

Teaching Notes for Lesson One:

How does air quality vary across London and how might we manage it?

Starter Activities:

The **1952 Great Smog** in London is said to be the worst bout of visible air pollution London has ever seen. Occurring for five days in December that year, a very thick layer of smog fell over the city, reducing visibility down to just a few metres, even in the middle of the day. This created the moniker 'pea-souper', derived from the greenish colour of the fog as well as its thickness. Public transport was unable to run as driving was almost impossible (Figures 1 and 2) and the smog even found its way into theatres and pubs, confining many people to their own homes. Sports fixtures were cancelled and ambulance and fire services were seriously compromised. The lack of traffic movement on the streets of London actually served to prolong the effects as the fog remained close to ground level undisturbed for far longer than would normally be the case.



Figure 1 Trafalgar Square in 1919 Smog days in London have been a common problem since the introduction of coal fired power production in the city in 1891. (Source: Flickr Creative Commons User Leonard Bentley)

This smog event was not completely caused by the emission of pollution from domestic coal burning in people's homes, but rather this combined with cold, windless, anticyclonic weather. This meant that a layer of cold, still air became trapped under a



Figure 2 A policeman directing traffic in 1953 Despite face masks, there was little to protect pedestrians and those working in the smog from the dangerous emissions. (Source: Flickr Creative Commons User Leonard Bentley)

higher layer of warm air over the city (known as a temperature inversion) and the pollution was unable to move above the city streets as it normally would on warm air currents. While the cold weather meant people were burning more coal in their homes, the nature of the coal itself created more dangerous emissions. Low grade coal, which tended to be burnt domestically, had a higher sulphur content, increasing the amount of sulphur dioxide created when combusted. Coal fired power plants at Bankside (what is now the Tate Modern art gallery) and Battersea also contributed to the high concentrations of sulphur dioxide and particulates in the London air. July that year had signalled the last running of a London tram, and their subsequent replacement by diesel powered buses might also be seen as a contributing

factor to the Great Smog.

As well as high levels of inconvenience for Londoners, the smog was also extremely dangerous. In the weeks following the smog event at least four thousand people are thought to have died prematurely as a result of respiratory problems, though more modern analyses believe treble this number were affected in this way. Few people in Inner London escaped without some form of ill health effect despite many people wearing 'smog masks'. Common problems included infections of the respiratory tract and a clogging of the lungs with black mucus (pneumoconiosis, or 'miner's lung') (Figure 3).

The Great Smog became a catalyst for change in air quality policy, most notably the introduction of the Clean Air Act in 1956 which saw restrictions on the amount of

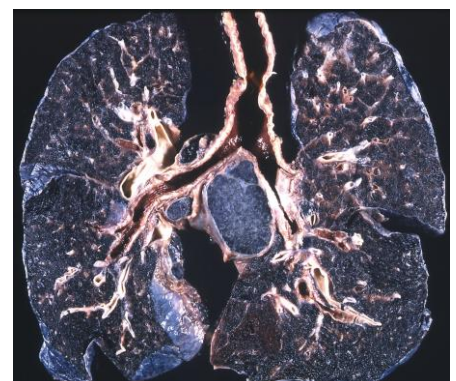


Figure 3 A cross section of lungs with fatal pneumoconiosis Some Londoners who died as a result of the 1952 smog were found to have the symptoms of the disease. (Source: Flickr Creative Commons User Yale Rosen)

coal burning allowed to power industry and the relocation of power stations away from the centre of UK cities. Financial incentives were given to home owners to encourage them to convert to gas fired heating and politicians became more proactive in funding research into the links between air quality and public health.

More recent hazes over the city are seemingly not as severe as the 1952 smog but their long term impacts are not yet known. Frequently seen in April and September, these smog days are characterised by a yellow or brown hazy fog sitting low over the city (Figure 4) which generally fails to disperse by the afternoon. These days have grown in frequency since 2000 and are now a common biannual event. Visibility is reduced a little but few Londoners notice the effects visually, while those who jog or cycle through the city are most likely to experience discomforts in breathing. These pollution events are usually caused by a slight shift in the flow direction of the tropical continental air mass which rolls off the Sahara. By blowing more intensely and more northerly than usual before heading west towards the UK, the air mass picks up pollution from across most of western Europe before descending on London, distributing high concentrations of Saharan dust as well as pollutants such as nitrous oxides and particulates over the city. The ‘home-grown’ pollution, from diesel engines and industrial power generation only adds to this concentrated chemical soup and the effect is one of pollutants seen to be literally ‘hanging’ in the air.



Figure 4 Haze over Docklands, London From the right height, the haze seen over London appears like a bubble, encompassing the city. (Source: Flickr Creative Commons User Bahi)

In the April 2013 event, the London Ambulance Service saw a fourteen percent increase in the number of calls it received where callers were experiencing breathing difficulties as well as significant rises in the number of people admitted with chronic shortness of breath such as in the experience of an asthma attack.

The ‘**Big Five**’ of modern air pollution are those pollutants which not only appear in the highest concentrations in developed cities but also those that cause the most damage to humans and the environment.

Nitrogen Oxides (NO_x) are produced when nitrogen (N) and oxygen (O₂) react together in high temperatures in an endothermic reaction during the combustion process to produce either nitric oxide (NO) or nitrogen dioxide (NO₂) as well as naturally through processes such as lightning strikes. That combustion engine was until recently found in motor vehicles but with the standardised installation of the catalytic convertor in vehicles, nitrogen oxides are now primarily released from the combustion process in fossil fuel based power plants. Coal has an especially high nitrogen content and coal fired power stations are a major contributor to air pollution globally.



Figure 6 Acid rain damaged statue The definition of this statue has been lost as mildly acidic rain has worn down the features. (Source: Flickr Creative Commons User mafleen)

Nitrogen oxides are a key component of photochemical smog. Breathing this in can cause health complications, especially in children, the elderly and those with respiratory conditions such as asthma. Long term exposure can result in tissue damage in the lungs as nitric acid vapour is formed inside them, and ultimately premature death as well as the development of emphysema and bronchitis. When nitric oxide reacts with smog and water vapour in the air, acid rain can form which is harmful to buildings (Figure 6) and natural features such as lakes and river courses.



Figure 7 A milkweed leaf with ozone damage The black spots here represent damage to chloroplasts as a result of ozone exposure. (Source: Flickr Creative Commons User Wisconsin Department of Natural Resources)

Ozone (O₃) is an unstable form of oxygen gas that one would normally associate with the filtering of the Sun's UV rays in the Earth's stratosphere but is a highly damaging pollutant at ground level. It is slightly blue in colour and has a mild, chlorine like smell, but even on days when higher than average concentrations have been recorded, most people would not notice it on a city street. Unlike many of the other pollutants, it is not formed directly as a result of the combustion process. Instead, ozone is formed by the reaction of sunlight on nitrogen oxides and so is a secondary pollutant from the combustion process. Ozone also reacts with sulphur dioxide in water vapour to create sulphuric acid which can damage the built and natural environment through acid rain.

Ozone causes long term damage to the mucus producing tissue in respiratory systems. It leads to premature deaths and increases one's chances of having a heart attack as well as developing numerous other cardiopulmonary problems. Exposure can also produce headaches, burning eyes and irritation in breathing. Environmentally, ozone will oxidise most metallic components, often weakening them in the process. It also damages leaf formation (Figure 7) and the potential for harm to crops and their yields is significant.

Sulphur dioxide (SO₂) is a highly toxic and colourless gas. It has a distinctive smell that resembles that of rotten eggs and is easily detectable in modest quantities. Though it is released naturally through volcanic eruptions (Figure 8), in millions of tonnes, these eruptions send the gases high up into the atmosphere. At ground level it is mostly produced through the combustion of sulphur in an elemental form: the form in which it is found naturally in fossil fuels. More recently, sulphur has been removed from the combustion process either by removing it from the fuel (in the case of petrol and diesel) or passing emissions over limestone beds to remove it from the waste gases.



Figure 8 Sulphur dioxide emissions from the Halemaumau vent, Hawaii The active vent is releasing sulphur dioxide almost constantly. (Source: Flickr Creative Commons User Tumanc)

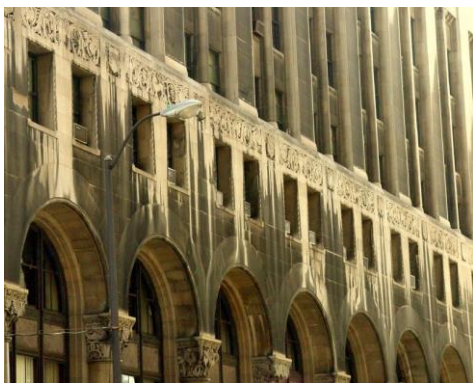


Figure 9 A soot covered building Soot and carbon build up on the outside of buildings is a clear indicator of particulate matter in the atmosphere. (Source: Flickr Creative Commons User Chris)

The inhalation of sulphur dioxide causes increased difficulty in breathing and there is growing evidence of its association with premature births in mothers exposed to the gas. It can irritate and narrow the linings of airways, reducing the flow of air to lungs and increasing one's chances of an asthma attack. Sulphur dioxide is also a major player in the formation of acid rain and its damage to old buildings across Europe is well documented.

Particulate Matter (PM) is a collection of minute, dust-like particles held up in the air which can be man-made (such as ash) or naturally occurring (such as pollen). In terms of air quality, particulate matter is measured in two forms: PM₁₀ (particles with a diameter of ten microns or less) and PM_{2.5} (particles with a diameter of 2.5 microns

or less). A human hair is sixty microns in diameter so most particulates are invisible to the human eye. Particulate matter can contain a variety of elements. Carbon dust (soot) from combustion is the most common constituent

(Figure 9) while larger particles such as ash and cement dust are equally damaging. While some particulate matter comes from natural sources, such as volcanic eruptions and wildfires, the burning of fossil fuels in combustion engines and in power plants has caused a significant increase in their levels.

The smaller the particle, the longer it is likely to stay in the air, with the force of gravity acting on the heavier particles straight away. Rainfall 'washes' most particulates out of the air but in the UK summer, when less rainfall occurs, PM_{2.5} can stay in the troposphere for weeks at the level of emission. The particulate matter has a deep felt impact on human health and causes substantial environmental damage too. The World Health Organisation has designated particulate matter as a group one carcinogen, due to its ability to be held deep in the lungs and blood streams of those who breathe it in. While the largest particles are filtered out by cilia in the nose and throat, smaller particles such as PM₁₀ actually settle in the lungs, while the smaller PM_{2.5} can form part of gaseous exchange in the blood stream. Heart attacks, cancers and DNA mutations have been attributed to particulate matter as well as increased incidence and severity of asthma. Premature births and birth defects have also been linked to poor air quality, much in the same way as smoking while pregnant has been proven to do the same.

Environmentally, particulate matter can change the albedo effect on radiation, scattering energy and absorbing sunlight in unnatural ways. Depending on the nature of the underlying surface, this can increase or decrease the amount of radiation at ground levels, raising or lowering temperatures too. A more predictable effect is that on clouds and precipitation: by increasing cloud condensation nuclei, particulate matter increases the density of the water droplets in clouds but also reduces their individual size (Figure 10). This makes rain less likely and prolongs the life of clouds, which in turn affects the levels of radiation that can penetrate to ground level.



Figure 10 Thick cloud cover Increased particulates in the atmosphere increase cloud thickness through higher rates of condensation but this does not always lead to higher rainfall values. (Source: Flickr Creative Commons User Simon Haslett)

While industry does employ filters, separators and wet scrubber mechanisms to remove the particulates, the emissions from diesel engines in vehicles remain difficult to 'clean'.

Main Teaching:



Figure 11 Traffic congestion on the A4 Arterial roads are key to moving vehicles around the capital, and are susceptible to high pollution levels too. (Source: Flickr Creative Commons User nikoretro)

If one were to **plot a pollution map of London**, one might expect to see the lowest air quality centred in the CBD and along the major transport routes. Despite the efforts of the Congestion Charge Zone, central London remains highly polluted by the diesel emissions of the public transport system as few buses and taxis have been converted to run off cleaner engines. Some of the main thoroughfares (Figure 11) such as the North Circular Road are easily recognisable by their pollution levels (indicated in the data by the cluster of high numbers WNW of central London). Equally poor air quality is seen around Heathrow airport, though not as a result of the planes themselves, but from the high numbers of diesel vehicles that operate in and serve that area.

As one moves to the outer suburbs of London, the air quality improves not only as a result of there being fewer vehicles but also because the

increase in green and open spaces means pollution can disperse more easily. It is important for students to recognise that even the greener suburbs of London are not pollution free – no value of zero has been recorded within the M25.

The **PM₁₀ data** comes from centrally held sources at the London Air Quality Network at Kings College London. Air quality is measured by monitoring stations placed in certain locations by central and local governments, industry and research bodies and the data is published and shared widely. Monitoring stations measure levels of all the main pollutants twenty four hours a day. Unfortunately the recording sites are not evenly spread out over London, and in fact they have traditionally been placed in areas where there have been previously high incidences of air pollution such as particularly busy road junctions. Today, new recording stations are put in place with less bias, but there is a legacy remaining that students should recognise as being influential on results.

The data shows the average level of PM₁₀ pollution over the whole month of October 2014. The data has been ranked into categories (known as the Daily Air Quality Index) according to severity (Figure 12) to allow easier comparisons between the different sites of the monitoring stations. There are ten points in the Index, grouped into four bands, for each of the five main pollutants.

Pollution Band	Index Value	Ozone µg/m ³	Nitrogen Dioxide µg/m ³	Sulphur Dioxide µg/m ³	PM _{2.5} µg/m ³	PM ₁₀ µg/m ³
		Eight hour average	One hour average	15 minutes average	24 hour average	24 hour average
Low	1	0 to 33	0 to 67	0 to 88	0 to 11	0 to 16
Low	2	34 to 66	68 to 134	89 to 177	12 to 23	17 to 33
Low	3	67 to 100	135 to 200	178 to 266	24 to 35	34 to 50
Moderate	4	101 to 120	201 to 267	267 to 354	36 to 41	51 to 58
Moderate	5	121 to 140	268 to 334	355 to 443	42 to 47	59 to 66
Moderate	6	141 to 160	335 to 400	444 to 532	48 to 53	67 to 75
High	7	161 to 187	401 to 467	533 to 710	54 to 58	76 to 83
High	8	188 to 213	468 to 534	711 to 887	59 to 64	84 to 91
High	9	214 to 240	535 to 600	888 to 1064	65 to 70	92 to 100
Very High	10	241 or more	601 or more	1065 or more	71 or more	101 or more

Figure 12 Banding for different levels of air pollution (Source: London Air)

These bands then allow advice to be given (Figure 13) as to the level of risk and precautions people can take to minimise the effects of poor air quality exposure. The EU places upper limits on the level of pollution deemed safe and acceptable in European cities. For PM₁₀ this limit is 50µm/m³ in any twenty four hour period and 40µm/m³ in any one year period, levels at which London regularly fails.

Pollution Band	Index Value	Advice for 'at risk' individuals	Advice for general population
Low	1-3	Enjoy your usual outdoor activities.	Enjoy your usual outdoor activities.
Moderate	4-6	Adults and children with lung problems, and adults with heart problems, who experience symptoms, should consider reducing strenuous physical activity, particularly outdoors.	Enjoy your usual outdoor activities.
High	7-9	Adults and children with lung problems, and adults with heart problems, should reduce strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also reduce physical exertion.	Anyone experiencing discomfort such as sore eyes, cough or sore throat should consider reducing activity, particularly outdoors.
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should avoid strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.	Reduce physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.

Figure 13 Health advice for different levels of air pollution (Source: Defra)

Presenting the PM10 data does not have to mean using the default methods in the students' GIS package. Choropleth colouring of regions or pinpoints demonstrates an easy to understand key but students can be encouraged to place data onto a London map using cited bar charts or proportional shapes. For stronger students the 'London Air' website has corresponding data sets for other pollutants and from this a radial graph for each site could be produced. Though the data sets are not complete, isoline or isopleth maps are both possible with students giving a little thought to the process. All of these methods can equally be deployed if students are designing their map by hand.

London's urban design could be said to contribute to the concentration of pollutants seen in the city. Like many world cities, London's radial pattern of roads means that vehicles converge in the centre of the city and its inner ring roads could be seen to encourage that convergence further by allowing places to become more connected between the feeder roads. With the River Thames running west to east through the city centre, there are a large number of 'choke points' (congested areas where many roads converge into one) as there are only limited places where the river has been bridged (Figure 14).

With a population density of 5285 people/km², London represents a highly congested city, but importantly one where the majority of that population are travelling to and from work or education every day. This puts an enormous strain on private and public transport systems which in turn create highly congested 'rush hours' at either end of the working day. Traffic slows to an average of 10.06mph



Figure 14 Traffic congestion on Blackfriars Bridge London bridges represent choke points where multiple lanes of traffic converge (Source: Flickr Creative Commons User ladelentes)

across the capital during the hours of 8am and 9am and so naturally, London's air pollution becomes concentrated in that time frame.

Until the mid-twentieth century, the main industrial centre of London was the Docklands area to the east of the city and with a prevailing wind coming from the south east of the UK, the pollution produced was swept over the rest of the city regularly. Today the main power stations in the city have been decommissioned and heavy industry is all but gone from the Docklands



Figure 15 Between skyscrapers in London's Docklands area Multiple tall buildings close together has the effect of reducing air flow and keeping pollutants close to ground level in high concentrations. (Source: Flickr Creative Commons User Simon and his Camera)

area. Yet the prevailing wind still brings in polluted air streams from northern Europe and in summer, when the dominant climate in south east England is dry and fairly still, this pollution can settle over the city unmoved for some days.

London may not sit below sea level or be surrounded by hills that would ordinarily 'hold' polluting air in place, but it is home to some of the tallest buildings in Europe. These can have a funnelling effect on winds; leaving some areas with more highly concentrated pollution than others (Figure 15). Poor air quality can get little chance to disperse if hemmed in on all sides by multi-storey buildings and although London boasts a high number of open city parks, with the exception of Hyde Park, these are not of a scale big enough to make a difference to these pockets of concentrated poor air quality in the city.

Looking at London and **Los Angeles** in terms of pollution makes the former appear somewhat clean by comparison. With a population density of 7545 people/km², Los Angeles is significantly more crowded than London. Being flanked on one side by ocean means that its main road networks do not form the same spread out radial pattern and the traffic is very much concentrated along fewer arterial roads. Los Angeles also does not have a comparable public transport system to London and far more people there will travel by car every day in order to work. Though Los Angeles is not famous for especially tall buildings, it has got a greater density of medium to tall height buildings which contain vehicle emissions often along relatively narrow streets.

Topographically, Los Angeles sits in a 'bowl' with high hillsides behind the city to the east and a dominant wind coming off the Pacific Ocean towards them. Los Angeles frequently therefore experiences a temperature inversion over the city, where cool sea breezes from the Pacific become trapped under a layer of warmer air descending off the Rocky Mountains. This concentrates polluted air at ground level, giving it limited chance of dispersal (Figure 16). The prevalence of wildfires in California also has an effect on the pollution levels in Los Angeles in the summer months. Fires are an almost annual occurrence and can last for many weeks depending on the weather conditions. Airborne



Figure 16 Smog sitting over Los Angeles A high car dependency and unhelpful topography have combined to make LA a highly polluted city. (Source: Flickr Creative Commons User Ben Amstutz)

soot and ash descend on Los Angeles where it settles and takes a long time to clear due to the sea breezes coming ashore there.

Plenary Activities:



Figure 17 The Congestion Charge Zone in central London Charging people to enter the city in their private vehicles has seen public transport use increase greatly. (Source: Flickr Creative Commons User mariordo59)

There are a number of **ways to reduce poor air quality in London**, some of which are already in place. Charging people to enter the city in private transport has proven to reduce the amount of cars on London's roads and equally reduce pollution levels too. The Congestion Charge Zone was brought in in February 2003 and charges people £11.50 a day (2014 prices) to drive into part of the centre of London (Figure 17). Since its introduction, Transport for London, who manage the scheme estimate that thirty percent fewer private cars enter central London every day and NO_x levels fell by 13.4% in its first year of operation. In addition, encouraging more people to walk or cycle in the capital can reduce traffic congestion. In their first two years, 'cycle super highways' such as the specifically designed lanes running from Barking to Tower Gate, and the Barclays Cycle Hire Scheme, in which Londoners and tourists can rent a bike at various zone one check points (Figure 18) around the city, nineteen million journeys were made by bicycle where previously a private car would have been used.

Transport alternatives such as the Croydon Tramlink, and the expansion of the Underground Tube network can allow for the rapid transit of commuters to suburban towns or to other transport hubs. Other forms of public transport can be made to run in a less harmful way: currently just under one thousand of the eight thousand strong fleet of London's buses and just under half of the capital's

twenty two thousand black cabs have been retrofitted to produce lower emissions. In addition greater strides can be made towards taking out of service the oldest and most polluting public transport vehicles as standard.

More of London could be pedestrianized and greened to make walking safer and more attractive to commuters. Routes, facilities and public transport connections can be redesigned to reflect the changing needs of commuters, such as by ensuring cycle racks and showers are available at commuters' offices and that train carriages are better designed to accommodate

bicycles. Electric vehicles and their charging points need further investment to make them viable options for London companies that run vehicle fleets and an expanded Low Emission Zone (a

zone in which vehicles that have high levels of polluting emissions have to pay a higher price to enter the city) to include large vans in their criteria as well as lorries and HGVs already covered could make further improvements to London's air quality.



Figure 18 Bicycle Rental in central London The cycling revolution in London has taken millions of car journeys off the roads. (Source: Flickr Creative Commons User Pavlina Jane)

Teaching Notes for Lesson Two:

What relationship is there between air quality and development?

Starter Activities:

There are many ways in which **air quality and development are linked**. A country's wealth is often a reflection of its level of industrial development. A country with high numbers of manufacturing industries and related power generation facilities is likely to produce a great deal more air pollutants than one where industrialisation is in its infancy, or indeed in a country which has passed through this phase and is in a state of deindustrialisation. A wealthy country also has greater power



Figure 1 Renewable energy production Technologies such as wind turbines, which produce no air pollution may only be available to rich nations. (Source: Flickr Creative Commons User Max Parker)

to invest in renewable energy (Figure 1) which comes away from the burning of fossil fuels and the soot emissions that come with it. This investment may also extend to new 'greener' technology which not only uses less energy and is more efficient but also 'clean' the emissions they produce, for example by the use of catalytic converters in cars to reduce levels of nitrogen oxides emitted and the use of 'flue scrubbers' in smoke stacks, which use liquids to 'wash' the harmful gases out of the emissions. While there are many examples of the developing world 'leapfrogging' technologically to more environmentally friendly products and processes, for the majority of transnational companies (TNCs) and state run businesses this is not a viable option. In an effort to turn profits quickly and with limited investment, the preferred route is to deploy older technologies which invariably produce greater levels of emissions and are less efficient.

The development level of a country is also strongly related to its demand for energy. Wealthier countries have greater energy demands per household as car ownership and access to energy thirsty devices appear in far higher numbers. Car ownership and one's need to travel or commute are especially connected to development, with nationals of poorer nations being less likely to regularly travel in motorised transport across long distances (Figure 2). Therefore lower vehicle emissions may be seen in developing nations, even though individual modes of transport may be older and more polluting. Though demand for energy may be higher in more developed nations the type of energy being used has a great effect on the air quality experienced in those nations. Developing countries with a sole reliance on coal for electricity production, rather than the nuclear processes open to more developed countries, will generate higher levels of polluting gases. Equally countries where burning firewood and charcoal is the dominant form of domestic heat production for cooking will experience indoor pollution levels way beyond that of more developed nations. The impact poor air quality has on a population's health is more likely to be treated in a wealthy nation and many people who suffer incidences such as heart and asthma attacks induced by breathing in poor quality air will make a full recovery. The same cannot always be said of poorer nations where people are more likely to die at a younger age from the effects of breathing in polluted air.



Figure 2 Bus travel, Tanzania Long distance travel in developing nations is not as common as in more developed countries. (Source: Author's own)



Figure 3 Round table discussions at G20 Summit 2013 Compliance with the decisions made at key IGO meetings may affect air pollution levels. (Source: Flickr Creative Commons User Number 10)

As a member of various geopolitical groups (Intergovernmental Organisations, or IGOs) a country may be bound to keep to certain emission levels as a result of cross-country agreements (Figure 3). A nation's position within these groups may be boosted or neglected as a result of their compliance or lack of compliance and a country's unique development position may make it easier or harder for them to fulfil these criteria. For example the Copenhagen Agreement and its predecessor, the Kyoto Protocol, allowed for the exclusion of the poorest nations from an agreement to reduce their greenhouse emissions in a wholesale fashion, while the more developed nations were expected to make the greater contributions to lowering harmful air pollutants.

Air quality is clearly dependent on a nation's level of development as development dictates the nature and level of the polluting activities taking place in that country. However one should also remember that poor air quality and other forms of pollution may prevent large companies and transnational corporations from investing in a particular region as the effort needed to 'clean up' is too great. Poor air quality or the lack of impetus to improve the air quality may make some countries vulnerable to aid sanctions, with overseas governments reluctant to donate or invest in a situation that could potentially be made worse by that very action. Poor air quality can also be a very real drain on the limited healthcare facilities in a developing country and money spent on treating people with respiratory diseases may reduce central spending on other key areas such as educational and infrastructural needs.

Some of these **linkages may change over time**. While current evidence suggests that the development gap is widening, in the future, our global expectation of what is an acceptable level of air pollution may become more universal and all, countries will find that they need to change their attitude to the problem for the sake of their ability to attract overseas investment and indeed tourist dollars. TNCs may find themselves subject to more scrupulous laws and guidance on the environmental impact of their activities overseas and under greater pressure from IGOs, host countries may have the ability to demand higher standards of emission control from these companies. However as industry becomes more home grown in the BRIC nations, TNCs may shift their operations more regularly and to new host countries who will savour the opportunity to see increased employment opportunities and infrastructural investment regardless of the TNCs green credentials.

With dependence on fossil fuels weakening as supplies are drained, more countries may look towards renewable energy production methods as a way forward and lower polluting gas emissions may result. The impact of this may be more widespread than just those countries that are able to invest in the new forms of technology: increasingly energy companies (who are themselves TNCs) are investing in renewable energy overseas (such as solar farms in Saharan Africa; Figure 4), the result being that countries at a variety of development levels may be able to benefit from lower fossil fuel emissions and better air quality.



Figure 4 Solar Farm at Kuraymat, Egypt Investment in renewable energy can cross international lines, blurring the relationship between development and air pollution. (Source: Flickr Creative Commons User Green Prophet)

Countries at the lower end of the development spectrum are increasingly being seen to undergo technological leapfrogging. Therefore, with the right level of investment, new industry and transport systems may be able to grow in developing nations without a reliance on older methods of power generation. For example while a large number of homes in the least developed countries are at present powered by kerosene lamps and wood burning cooking stoves, many households may make the direct

transition to solar powered appliances, reducing the need for cabling and power lines to be built in a national grid first. This would reduce the emission of polluting gases and create a possible model for other, more developed nations, to follow.

Main Teaching:

It would be natural to **form a hypothesis** that assumes that the greater car ownership in developed countries would be a precursor to there being higher levels of pollution in the lower atmosphere in those nations, represented in the graph by a straight line positive correlation. However while many cities in the developed world have problems with congestion and diesel fumes blighting their roads, the absence of large scale polluting power plants in those cities, and their presence in less developed cities may offset this as an idea. In fact it would not be unreasonable to suggest that countries with the highest levels of industrialisation (middle income countries such as the BRIC nations) would be the greatest polluters on the development spectrum. On the other hand the poorest nations may attract overseas investment from companies with the poorest track record of trying to reduce their gas emissions and equally these countries have the least disposable income at central governance level to internally invest in measures to reduce emissions.

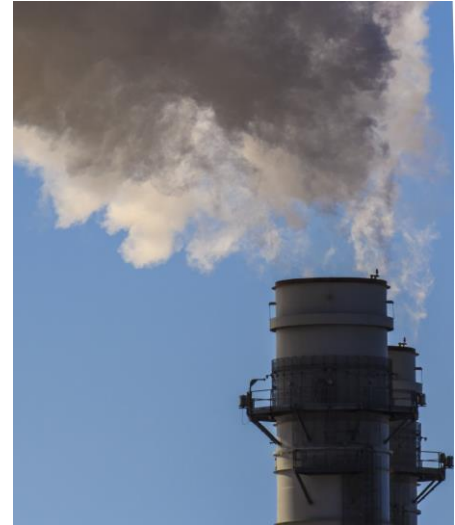


Figure 5 Smoke stacks TNCs can exploit relaxed emission laws in developing countries in order to turn over a higher profit. (Source: Flickr Creative Commons User David J)

The data **GDP v Air Quality** creates a graph that in fact shows a negative correlation between the two: as the income per capita increases, the average annual levels of PM₁₀ decreases. This relationship can be explained by thinking about the levels of industrialisation present in many developed nations' cities and the extent to which through the migration of labour these countries have effectively exported their pollution too. Developing countries are over reliant on 'dirty' fuels such as coal, natural gas and oil for their energy production in industry, resulting in high levels of pollution in many of their cities.



Figure 6 Fieldworker, Tanzania A lack of mechanical industries has kept the country in a state of low atmospheric pollution levels. (Source: Author's own)

One should also attempt to explain the **anomalies in the data**. Saudi Arabia and the United Arab Emirates appear far away from the line of best fit and one can think about this in one of two ways: these Arab nations are either far richer than their pollution levels suggest or they are producing far too much air pollution for their level of wealth. In this case, the latter could be seen to be true: one has to remember that Saudi Arabia and the United Arab Emirates are essentially nations where the majority of people live in poor conditions, but their GDP per capita average is increased artificially by the minority who own almost all the real wealth. Therefore it may be of little surprise that these nations pollute like poor nations – which is what they essentially are for the majority of their citizens. Tanzania on the other hand represents the country with the lowest GDP per capita of the set and according to the graph, would be expected to actually be producing more pollution than it is. This result is indicative of just how low Tanzania is in the development spectrum: it still has its industrial roots so firmly in agriculture that its pollution production is quite low by comparison with other nations (Figure 6).

Botswana has the highest level of pollution of the set, something one might think does not correspond to its wealth level. However, Botswana has seen one of the fastest growing income per person rates globally in the last ten years, but little of this has been invested in a manner that has sought to reduce air pollution emissions. Due to the rapid rise in demand for metals, the development of the ore mining and processing industries have been faster than

anyone anticipated and so environmental concerns over the quality of emissions being released from these industries has very much been put to one side.

Other factors need to be considered when hypothesising why certain countries may not fall directly close to the graph's line of best fit. Wind-blown air pollution produced in a neighbouring country can artificially raise the levels experienced by a nation that may actually have very low home grown emissions. Equally the data in this exercise takes no account of the real geography of the country in question; it is hard to compare the emissions of China with that of Singapore when one considers the population size and the land mass area in which it is concentrated. The data also takes no account of the urban-rural divide that can occur in some countries and it is very likely that both pollution levels and wealth will vary dramatically between different areas.

A **Kuznets Curve** is a theoretical model developed by economist Simon Kuznets in the 1950s. It was originally designed to show how as income per capita increases for a nation, its citizens' levels of economic equality goes through particular changes, with most inequality felt by those most recently urbanised in the middle incomes. The environmental Kuznets Curve follows a

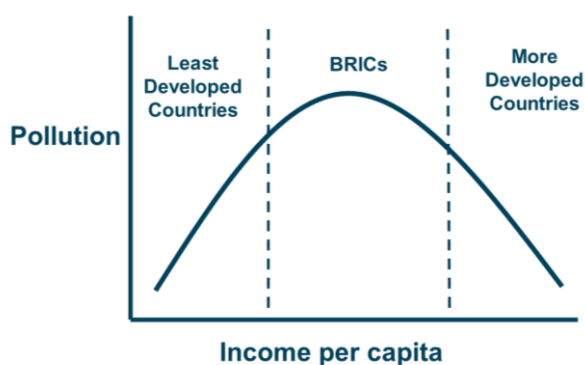


Figure 7 Environmental Kuznets Curve (Source: Author's own)

similar idea but compares income per capita with various environmental degradation variables (Figure 7). In low income states, environmental pollution can be seen to worsen as incomes rise until it reaches a peak. At this stage one should think of the country as having reached its most industrialised point, with outsourced manufacturing bases rising from TNC investment and pollution levels reaching a similar peak. After this point, as the country's economy becomes stronger and manufacturing has been moved to more profitable regions of the world, pollution levels will drop and greater investment may be made in trying to improve emission standards further.

The real data in this instance does not match the Kuznets Curve. One reason for this is many countries do not neatly fit into Low, Middle and High income categories with all the various associations that are seen synonymously with each. In fact in an increasingly globalised world, few countries act independently of each other and this will most certainly have an impact on the levels of pollution they alone produce and their level of wealth. Equally, the rate of countries' economic growth means that to an outside observer, not all will transfer naturally from low to middle to high income countries. Some will jump stages and others will never move along the development spectrum at all, but change economically in other ways.

Plenary Activities:

The **main source of indoor air pollution** in developing countries is burning wood, coal and charcoal with an open flame to order to heat water and cook food. Currently there are three billion people in the world who cook on open fires in their homes every day and four million people a year die from respiratory diseases linked to indoor air pollution. Smoke not only affects their ability to breathe but can cause eye infections and irritations and skin burns. An estimated eighty two percent of rapes in Africa occur when girls are collecting firewood for the purpose of cooking (Figure 8).



Figure 8 Girls collecting firewood, Malawi Girls face more risks than just smoke inhalation by using fire wood in their homes. (Source: Author's own)



Figure 9 Cooking with charcoal on a three stone stove, Malawi. Most African homes rely on 'dirty' fuels for meal preparation.

A **'technical fix' from a developed nation** could come in a variety of large scale forms. One top-down example that could reduce the health impacts of indoor pollution is the implementation of electronic air purifiers in homes. These actively remove the toxic gases produced during the cooking process and release them via a valve to the outside spaces. This may be a good short term solution to the problem as it can be implemented quickly for a very large number of people, so the effects can be felt straight away. The best research and design can inform the construction of the purifiers and the device itself can be mass produced to save time and money. As top companies are continually investing in such devices, the impact can trickle down to more and more people and the effect felt widely. Centralised control and management of the systems means decisions may happen a lot faster.

A **'technical fix' from a developing nation** could come in a variety of small scale forms. One example that could be used to reduce the inhalation of soot and ash from indoor pollution is a biogas tank. These tanks, which can be shared by more than one household, collect methane which has been produced from fermenting cow dung. This gas is then fed into a stove from which it can be burnt during cooking: a far

cleaner form of combustion than the heavily polluting burning of charcoal or fuel wood. This example is a form of appropriate technology (sometimes called alternative technology) – a sustainable form of technology which is designed by and managed by the people most affected by the problem. These are better thought of as long term solutions to the problem of indoor air pollution as this form of technology is controlled by local people, not by a large overseas company, who via a top-down approach, could withdraw their funding for the scheme at any time. While appropriate technology can take a long time to implement and can require funding streams to come from local sources which might be difficult to secure, it can be more reliable and sustainable in a number of ways:

- It is usually built from locally sourced materials which are easy to resource if something were to become damaged and need repair.
- It is usually built and maintained by local people, creating a stronger sense of ownership for the community.
- It is designed to be as environmentally sensitive to their locality as possible.
- It is designed to be cheap to install and maintain so that they can last for many generations.

Key Terms

Air Quality Monitoring Station A device, normally set along a road side that measures a variety of common air pollutants and records the data for download by relevant parties.

Appropriate / Alternative Technology Technological devices that are locally produced and maintained and therefore create a more sustainable means of managing a problem.

Arterial Roads An urban road that is designed specifically to transfer high volumes of traffic from outer urban areas to inner ones.

Cloud Condensation Nuclei Small particles around which water droplets need to cluster prior to precipitation.

Intergovernmental Organisations (IGOs) A group of countries whom together have an agenda for change. For example the Group of Twenty (G20) is a forum of twenty countries that (among other things) focuses each year on international economic cooperation to secure stronger trade links.

Kuznets Curve A model that describes how environmental degradation changes as a country grows economically.

Micron (µm) The unit for measuring particle size in atmospheric pollution. One micron is one thousandth of a millimetre.

Particulate Very small fragments of man-made substances (such as cement dust) or elemental pieces of waste products for example (soot).

Technical Fix The deployment of technology and design to manage a particular problem rather than finding the solution via behaviour change or a restructuring of a societal norm.

Technological Leapfrogging The process by which individuals or a country in a developing region rejects the next logical step in technical advancement and instead leaps straight to the latest development, bringing it in line with developed regions.

Temperature Inversion A layer of warm air sitting on top of a ground level layer of colder air, meaning that temperature rises, rather than falls with increased altitude. They usually occur in a hollow in the landscape as a result of an extreme high pressure.

Traffic Congestion An overwhelming amount of vehicle traffic for the amount of road space available. This can lead to slow moving or static lines of vehicles.

Transnational Corporations / Companies (TNCs) A company or business that operates in more than one country. This often takes the form of a company headquarters being in a developed nation while secondary labour and distribution is centred on a developing nation.

Transport Hub A place where many forms of transport (public and private) converge and thus where connections can be made from one form to another.

Links

Air pollution index:

<http://www.londonair.org.uk/london/asp/airpollutionindex.asp?BulletinDate=30/10/2014&zoom=9&lat=51.50979889870406&lon=0.0420696249999537&Species=All&laEdge=N&WhoBulletin>

Committee on Medical Effects of Air Pollutants (COMEAP) <https://www.gov.uk/government/groups/committee-on-the-medical-effects-of-air-pollutants-comeap>

Health advice for different pollution bands:

<http://www.londonair.org.uk/london/asp/airpollutionhealth.asp?HealthPage=HealthAdvice>

Healthy Air Campaign – A campaign that targets policy makers and industry heads and tries to make them pollute less:

<http://healthyair.org.uk/>

Home page for 'London Air' at Kings College London: <http://www.londonair.org.uk/LondonAir/Default.aspx>

Love Clean Air – a South London initiative to inform people about and reduce the levels of air pollution: <http://lovecleanair.org/>

Mayor's Air Quality Strategy http://www.london.gov.uk/sites/default/files/archives/Air_Quality_Strategy_v3.pdf

Wonderbag <http://nb-wonderbag.com/>

World Bank GDP data:

http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?order=wbapi_data_value_2013+wbapi_data_value+wbapi_data_value-last&sort=desc

World Health Organisation, Household Pollution and Health Factsheet: <http://www.who.int/mediacentre/factsheets/fs292/en/>

World Health Organisation, International Outdoor Air Pollution data:

http://www.who.int/gho/phe/outdoor_air_pollution/exposure/en/

World Health Organisation, Burden of Disease from Outdoor Air Pollution:

http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf

Resources

Lesson One

Data: London PM10 XLS | CVS

Handout: London PM10 data PDF | WORD

James Thornton's discussion of ClientEarth's case against the UK government on [video](#)

Presentation: Comparing pollution images PPT

Presentation: Imagining London's pollution

Presentation: The big five of air pollution PPT

Presentation: Urban design problems PPT

Lesson Two

Data: GDP v Air Quality

Handout: GDP v Air Quality

Presentation: Air Quality and Development PPT

Presentation: GDP v Air Quality

Presentation: Kuznets Curve

Presentation: Plot Hypothesis

Sarah Collins' discussion of Wonderbags on [video](#)