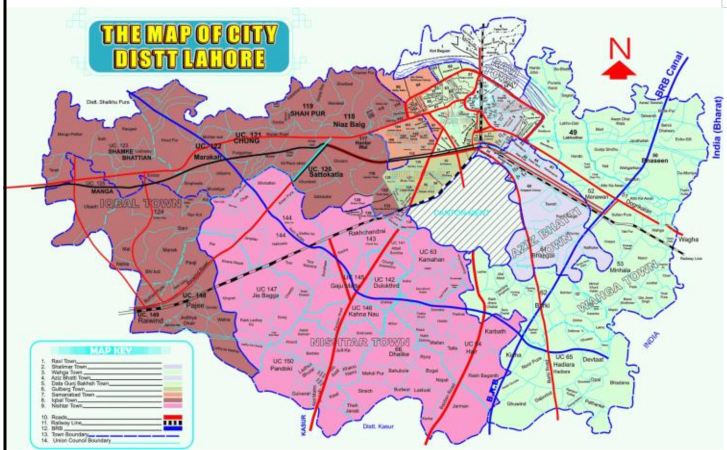
# Appendix

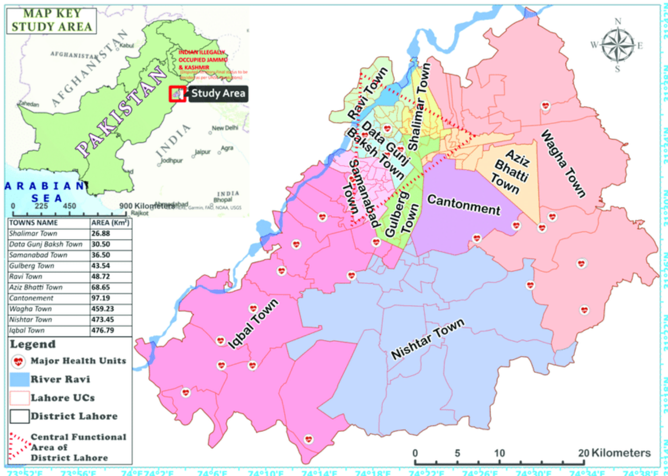
## Link to Video presentation, all Resources & Data

https://pern-my.sharepoint.com/personal/24110167_lums_edu_pk/_layouts/15/onedrive.aspx?ga=1&id=%2Fpersonal%2F24110167%5Flums%5Fedu%5Fpk%2FDocuments%2FGroup%2011%5FDISC%20321

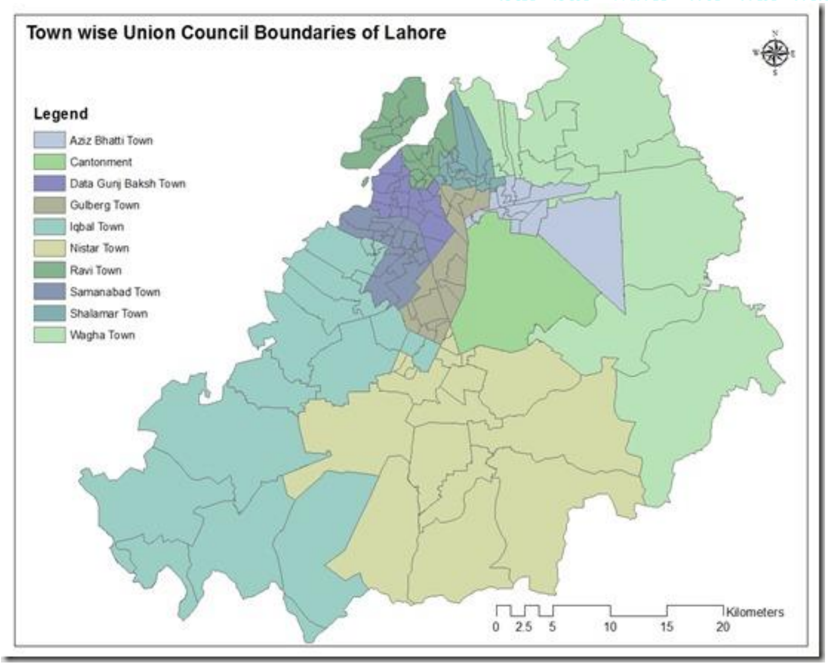



| TOWNS NAME | AREA (Km²) |
|---|---|
| Shalimar Town | 26.88 |
| Data Gunj Baksh Town | 30.50 |
| Samanabad Town | 36.50 |
| Gulberg Town | 43.54 |
| Ravi Town | 48.72 |
| Aziz Bhatti Town | 68.65 |
| Cantonment | 97.19 |
| Wagha Town | 459.23 |
| Nishtar Town | 473.45 |
| Iqbal Town | 476.79 |



Simple Linear regression | Multiple Linear regression | Logistic regression | Multinomial logistic regression

| X | Y | Ŷ (Predicted Y) | Residual |
|---|---|---|---|
| | 416.1 | | |
| 20 | 416.09 | 413.2494 | -3.3294 |
| 9 | 417.54 | 413.2494 | -3.2294 |
| 14 | 416.94 | 413.1539 | -2.9639 |
| 25 | 416.46 | 412.7721 | -2.5521 |
| 21 | 416.16 | 413.4403 | -4.2003 |
| 16 | 416.4 | 413.7266 | -2.058 |
| 24 | 416.33 | 413.6311 | -2.4411 |
| 18 | 416.3 | 413.3448 | -2.4248 |
| 23 | 416.14 | 413.4403 | -2.6203 |
| 17 | 416.33 | 412.8676 | -3.7676 |
| 13 | 416.51 | 413.2494 | -3.7594 |
| 13 | 416.67 | 413.2494 | 0.4106 |
| 17 | 417.86 | 412.7721 | -1.0482 |
| 21 | 417.98 | 412.4858 | -0.7572 |
| 24 | 418.3 | 412.7721 | -3.4921 |
| 20 | 418.23 | 412.8676 | -1.129 |

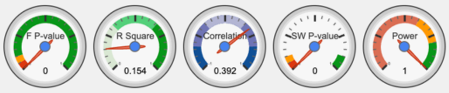
X values for prediction: (You may leave empty)

x

Right click on: Save image, (please use 'save link as...' or 'open link in new tab').

### Prediction

## Interpretation of the results




### Regression ANOVA

Hover over the cells to see the formulas.

| Source | DF | Sum of Square | Mean Square | F Statistic ($df_1$,$df_2$) | P-value |
|---|---|---|---|---|---|
| **Regression** (between $\hat{y}_i$ and $\bar{y}$ ) | 1 | 1244.8695 | 1244.8695 | 197.3771 (1,1087) | 0 |
| **Residual** (between $y_i$ and $\hat{y}_i$) | 1087 | 6855.7748 | 6.3071 | | |
| **Total** (between $y_i$ and $\bar{y}$) | 1088 | 8100.6443 | 7.4454 | | |

### 1. Y and X relationship

R-Squared ($R^2$) equals **0.1537**. This means that 15.4% of the variability of Y is explained by X.
Correlation (R) equals **0.392**. This means that there is a **weak direct relationship** between X and Y.
The slope: $b_1$=**0.09545** CI[0.08212, 0.1088] means that when you increase X by 1, the value of Y increases by 0.09545.
The y-intercept: $b_0$=**412.0086** CI[411.6795, 412.3377] means that when X equals 0, the prediction of Y's value is 412.0086.
The x-intercept equals -4316.6413.

Less options ▲

Line fit title: Line Fit Plot
Y | Estimated-Y | Predicted-Y

Significance level (α): 0.05
Effect: Medium
Effect type: f
Effect size: 0.39
k (residual outliers): 3
Digits: 4

**Constant is zero** , force zero Y-intercept, $b_0$=0.
**Trend Line**, Line fit plot.
Step by step

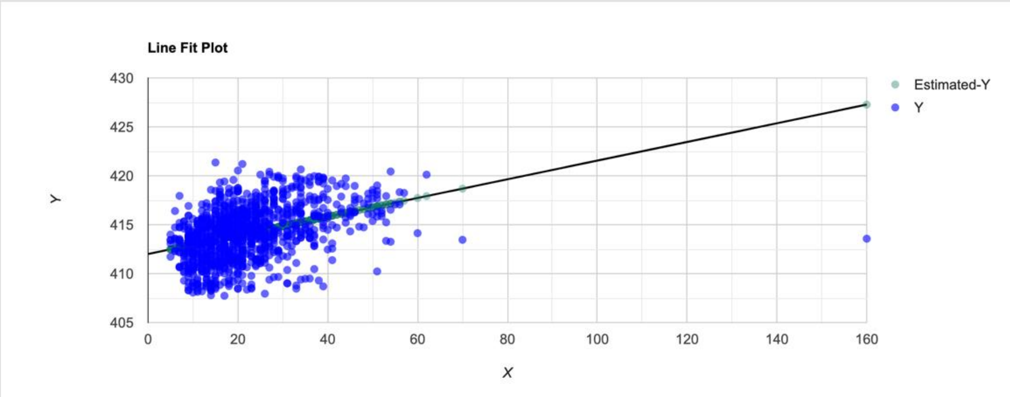
### Regression line equation

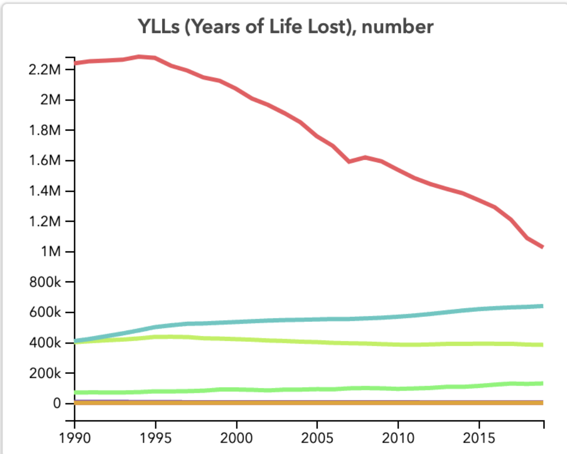
$$\hat{Y} = 412.0086 + 0.09545X$$

### Reporting linear regression in APA style

X predicted Y, $R^2 = .15$, $F(1,1087) = 197.38$, $p < .001$.
$\beta = .095$, $p < .001$, $\alpha = 412.01$, $p < .001$.

### Line Fit Plot




**Legend**

- Punjab, Both sexes, All ages, Sudden infant death syndrome, risk: Air pollution
- Punjab, Both sexes, All ages, Otitis media, risk: Air pollution
- Punjab, Both sexes, All ages, Lower respiratory infections, risk: Air pollution
- Punjab, Both sexes, All ages, Upper respiratory infections, risk: Air pollution
- Punjab, Both sexes, All ages, Chronic obstructive pulmonary disease, risk: Air pollution
- Punjab, Both sexes, All ages, Chronic obstructive pulmonary disease, risk: Ambient ozone pollution
- Punjab, Both sexes, All ages, Stroke, risk: Air pollution
- Punjab, Both sexes, All ages, Blindness and vision loss, risk: Air pollution

GBD Results

Visualizations ? Help

## Results

Table Charts About Sign out

Risk factor

| Measure | Metric | Risk | Cause | Location | Age | Sex | Year | Value | Upper | Lower |
|---|---|---|---|---|---|---|---|---|---|---|
| Deaths | Rate | Air pollu... | All causes | Punjab | All ages | Both sexes | 2018 | 115.53 | 139.14 | 95.61 |

1 100 / page

GBD Results

Visualizations ? Help

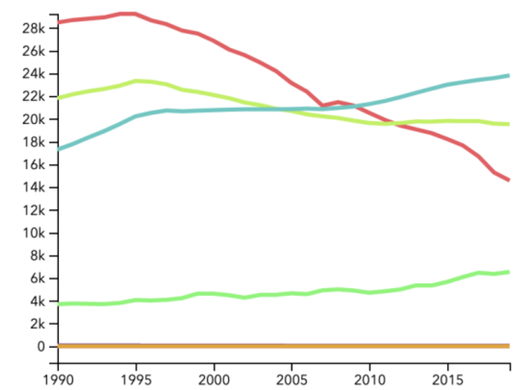
## Results

Table Charts About Sign out

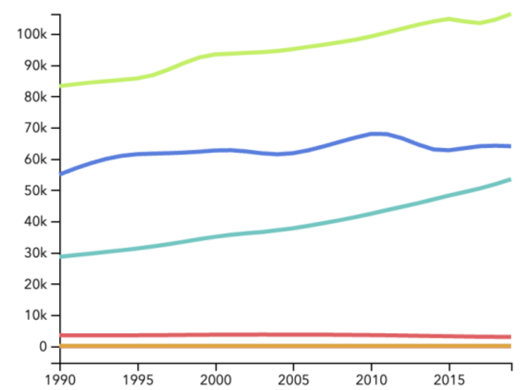
Risk factor

| Measure | Metric | Risk | Cause | Location | Age | Sex | Year | Value | Upper | Lower |
|---|---|---|---|---|---|---|---|---|---|---|
| Deaths | Rate | Air pollu... | All causes | Punjab | All ages | Both sexes | 2019 | 113.32 | 136.14 | 92.91 |

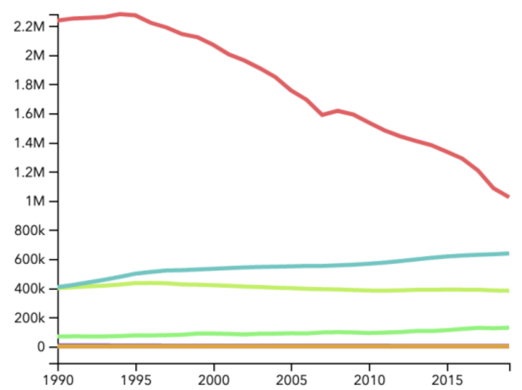
1 100 / page



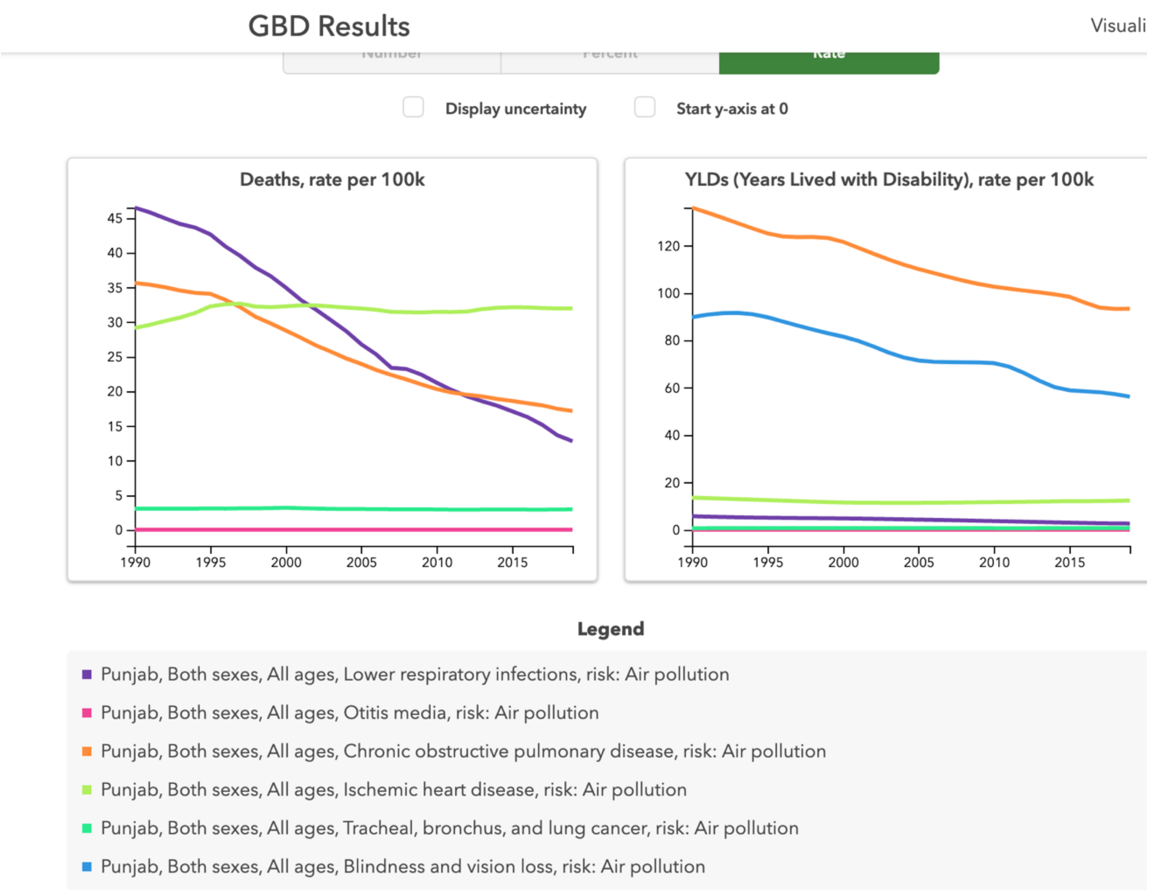

Deaths, number




YLDs (Years Lived with Disability), number




YLLs (Years of Life Lost), number


GBD Results
Visuali
Number
Percent
Rate
Display uncertainty
Start y-axis at 0
Deaths, rate per 100k
0
5
10
15
20
25
30
35
40
45
1990
1995
2000
2005
2010
2015
YLDs (Years Lived with Disability), rate per 100k
0
20
40
60
80
100
120
1990
1995
2000
2005
2010
2015
Legend
Punjab, Both sexes, All ages, Lower respiratory infections, risk: Air pollution
Punjab, Both sexes, All ages, Otitis media, risk: Air pollution
Punjab, Both sexes, All ages, Chronic obstructive pulmonary disease, risk: Air pollution
Punjab, Both sexes, All ages, Ischemic heart disease, risk: Air pollution
Punjab, Both sexes, All ages, Tracheal, bronchus, and lung cancer, risk: Air pollution
Punjab, Both sexes, All ages, Blindness and vision loss, risk: Air pollution