Silent Killer: Fine Particulate Matter

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The World Health Organization designated fine particulate matter (PM2.5) or airborne particulates a Group 1 carcinogen in 2013. These pollutants have recently gained growing attention and are known to be able to penetrate deep into the lungs and further into the bloodstream, inflicting serious harm, such as heart disease, to the human body.

A common misconception in South Korea is that the majority of fine particulate matter in the country originates in China. However, in 2013 the Korean government reported the amount of fine particulate matter in South Korea originating in China to be just 30 to 50%, meaning more than half of this dangerous pollutant is domestically produced. The main sources of these emissions are vehicles, factories and coal-fired power plants.

In 2014, Greenpeace published the results of modelling conducted by Professor Daniel Jacob and his research team at Harvard University, which investigated the number of early deaths caused by fine particulate matter from coal-fired power plants in South Korea. Using the GEOS-Chem atmospheric model, the research concluded that, currently, fine particulate matter from coal-fired power plants is causing an estimated 1,100 premature deaths each year. South Korea is also planning an expansion on its number of coal-fired power plants: if the construction of these is complete by 2021 as intended, Professor Jacob's research anticipates the number of premature deaths to increase by 800 per year. Considering that such plants usually run for 40 years or more, the new polluting power plants would cause tens of thousands of deaths over their operating life. This study holds great significance in that it quantifies the level of harm inflicted on health by coal-fired power plants in South Korea, which to date has been largely ignored by authorities, though it is well known to those citizens who suffer impacts locally.

South Korea is the fourth largest coal importing country in the world. It also generates the sixth largest amount of electricity from coal. As of 2015, 53 coal-fired power units across 11 power plants are in operation in South Korea, with 39% of total electricity generation based on coal. In addition, 24 new coal-fired units across 13 plants are planned to be set up by 2021, at which point a total of 77 units would be in operation. This will double the current coal-fired generating capacity.

Of the global carbon dioxide emissions generated from fossil fuels, 44% come from coal. Most of this is produced by coal-fired power plants, making coal not only the main contributor to climate change, but the cause of numerous types of environmental pollution and harm to our health. It is also diminishing the economic competitiveness of regions that choose it as a power source: in consideration of plans to increase the number of East Asia's coal-fired power plants, a 2013 joint report published by Trucost Plc and TEEB for Business Coalition identified the coal industry as the industry with the highest environmental impact cost in the world.

Elsewhere, the world is finally reducing its reliance on coal. Economic superpower China has been actively pursuing a coal consumption reduction policy since 2013, to combat the serious problem of air pollution. The US plans to close more than 100 coal-fired power plants by 2020. In contrast, South Korea plans to build more coal-fired power plants. With the technological advancements and clean energy options available today, it is tragic that the number of premature deaths in the country continues to increase due to the generation of outdated coal-fired power.

Greenpeace demands that South Korea face up to the fatal impacts of coal-fired power plants, reduce their number, and replace them with modern technology based on renewable energy. It also emphasizes the importance of strengthening regulations on pollutants emitted by coal-fired power plants, which directly harm public health.
Coal-fired power plants currently produce 41% of the world’s electricity. Coal makes up a significant portion of the global energy mix, yet it also poses a serious threat to society due to the pollutants emitted throughout the process, from coal mining to electricity generation.

Air pollutants emitted in the course of coal-fired power generation have a particularly harmful impact on health: following generation these pollutants remain airborne for days, where they are spread over hundreds or even thousands of kilometers by wind. Among them, fine particulate matter (PM2.5) has recently been recognised as causing particularly serious damage to health. Major precursors of particulate matter – nitrogen oxides (NOx) and sulfur dioxide (SO2) – as well as smoke and dust, and harmful mercury and arsenic, are also being emitted in large quantities. This contributes to high levels of outdoor air pollution, which are responsible for approximately 3 million deaths and countless cases of disease every year. In 2011, the World Health Organization (WHO) released data comparing the atmospheric quality of 1,100 cities in 91 countries. It concluded that over 2 million city-dwellers are die from indoor and outdoor air-pollution, and identified coal-fired power generation as one of the major reasons for this.

According to the International Energy Agency (IEA), coal accounted for 29% of the world’s primary energy supply in 2012, with 44% of global carbon dioxide (CO2) emissions from fossil fuels caused by coal combustion. This suggests that coal is the single largest source of greenhouse gas emissions, and the main culprit behind climate change.

In 2009, Dr. James Hanson of NASA wrote an article in British newspaper The Guardian entitled, ‘Coal-fired power plants are death factories. Close them.’ His discussion of carbon dioxide emissions and environmental problems caused by coal in the article identified coal as ‘the dirtiest fuel’ and ‘the single greatest threat to all life on our planet.’

CoalSwarm’s Global Coal Plant Tracker reports that construction has begun on approximately 570 new coal-fired power plants since 2010, with plans for the construction of a further 1,721 in the pipeline. The completion of these power plants will lock us into the emission of huge amounts of harmful pollutants for several decades, with subsequent expensive and painful impacts to our health. The emission of such an enormous amount of greenhouse gases would also keep power sector CO2 emissions growing in line with projections that result in a global temperature increase of more than 5°C above the current average, causing catastrophic climate change.

Countries around the world are finally catching on to this high cost of coal, and turning to alternative power sources. The US Energy Information Agency’s data shows that 145 of a total 1,308 coal-fired power plants (with a total generating capacity of 310GW; figures from 2012) were closed down between 2010 and 2012. Additionally, over 100 plants with a combined total output of 60GW are marked for closure by 2020. Meanwhile, energy generation based on renewable resources such as wind power has increased, and LNG power plants are growing as an alternative to coal-fired power plants in the US.

In 2013 the Chinese government announced that it would control air pollution by reducing coal consumption in the 12 regions which consume 44% of the total amount of coal consumed in the country, an ambition calculated to lower coal consumption by 655Mt by 2020 compared with business-as-usual. Furthermore, it banned any additional approval for the construction of coal-fired power plants in the Beijing-Tenjin-Hebei Area, the Yangtze River Delta, and the Pearl River Delta. As a result, in 2014, China’s coal imports decreased for the first time in 10 years. This suggests that the coal market is facing a great change.

Thus, the contemporary global trend has been to increase investment in renewable energy rather than in coal-fired power plants which emit a high amount of pollution. In World Energy Outlook, published in 2014, the IEA predicts considerable regulations on coal use, due to the global demand for a reduction in carbon dioxide emissions to address the issue of air pollution.

In contrast to this global trend, South Korea plans to build 24 coal-fired power units (21,944MW) by 2021. In this report, Greenpeace examines the current level of damage caused by fine particulate matter from coal-fired power plants in the country, and presents the actions that must be taken immediately to combat the harm being wrought to South Korea’s health.
Chapter 1. The Present Condition of Coal-Fired Power Plants in South Korea

Facts and Figures on Coal-Fired Power Plants in South Korea

The World’s Fourth Largest Coal Importing Country: South Korea

Coal-Fired Power Plant Expansion Plans

The Problems of Coal-Fired Electricity Generation

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Sources of Fine Particulate Matter

The Impact of Fine Particulate Matter on Health

South Korea’s Air Quality Standards

Unreliable Forecasting of Fine Particulate Matter

South Korea Threatened by Fine Particulate Matter

A Key Source of PM2.5 Emissions: Coal-Fired Electricity Generation

Harmful Pollutants Emitted by Coal-Fired Power Plants

Chapter 3. Premature Deaths in South Korea Caused by Coal-Fired Power Plants

Methodology of the Study of the Health Impacts of Coal-Fired Power Plants in Asia

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Facts and Figures on Coal-Fired Power Plants in South Korea

South Korea has developed coal as a relatively inexpensive energy source since the 1960s. Anthracite accounted for about 40% of total energy consumption in the 1960s, though this began to decrease in 1988 and by 2012 had dropped to 2.1%. As anthracite-based energy consumption declined, the use of bituminous coal consumption increased. While oil consumption began to increase in the 1970s, LNG and nuclear power began to grow as major energy sources in the 1980s and 1990s, respectively. The main energy source until 2006 was nuclear power, but after 2007 bituminous coal power emerged as the biggest source of power generation as bituminous coal power plants were successively constructed.13

As of 2012, coal accounted for 29% (80,978,000TOE) of the primary energy supply, and the capacity of its generating facilities accounted for 29% (26,273.6MW) as of 2014. As an energy source, coal accounts for 39% (203,196GWh) of the total amount of energy generated nationally. This is through the operation of a total of 11 coal-fired power plants – a total of 53 units - across South Korea.14

Of these 53 coal-fired units, six burn anthracite†, with a total installed capacity of 1,125MW. The remaining 47 units burn bituminous coal‡, with a combined total installed generating capacity of 25,148.6MW. More than two thirds (67%, 17,480MW) of existing Korean coal-fired power plants are located in South Chungcheong Province and Incheon City, near the densely-populated Seoul. An additional six coal-fired power

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† Anthracite: the type of coal with the highest carbon content (91% or greater). It is characterized by a high density and luster with few impurities, and produces a smoky flame when burned. Combustion of anthracite produces carbon monoxide, which causes yeontan or coal briquette gas poisoning. It is still produced in South Korea for use in heating and power generation.

‡ Bituminous coal: the most commonly used type of coal, bituminous coal has a lower carbon content than anthracite (60-91% carbon). It ignites easily, burning with a yellow smoky flame and high heat. South Korea imports most of the bituminous coal it consumes from overseas. Bituminous coal has good coking properties and is used in forging or steel-making, as well as for cement, power generation, and fuel.
plants (11 units, with a total installed capacity of 9,764MW) are currently under construction. The Sixth Basic Plan for Long-term Electricity Supply and Demand was announced in 2013 and stated that an additional seven coal-fired power plants (13 units, with an installed capacity of 12,180MW) are planned for construction by 2020. If all of these are constructed, by the year 2020 South Korea will have 77 coal-fired units across 24 power plants with a total installed generating capacity of 48,217.6MW. The health impacts of the level of air pollution produced by this amount of coal combustion will be serious and wide-ranging.
The World’s Fourth Largest Coal Importing Country: South Korea

South Korea imports coal from Australia (40%), Indonesia (29%), Russia (12%), Canada (10%), USA (5%), China (2%), and Vietnam (1%). IEA statistics show that the amount of coal imported by South Korea in 2013 reached 127Mt, making it the fourth largest coal importer in the world. Imported coal is usually used for power generation (67%), steel making (27%), cement and other uses (6%). Electricity generated from coal amounted to 239TWh as of 2012, ranking South Korea sixth in the world in its use of this fuel for electricity.  

Coal Imported by South Korea in 2013

- Australia: 40%
- Indonesia: 29%
- Russia: 12%
- Canada: 10%
- USA: 5%
- China: 2%
- Vietnam: 1%
- Others: 6%

Coal Imported by South Korea in 2013

- 1st China: 320 Mt
- 2nd Japan: 196 Mt
- 3rd India: 178 Mt
- 4th South Korea: 127 Mt
- 5th Taiwan: 68 Mt
- 6th Germany: 50 Mt
- 7th United Kingdom: 49 Mt
- 8th Turkey: 28 Mt

Amount of Electricity Generated from Coal in 2013 by Country

- 1st China: 3,785 TWh
- 2nd USA: 1,643 TWh
- 3rd India: 801 TWh
- 4th Japan: 303 TWh
- 5th Germany: 287 TWh
- 6th Republic of South Africa: 239 TWh
- 7th United Kingdom: 196 TWh
- 8th Australia: 171 TWh

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Coal-Fired Power Plant Expansion Plans

South Korea is currently constructing 11 coal-fired power units (6 projects with a total generating capacity of 9,764MW) in the areas of South Chungcheong Province, Gangwon Province, South Gyeongsang Province, South Jeolla Province, and Incheon City. An additional 13 coal-fired power units (7 projects with a total generating capacity of 12,180MW) are planned for construction in the near future. If the planned construction is completed by 2021, South Korea will have 77 coal-fired power units with a total combined capacity of 48,218MW. The government’s project to double the number of domestic coal-fired power plants contradicts the fact that it is discussing measures to decrease particulate matter at the national level.

The Problems of Coal-Fired Electricity Generation

Thus, coal is the major national energy source in South Korea. Yet the mining, combustion and disposal of coal is also the source of critical environmental threats to our society, including climate change, air pollution and water pollution. These problems, as detailed below, reveal just how much the consumption of coal costs us, and remind us that coal can never be truly cheap, efficient or sustainable.

Climate Change

The Intergovernmental Panel on Climate Change (IPCC) reported in 2013 that in order to prevent the most severe and widespread disaster due to climate change, the increase in global temperatures must be capped at 2°C relative to pre-industrial levels. To do this, 40 to 70% of greenhouse gas emissions - including carbon dioxide (CO2) - must be cut by 2050. Coal is the greatest single source of greenhouse gas emissions, responsible for 44% of the total amount of carbon dioxide emitted by fossil fuels globally. Attempts to lower CO2 emissions within coal-fired plants are farcical in comparison to other technologies: even the coal plant with the highest efficiency technology emits more than double the amount of CO2 emitted by a LNG power plant, and over 15 times as much as a power plant based on renewable energy. A typical 500MW coal-fired power plant emits three million tons of carbon dioxide a year, equivalent to the amount of carbon dioxide emitted by 630,000 vehicles in the same timeframe.

Carbon emission data, collected since 2007 by Carbon Monitoring for Action (CARMA) for 60,000 power plants worldwide, shows that the 25 power plants emitting the most CO2 in 2009 were all based on coal.22
Such grave environmental impact is also making coal power a poor choice economically. A joint report by Trucost PLC and TEEB for Business Coalition, published in 2013, states that the environmental impact cost of greenhouse gas emissions from East Asian coal-fired power plants amounts to 452.8 billion US dollars. This means that the coal energy industry ranks number one in terms of environmental impact cost outweighing economic value generated.23

If all of the 1,721 coal-fired power plants planned globally are put into operation, power sector greenhouse gas emissions will increase in line with the most pessimistic projections, which would cause climate change to become catastrophic: it is estimated that the emission scenarios in which these plants are built will cause the planet’s temperature to have increased by a minimum of 4°C and maximum of 6°C by 2050.24 Renowned climatologist Professor Kevin Anderson stated that, “a 4°C future is incompatible with an organized global community, is likely to be beyond ‘adaptation’, is devastating to the majority of ecosystems, and has a high probability of not being stable.”25

In 2012 South Korea emitted 592.92Mt of carbon dioxide, making it the seventh largest emitter in the world: eighth in the cumulative emissions over 10 years, and first among OECD countries in terms of emissions rate increase.26 South Korea must take responsibility for its role in global climate change.

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<td>World’s 7th largest</td>
<td>World’s 8th largest</td>
<td>No.1 in OECD countries</td>
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<td>592.9Mt</td>
<td>5556.9Mt</td>
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Korea's CO2 Emissions27

The Greenhouse Gas Inventory & Research Center of Korea announced in its 2015 report that the main source of greenhouse gas emissions in 2012 was coal used for public electricity and heat generation.28 In 2009, South Korea announced its intention to reduce greenhouse gas emissions by approximately 27% from the ‘Business as Usual’ level by 2020.29 Yet the South Korean government seemingly

contradicts this by continuing to adhere to a policy of increasing coal-fired power generation. Before the COP 21 is held in December 2015 to replace the Kyoto Protocol with a new universal climate change agreement, the world has already begun preparing for a reduction in greenhouse gas emissions. It is time to change South Korea’s policy of coal-fired power generation expansion.

Air Pollution

Air pollutants emitted from the generation of coal-fired power are spread by wind, travelling hundreds or even thousands of kilometers. In particular, coal-fired power plants emit a large amount of fine particulate matter (PM2.5) that is now recognized as a severe health risk. Coal-fired power plants are also the main emissions source of harmful chemicals like mercury and arsenic, which can be fatal to the human body, as well as nitrogen oxides (NOX) and sulfur dioxide (SO2) which are the main components of fine particulate matter and acid rain.

Emitted air pollutants cause cardiovascular diseases and respiratory diseases, including lung cancer, stroke, heart disease, chronic respiratory disease, and acute respiratory infection. Infants, the elderly and pregnant women are especially vulnerable, and globally over a million people are hospitalized with asthma and heart disease.30

China has also been harmed by its energy choices, where around 256,000 premature deaths are caused by coal-fired power plants every year.31 A joint study by Urbanemissions, Greenpeace and Conservation Action Trust on India’s coal-fired power plants, Coal Kills, estimates that between 80,000 and 115,000 people are sent to their graves prematurely every year as a result of airborne pollutants from coal-fired power plants.32 The effects are found across the world: studies show that the US loses 13,000 lives prematurely each year due to domestic-coal fired power plants33 while there were 22,000 premature deaths in Europe due to pollutants emitted by coal-fired power generation in 2010 alone.34

Water Pollution

Coal is one of the most-water intensive methods of generating
Coal’s Impacts on the Environment and Human Health

1. Coal Mining and Neglected Waste
   - Mountain Top/Surface Removal, Underground Mining, Deforestation
   - River Contamination, Damage to Local Communities, Animals and Plants
   - In the process of coal washing with fresh water in sludge disposal plants, heavy metals and other toxic substances are leached. They pollute rivers and cause deadly harm to local communities, animals and plants.

2. Preparatory Preparation
   - Water Pollution by Heavy Metals and Toxic Matter
   - Preparatory processing for coal requires a huge amount of water: from washing out impurities for refinement, to steam generation and cooling in the power plant, to wet ash disposal through pipes and in ponds. All of these deplete and pollute local water resources. With more than 1,200 new coal plants proposed around the world and much of that coal expansion in places such as China, India, and Russia where, together, 63% of the population is already suffering from water scarcity, the impact of coal power on water resources could have devastating consequences. According to Greenpeace data, a typical large coal-fired power plant consumes enough water to fill an Olympic-size swimming pool every three and a half hours. A 1,000MW coal-fired power plant typically consumes as much water as half a million people will use in a year. The IEA predicts that water used by the electricity generation industry will almost double from 66 billion cubic metres (bcm) in 2010 to 135 bcm in 2035, of which 50% will be used for coal-fired power.

3. Coal Transportation
   - Slurry Pond
   - Coal dust lost in the transportation process increases rates of heart and lung disease.

4. Coal Combustion
   - As pollution damages heart, lung and nervous systems, CO2 causes global warming. Pollutants include nitrogen oxides, sulfur dioxide, particulates, soot, heavy metals and carbon dioxide.
   - Water withdrawals for cooling systems can cause water scarcity and kill aquatic life.
   - Thermal water releases kill aquatic life.
   - Ash Pond
   - Leaching of heavy metals and other toxins pollute water and increase rates of cancer, birth defects and neurological damage. Spills harm humans and ecosystems.

- Leaching of heavy metals and other toxic substances from coal ash.
- Ash from burning coal is transported dry by truck, or mixed with electricity. Huge amounts of water are required at all stages of the process, from the cooling of drilling equipment during mining, to the washing out of impurities for refinement, to steam generation and cooling in the power plant, to wet ash disposal through pipes and in ponds. All of these deplete and pollute local water resources. With more than 1,200 new coal plants proposed around the world and much of that coal expansion in places such as China, India, and Russia where, together, 63% of the population is already suffering from water scarcity, the impact of coal power on water resources could have devastating consequences.

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Coal-fired electricity generation also produces heavy metals, which are toxic and can be fatal to humans if built up to sufficient concentrations. Research conducted at the University of Pittsburgh found that fish caught downstream of a coal-fired power plant contained levels of mercury 19 times higher than the normal rate in store-bought fish. As mercury is a neurotoxic heavy metal that tends to accumulate in the food chain and in the human body, eating fish contaminated with mercury has serious effects on the physical and mental development of babies and children.

Pollution by Coal Ash

In the process of coal-fired electricity generation, pulverized coal is burned in a boiler, producing ash. The ash that falls to the bottom of the boiler in piles is bottom ash; fly ash is carried by smoke and mostly collected by filtration before the flue gases reach the chimneys. Generally, coal ash makes up 10% of coal before it is burned, of which 75 to 85% is fly ash and 25 to 15% is bottom ash.

Ash from burning coal is transported dry by truck, or mixed with
water and sent through pipelines for disposal. Fugitive dust is scattered in the course of transportation by truck, and heavy metals and other toxic materials carried through pipelines are released near reservoirs, contaminating groundwater. Coal ash includes not only heavy metals including arsenic, cadmium, chromium, cobalt, lead and mercury, but also radioactive substances including radium, thorium, and uranium. These contaminate soil, destroy eco-systems, and are harmful to health.

Uneconomical Recycling of Coal Ash
Coal ash is usually disposed of in suspension in water in the ash disposal plant or recycled for plaster, cement, or other aggregates. However, as of 2013, four of Korea’s five power generation companies (with the exception of The Korea Western Power) suffered financial losses, as the cost of disposal outweighed the profit from recycling coal ash. One reason for this is that coal ash is classified as general workplace waste once it reaches the disposal unit, meaning it is not of sufficient quality for recycling and is inefficient to use in cement, as the mixture ratio with base materials is less than 10%. Additionally, a solution for disposing of bottom ash is needed as it is mostly fly ash that is recycled, while bottom ash is mixed with silt at a ratio of 1:1 and buried in the ash disposal plant.

Instability of the Coal Market
The coal industry insists that coal is economical and the most appropriate solution to meet the demand for energy. The future outlook for the coal market, however, is not as optimistic. In particular, experts predict that coal will not be able to provide for future energy demands with stability. The following four factors demonstrate the uncertainty of the coal market, and, by association, the dangers of relying on coal for energy requirements.

The first factor is that it is uncertain when coal supplies will be exhausted. The IEA reports that, after the 2009 to 2011 period when the price of coal peaked, prices have remained low due to excessive supply. Yet, as the continuous oversupply began to reduce profits, the coal industry decreased coal production. This demonstration of the industry’s unwillingness to make additional investments in coal mines and infrastructure which no longer guarantee profitability demonstrate that the world cannot expect the supply of coal to be consistent or stable. If South Korea continues to depend upon coal imports, its energy security will be highly compromised.

Secondly is the impact on the coal markets that occurred when China, a limited consumer in global coal trading, adjusted its domestic coal price. China’s recent adoption of an ambitious policy to reduce air-pollution, in addition to economic restructuring, reduced its domestic coal requirements and caused domestic coal prices to drop to unsustainably low levels. Seeing the crisis in the market, the Chinese government is attempting to recover the coal price. Similarly, India has been unable to manage the increasing local demand for coal through imports, and so has decided to increase the quantity of local production rapidly. As India is regarded as a major player in the international market, it is predicted that this will have a similarly destabilising impact on the world coal market.

Third, the international community’s tendency to increase the regulation of carbon emissions must also be considered. The cost of maintaining electricity generation is expected to rise over the next decade as regulations on coal-fired power plants increase. The Compact against Climate Change, which is currently under discussion by many countries around the world, aims to change the global electricity generation market into a carbon constrained development model. As the carbon credit trading system is expanding and spreading to North America, Asia, and Oceania, the market price is gradually being formed. Emission regulations on nitrogen oxides, sulfur dioxide, mercury, and carbon dioxide are being tightened to tackle air pollution. Therefore the cost of future investment in, and maintenance of, coal-fired power plants will continue to increase. This will bring a lot of pressure to bear on the coal market in the near future.

Finally, with technological development, renewable energy will become more economical and efficient. The cost of investing in renewable energy will reduce over time. The Greenpeace report, Energy Revolution: A Sustainable Energy Outlook for South Korea, predicts
that 3.7 billion US dollars will be saved annually by the year 2050 due to renewable energy not incurring fuel costs. In contrast, fuel costs for coal-fired power plants will put a lot of pressure on the national economy of South Korea. As countries around the world increasingly invest and compete in the renewable energy markets, remaining reliant on importing coal will leave South Korea vulnerable.

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<tr>
<td>Operational Costs ($/kWh)</td>
<td>57</td>
<td>53</td>
<td>53</td>
<td>56</td>
<td>57</td>
</tr>
</tbody>
</table>

Efficiency & Investment Cost Outlook by Power Plant

Chapter 2
The Threat of Fine Particulate Matter (PM2.5)
On February 24, 2014, most parts of South Korea except Jeju Island were exposed to the worst levels of particulate air pollution on record. Seoul remained under fine particulate matter warning for 75 hours, the longest such alert issued since the introduction of the fine particulate matter warning system. This event is particularly serious when compared to fine particulate warnings issued in December 2013 and January 2014, both of which were lifted within 24 hours. Citizens suffered during this period, and were urged to stay indoors.

Seoul Air Quality Information data shows that Seoul issued a total of six fine particulate matter warnings (lasting a total of 13 days) and 14 preliminary warnings (lasting 27 days) in 2014. The density of fine particulate matter peaked at 112㎍/㎥ that year, nearly five times the daily average limit set by the World Health Organisation (WHO).

The WHO's Global Burden of Disease Study revealed that 3.2 million people around the world died prematurely due to fine particulate matter in 2010. Of these, the number of premature deaths in South Korea was 23,000.

What is PM2.5?

'PM' stands for 'particulate matter', meaning a very fine dust. The number refers to the size of the particles, measured in ㎛ (micrometers or a millionth of a meter). The Korean standard classifies matter below PM10 as particulate matter and below PM2.5 as fine particulate matter. PM2.5 particles measure less than 2.5㎛ in diameter: smaller than one twenty-fifth the thickness of a human hair. This fine particulate matter penetrates through the bronchial tubes directly into the alveoli, into the bloodstream and deep into the body, causing cardiovascular disorders.

Fine particulate matter consists of primary particles and secondary particles: the first are emitted directly into the air, and the latter formed through chemical reactions with pollutants in the atmosphere in multiple stages. Primary fine particulate matter consists mainly of organic carbon, elemental carbon, minerals and ash, which contain heavy metals. Secondary fine particulate matter is divided into two categories: secondary organic particles are formed from the oxidation
of organic compounds with hydroxide, ozone or nitrate; and secondary inorganic particles are sulfate, nitrate or ammonium generated by the atmospheric reactions of ammonia, sulfur dioxide or nitrogen oxides.  

Sources of Fine Particulate Matter
Fine particulate matter occurs naturally, though may also be produced as the result of human activity or other chemical reactions. It originates from volcanic eruptions, yellow dust storms, forest or pasture fires, pollens, microorganisms, and even oceanic water spray. Human activity, such as pollutants emitted by cars and power plants, also produces a considerable amount of fine particulate matter.  

Statistics on air pollutant emissions published in 2011 by South Korea’s National Institute of Environmental Research indicate that the greatest source of fine particulate matter emissions is combustion in manufacturing, which accounted for 40.4% of all national PM2.5 emissions.

Secondary fine particulate matter is also of critical importance: air pollutants like nitrogen oxides (NOx), sulfur dioxide (SO2), ammonium (NH4) and volatile organic compounds (VOCs) are formed through atmospheric chemical reactions of other airborne pollutants. The Seoul Metropolitan Government researched the make-up of fine particulate matter in 2009, finding that 41.7% of total PM2.5 compositions came from secondary formation (of which nitrates 19%, sulphates 22%), making it the largest source of PM2.5 emissions. 

Even the 2nd Seoul Metropolitan Air Quality Improvement Plan, announced in 2014, predicts that, while by 2024 primary fine particulate matter emissions will have decreased in comparison to 2010 levels, an increase in secondary emissions will have prevented a substantial reduction in overall fine particulate matter pollution. It is clear that both primary and secondary fine particulate matter emissions must be controlled.

The Impact of Fine Particulate Matter on Health
Fine particulate matter has wide-ranging impacts. It reacts with harmful heavy metals, acidic oxides, organic pollutants, and other chemical matter in the air, and may also carry microorganisms such as bacteria and viruses in the atmosphere. Fine particulate matter accumulates in the pulmonary alveoli when inhaled, causing inflammation and lung-related diseases. It can also penetrate further into the bloodstream, impacting cardiovascular function. Therefore, as the risk of cardiovascular, cerebral, respiratory diseases and cancers increases with exposure to PM2.5, death rates will also increase.

A short-term study by the WHO conducted in 2004 shows that a 10µg/㎥ increase in atmospheric PM2.5 concentrations leads to an increase in death rates of 0.9%, the rate of death from respiratory disease increases by 1.3% and from cardiovascular disease by 1.1%. This study suggests that even short-term exposure has serious impacts. To confirm this, the WHO’s Global Burden of Disease Study found that fine particulate matter caused 3.2 million premature deaths in 2010. In 2013, the WHO designated fine particulate matter a Group 1 carcinogen.
South Korea’s Air Quality Standards

According to South Korea’s Air Quality Standards, the average level of fine particulate matter is 25㎍/㎥ per year and 50㎍/㎥ per day, which is equal to interim level 2 based on the fine particulate matter environmental standards issued by the WHO in 2006. The annual average level of fine particulate matter in Seoul compares poorly to many cities among the world (see below) but Korea’s Air Quality Guidelines on PM2.5 are relatively weak. The US maintains its annual and daily standards as 12㎍/㎥ and 35㎍/㎥; Japan as 15㎍/㎥ and 35㎍/㎥; and Canada as 10㎍/㎥ and 28㎍/㎥, respectively. In case of China, which suffers serious problems with fine particulate matter, has an ambitious plan to meet a standard of 35㎍/㎥ as an annual level and 75㎍/㎥ as a daily level in urban areas, which requires more than halving current levels in most polluted cities, including in Beijing.

<table>
<thead>
<tr>
<th>Level</th>
<th>Annual Mean</th>
<th>24 Hour Mean</th>
<th>Basis for the selected level</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO interim target 1 (IT-1)</td>
<td>35</td>
<td>75</td>
<td>These levels are estimated to be associated with 15% higher long-term mortality than at the AQG level</td>
</tr>
<tr>
<td>WHO interim target 2 (IT-2)</td>
<td>25</td>
<td>50</td>
<td>In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% (2-11%), compared to the WHO-IT-1 level</td>
</tr>
<tr>
<td>WHO interim target 3 (IT-3)</td>
<td>15</td>
<td>37.5</td>
<td>In addition to other health benefits, these levels reduce premature mortality by an additional approximate 6% (2-11%), compared to the WHO-IT-2 level</td>
</tr>
<tr>
<td>WHO Air Quality Guidelines (AQG)</td>
<td>10</td>
<td>25</td>
<td>These are the lowest levels at which total, cardiopulmonary, and lung cancer mortality have been shown to increase with more than 99% confidence in response to PM2.5. The use of PM2.5 guideline is preferred.</td>
</tr>
</tbody>
</table>

WHO Air Quality Guidelines on Fine Particulate Matter (㎍/㎥)

<table>
<thead>
<tr>
<th>Country</th>
<th>Annual Mean (㎍/㎥)</th>
<th>24 Hour Mean (㎍/㎥)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Korea</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>China Class 2</td>
<td>35</td>
<td>75</td>
</tr>
<tr>
<td>USA</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td>Japan</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>Canada</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Australia</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>EU</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>WHO</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

Comparison of Air Quality Guidelines on Fine Particulate Matter by Country

Unreliable Forecasting of Fine Particulate Matter

South Korea began forecasting particulate matter (PM10) levels in February 2014. Since January 1, 2015, the 157 measurement networks (36 under state management and 121 under local government management) across the country have offered the nation-wide forecasting systems on fine particulate matter, PM2.5. The Real Time Air Quality Information Center (www.airkorea.or.kr) releases PM2.5 concentration data in real time and operates the forecasting systems. However, monitoring stations are currently under construction across the country, with the exception of Seoul, Gyeonggi, and Gyeongnam. These stations are not distributed evenly, so the accuracy of its real time PM2.5 forecasting is unreliable.

Before launching the regular PM2.5 forecasting system, the Particulate Matter Forecasting System operated a system with behavioral guidelines divided into four levels: Good (0 to 30㎍/㎥/day); Moderate (31 to 80㎍/㎥/day); High (81 to 150㎍/㎥/day); and Very High (150㎍/㎥/day and above). South Korea’s Fine Particulate Matter Forecasting System was established relatively late in comparison to other countries and its regulations are loose. However, through this revised system the country
is attempting to adopt an appropriate forecasting standard. According to the government, the fine particulate matter warning system will be standardized across the country and instances of high fine particulate matter concentration will result in no-driving days and other measures like the hosing down of roads. There is also legislation which states that if a high concentration of fine particulate matter causes a warning to be issued, industry and power plants should temporarily suspend operations. However, a few powerful administrative measures are insufficient and unenforceable. Unless central and local governments agree to enforce regulations to reduce the concentration of fine particulate matter through measures such as traffic restrictions, these measures will not be implemented.

<table>
<thead>
<tr>
<th>Level</th>
<th>Issuing Standard</th>
<th>Clearing Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warning</td>
<td>24 hour shifting average of over 65 µg/m³ or greater for two hours (or hourly average concentration is below 100 µg/m³)</td>
<td>24 hour shifting average of below 50 µg/m³ or greater for two hours (or hourly average concentration is below 100 µg/m³)</td>
</tr>
<tr>
<td>Advisory</td>
<td>24 hour shifting average is over 150 µg/m³ or greater for two hours (or hourly average concentration is between 65 µg/m³ and 150 µg/m³)</td>
<td>24 hour shifting average is between 65 µg/m³ and 150 µg/m³ (or hourly average concentration falls to between 120 µg/m³ and 250 µg/m³)</td>
</tr>
</tbody>
</table>

National Fine Particulate Matter (PM2.5) Warning Standards (implemented on January 1, 2015)

**South Korea Threatened by Fine Particulate Matter**

So what will fine particulate matter pollution do to South Korea? In the case of Seoul, the annual average concentration of fine particulate matter reduced from 29.43 µg/m³ in 2006 to 25 µg/m³ in 2013. Yet, South Korean levels of PM2.5 are still much higher than the 10 µg/m³ WHO annual guideline, and compare poorly with New York, London, Paris and other major OECD cities.

The city of Seoul sits in a basin in the middle of the Korean Peninsula,
surrounded by the high mountain ranges of Mt. Bukhan, Mt. Dobong, and Mt. Gwanak. This geographical formation means that when the wind is weak there is little airflow, and the city is vulnerable to air pollution. The number of days and the frequency of particulate matter warnings are generally more consistent than before, and the maximum concentration of fine particulate matter is also high. Additionally, the large-scale coal-fired power plants located in Incheon and South Chungcheong Province directly impact Seoul’s air quality.

The City of Seoul only began to announce real time measurements of fine particulate matter in October 2013. Because of this, it is difficult to calculate the long-term trends in PM2.5. Analysis of annual data for 2014 reveals that warnings or preliminary warnings were issued on 40 days, and the maximum concentration was 112㎍/㎥ by the hour. The average concentration in December 2013 and January to February 2014 was 31.28㎍/㎥.16

Fine particulate matter particle formation also depends upon season: there is more atmospheric diffusion during the summer than in other seasons, and frequent and large volumes of rain during the summer monsoon keeps the concentration of fine particulate matter relatively low. In particular, the concentration of organic carbon (OC), a major component of fine particulate matter which impacts human health, is highest in spring and winter. Among the metallic components of fine particulate matter, those highly harmful to humans such as arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb) are relatively high in concentration in winter. The main source of arsenic is known to be coal-fired power plants.18

<table>
<thead>
<tr>
<th>Metro Air Measurement Station Air Quality</th>
<th>Spring (March, April, May)</th>
<th>Summer (June, July, August)</th>
<th>Autumn (September, October, November)</th>
<th>Winter (December, January, February)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seoul’s Average PM2.5</td>
<td>-</td>
<td>-</td>
<td>18.04</td>
<td>31.28</td>
</tr>
<tr>
<td>Seoul’s Average PM10</td>
<td>34</td>
<td>36</td>
<td>33</td>
<td>55</td>
</tr>
</tbody>
</table>

Seasonal Concentration of Fine Particulate Matter in Seoul in 2013 (㎍/㎥)17

Local air pollution due to fine particulate matter is very serious, but regulations to directly control emission sources are still incomplete. If a high concentration of PM2.5 occurs, there are not sufficient measures in place to respond to it. For example, one investigation reports that the Korea Western Power emitted 260 tons more than the permitted level in 2013. The Korea Southern Power emitted five times more nitrogen oxide than in 2012, and the Korea East-West Power one and a half times more. However, the fine imposed on these five power companies for excess emission of air pollutants in 2013 was just 26 million won.18 NOx, a major precursor of secondary fine particulate matter, is not on the list of penalized emissions, meaning there is no penalty charge for its production under existing law. This shows how insufficient air pollution regulations are in South Korea. On the other hand, China is taking powerful action: making efforts to reduce coal consumption, one of the main causes of fine particulate matter emissions; enforcing a no-driving day system; and suspending the operation of nearby power plants and factories in cases where a high concentration of fine particulate matter is detected.

South Korea must now adopt immediate and enforceable regulations to control fine particulate matter effectively.

The first and most urgent steps must be to extend the measurement network nationwide, carry out an assessment of major emission sources, and support academic research on the health impacts of PM2.5, and the environmental, sociological and economic damage it causes. The resulting research and measurement data should be open to the public and easily accessible. Based on these measures, a system to control emission sources should be adopted.

Stop Blaming China

Intense occurrences of fine particulate matter in South Korea are often
attributed to China, by both governments and the media. In reality, a 2013 collaborative survey on The Comprehensive Plan on Fine Particulate Matter by related departments of the South Korean government indicates that dust in the wind shifting from China did impact local levels of fine particulate matter in South Korea, amounting to 30 to 50% depending on season and wind condition. The Seoul Metropolitan Government published a survey on fine particulate matter (PM2.5) reduction measurements taken in 2011 which indicates that about 49% of fine particulate matter in Seoul area originates from outside of the country.

However, this means 51% of local fine particulate matter is formed within South Korea. The 2nd Seoul Metropolitan Air Quality Improvement Plan is expected to be implemented between 2015 and 2024, but given that the construction of coal-fired power plants is expected to continue outside of Seoul and the surrounding area, this reduction policy will be compromised. If measures for air quality control are adopted not only in Seoul and the surrounding area but across the country, and if central and local governments cooperate with industry to reduce fine particulate matter emissions, domestic PM2.5 emissions can be cut, thereby reducing the damage caused by PM2.5 by half.

As one of the countries responsible for air pollution, China has recently taken powerful measures to reduce coal consumption. Korea should also take responsibility by taking the lead itself to reduce local damage and harm.

<table>
<thead>
<tr>
<th>PM2.5</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC/BC</td>
<td>2.70%</td>
<td>4.20%</td>
<td>5.20%</td>
</tr>
<tr>
<td>Seoul</td>
<td>18.50%</td>
<td>20.90%</td>
<td>22.60%</td>
</tr>
<tr>
<td>Incheon</td>
<td>0.90%</td>
<td>2.80%</td>
<td>6.00%</td>
</tr>
<tr>
<td>East Gyeonggi</td>
<td>4.40%</td>
<td>8.50%</td>
<td>11.50%</td>
</tr>
</tbody>
</table>

A Key Source of PM2.5 Emissions: Coal-Fired Electricity Generation
Coal consumption produces particulate matter. Of the various types of coal consumption, fine particulate matter emitted by coal-fired power plants accounts for 3.4% of all PM2.5 emissions in South Korea, a hefty 2,752 tons of this micro matter. Nitrogen oxides (NOx) and sulfur dioxide (SO2), emitted mainly from coal-fired power plants, also form secondary fine particulate matter through chemical reactions in the atmosphere, and have further wide-ranging impacts. The 2024 Outlook on Fine Particulate Matter in the Seoul Area, published by the Ministry of Environment, shows that future primary emissions will be reduced compared to 2010 levels, but that the formation of secondary fine particulate matter will increase. This means the overall pollution levels are unlikely to improve. Data issued by the Seoul Metropolitan Government in 2009 indicates that 41% of fine particulate matter is formed by secondary dust, meaning fine particulate matter has a far-reaching effect and subsequently greater impact than may be initially thought. Whether the amount of primary fine particulate matter directly emitted by coal-fired power plants is large or not, the long-term impacts on air pollution levels over a wide-ranging area created by secondary particles must be examined.
<table>
<thead>
<tr>
<th></th>
<th>Bituminous Coal</th>
<th>Anthracite Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Amount of Emitted Pollutants in South Korea (kg)</td>
<td>718,345</td>
<td>1,040,214</td>
</tr>
</tbody>
</table>

**Percentage of Local Emissions from Coal-Fired Power Plants**

- Bituminous Coal: 3.4%
- Anthracite Coal: 2.8%

**Amount of Emitted Pollutants by Coal-Fired Power Plants in 2011**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Bituminous Coal</th>
<th>Anthracite Coal</th>
<th>Total Amount of Emitted Pollutants in South Korea (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>21,353</td>
<td>480</td>
<td>718,345</td>
</tr>
<tr>
<td>Nitrogen Oxides (NOx)</td>
<td>104,693</td>
<td>3,601</td>
<td>1,040,214</td>
</tr>
<tr>
<td>Sulfur Oxides (SOx)</td>
<td>65,646</td>
<td>2,274</td>
<td>433,959</td>
</tr>
<tr>
<td>Total Suspended Particulates (TSP)</td>
<td>3,847</td>
<td>113</td>
<td>201,810</td>
</tr>
<tr>
<td>Particulate Matter (PM10)</td>
<td>3,555</td>
<td>66</td>
<td>131,176</td>
</tr>
<tr>
<td>Fine Particulate Matter (PM2.5)</td>
<td>2,718</td>
<td>34</td>
<td>81,793</td>
</tr>
<tr>
<td>Volatile Organic Compounds (VOC)</td>
<td>2,562</td>
<td>240</td>
<td>872,108</td>
</tr>
<tr>
<td>Ammonia (NH3)</td>
<td>21</td>
<td>0.5</td>
<td>276,415</td>
</tr>
</tbody>
</table>

**Harmful Pollutants Emitted by Coal-Fired Power Plants**

Coal-fired power plants emit a toxic cocktail of harmful materials, including ozone (O3), sulfur dioxide (SO2), nitrogen oxides (NOx), soot and dust, mercury (Hg), lead (Pb), arsenic (As), chromium (Cr), nickel (Ni) and Cadmium (Cd). The heavy metals are bound to fine particulate matter and penetrate deep into the lungs and blood vessels. Exposure to the pollution from coal-fired power plants increases the risk of the following diseases:
Premature Deaths in South Korea Caused by Coal-Fired Power Plants

Primmersdorf Coal-Fired Power Plant in Germany. In operation since 1955, Primmersdorf is known as one of the dirtiest power plants producing the largest amount of CO2 emissions in the country.

©Paul Langrock / Greenpeace
Air pollutants from coal-fired power plants are known to cause premature deaths around the world. It is estimated that 260,000 people in China¹ and between 80,000 and 115,000 people in India² die prematurely every year as a result of pollution created by coal-fired power plants. This slow tragedy is occurring worldwide: according to statistics from 2010, coal-fired power plants also caused 13,000 premature deaths in the US³ and 22,000 in Europe⁴. As South Korea’s coal-fired power plants are by no means exceptional, this chapter presents a modeling exercise conducted by a research team at Harvard University, and published by Greenpeace, to examine and attempt to quantify the harm being done by South Korea’s coal-fired power plants.

Research on Premature Deaths in South Korea Caused by Coal-fired Power Plants

1,100 Premature Deaths in South Korea Each Year

According to a study conducted by Greenpeace and Professor Daniel Jacob and his research team at Harvard University, 1,100 premature deaths currently occur every year in South Korea as a result of air pollutants emitted by the domestic coal-fired power plants presently in operation. The specific causes of these premature deaths are calculated to be due to increased risk of: stroke (370 premature deaths), ischemic heart disease (330), chronic obstructive pulmonary disease (150), lung cancer (120), and other heart and lung diseases.

Building Additional Coal-Fired Power Plants Will Cause An Increase in Premature Deaths

South Korea plans to expand the current number of coal-fired power plants, in order to double its current power capacity by 2021. This will lead to a direct increase in premature deaths from fine particulate matter emissions from these coal-fired power plants. According to the modeling conducted at Harvard University, a realization of the current plan to extend the number of coal-fired power plants in South Korea will lead to an increase in premature deaths to 1,900 per year from 2021:
800 (between 470 and 1,200) more than the current level. Of these total premature deaths anticipated to occur, stroke is again the highest cause of death (640 people), followed by ischemic heart disease (580), chronic obstructive pulmonary disease (260), lung cancer (210), and other heart and lung diseases (220).

If the coal-fired power plants planned for construction between 2015 and 2021 are built, and remain in operation for the average lifespan of 40 years, by the time these power plants are all closed in 2061 they will have caused an additional 32,000 premature deaths as the result of air pollution by fine particulate matter. (See table)

Coal-fired power plants bring harm to all parts of the country, regardless of their location. In the continually technologically advancing 21st century, an increase in premature deaths due to outdated coal-fired power plants is a tragedy. While other countries of the world acknowledge the problems of fossil fuels and begin to shift to renewable energy, South Korea’s decision to expand coal-fired power production is an anachronism.

### Conditions of coal-fired power plants

<table>
<thead>
<tr>
<th>Diseases occurring due to coal-fired power plants</th>
<th>Stroke</th>
<th>Ischemic heart disease</th>
<th>Chronic obstructive pulmonary disease</th>
<th>Lung cancer</th>
<th>Other heart and lung diseases</th>
<th>Total deaths (central estimate)</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned coal-fired power plants</td>
<td>370</td>
<td>330</td>
<td>150</td>
<td>120</td>
<td>120</td>
<td>1100</td>
<td>Minimum</td>
</tr>
<tr>
<td>Planned coal-fired power plants</td>
<td>640</td>
<td>580</td>
<td>260</td>
<td>210</td>
<td>220</td>
<td>1900</td>
<td>Maximum</td>
</tr>
<tr>
<td>Planned coal-fired power plants</td>
<td>270</td>
<td>250</td>
<td>110</td>
<td>90</td>
<td>100</td>
<td>810</td>
<td></td>
</tr>
</tbody>
</table>

Numbers of diseases and caused by operating and planned coal-fired power plants in South Korea

### Methodology of the Study of the Health Impacts of Coal-Fired Power Plants in Asia

The most common approach for studying the health impacts of coal-fired power plants is the impact pathway approach, which follows air pollution through its life cycle, from emissions from the studied sources, to the dispersion and chemical transformation of emissions, to resulting pollution levels in different locations, to population exposure, resulting increase in health impacts and finally to the total health impacts on the population-level.

#### Emissions

First, the study of the health impacts of coal-fired power plants requires detailed information on the location, operation and emissions of the power plants. The inventory is based on a detailed listing of coal-fired power plants and their technical data in the covered countries. The basis for the listing is the Platts World Electric Power Plants Database, complemented by a comprehensive mapping of new power plant projects by CoalSwarm and by the national groups participating in this project.

The operating data (thermal efficiency and capacity factor) for most
plants was obtained from the Carbon Monitoring for Action (CARMA) database, and, for the remaining plants, average national values were calculated by power plant size category and steam condition. Total coal consumption estimated in this way for each country for 2011 matched the official fuel use data compiled by the IEA quite well, but fuel use was scaled to the IEA numbers. In this way, the plant-specific operating data was used to differentiate coal use among power plants. Flue gas volumes were estimated using EEA default factors for hard coal and lignite.

Utilization rates of newly built power plants were assumed as 80%. When there was no clear data on thermal efficiency, default rates were applied according to boiler types. The national emission standards applying to each power plant were identified and were used to calculate air pollutant emissions as a first approximation. Indonesia’s state power company, PLN, has said they design their power plants for 4,300 kcal coal with 0.35% sulfur content, so emission rates for plants for which Platts reports ‘compliance fuel’ as the SO2 control method were calculated on this basis. Non-PLN plants without SO2 controls were assumed to burn average Indonesian coal, which has a 0.6% sulfur content.

However, it is common for the power sector to perform significantly under or over the legally required levels: for example, all Japanese utilities report average emission rates far below the legal standards, and in Indonesia it is common for small power plants not to have any pollution controls, resulting in emission levels exceeding the national standards. The following sources were used to adjust emission rates for power plants:

- Power-plant specific information, if this could be found, from company presentations etc.
- Company average emissions performance, typically in g/kWh from CSR reports
- National emissions statistics
- Regional emission inventory in Asia (REAS) version 2.1 estimates for air pollutant emissions from coal-fired power plants for each country, scaled by change in coal consumption from 2008 to 2011.

When the available statistics covered all thermal power plants, the REAS values for average emission per TJ fuel were used to estimate share of coal, using fuel use data from IEA (national statistics) or from company reports. When plant-specific data was available, this was preferred. Emission rates for those power plants for which individual data was not available were scaled to the available national emission data.

The overall inventory is significantly lower than national statistics or the REAS 2.1 estimates. In many cases (Thailand SO2, Indonesia SO2 and PM, Philippines PM emissions), it was not possible to reconcile national statistics with emissions performance reported by operators of individual large power plants without assuming very high emission rates for the rest of the power plant fleet, bordering on the physically implausible. In these cases, the information reported by power plant operators, even if potentially selective, was relied on, making the estimates conservative.

Power plant emission standards for primary particulate matter are set in terms of total PM. The PM10 and PM2.5 fractions were estimated using US EPA AP-42 PM size distributions for different control technologies on the plant level, when information on technique was available from Platts. In other cases, an ESP was assumed for stack emission concentrations below 500 mg/Nm3 and uncontrolled combustion otherwise.

New power plants are assumed to meet national emission standards for new plants (when more specific information is not available), with the exemption of SO2 emissions from ‘compliance fuel’ plants which are treated the same way as in the case of operating power plants. New units are assumed to operate at a capacity factor of 80%, in line with available data for newly commissioned units in the region. For countries and power plant operators whose actual reported emission rates are below national standards, new power plants are assumed to over-achieve the standards by the same ratio. In addition, technology-specific minimum emission control performance is defined for circulating fluidized bed boilers, flue gas desulfurization and selective catalytic reduction devices, low-NOx boilers, subcritical boilers.
burning subbituminous coal without NOx control measures\(^\text{†}\) and for baghouses. All new power plants for which information on particulate control technology is not available are nevertheless assumed to install an electrostatic precipitator with a minimum 99% removal rate. In countries with lenient emission standards for new power plants such as the Philippines, Indonesia and Myanmar, all of these minimum performance assumptions lead to significantly lower estimated emission rates from new plants than simply assuming the highest permissible emission rates.

**Atmospheric Modeling**

Atmospheric modeling was carried out by the research group of Professor Daniel Jacobs at Harvard University. The group used the GEOS-Chem global model of atmospheric composition (www.geos-chem.org) to quantify the surface air concentrations of particulate matter (PM) and ozone resulting from present and future scenarios of coal-fired power plant emissions. GEOS-Chem is a widely used, open-source tool for modeling atmospheric composition on global and regional scales. It describes the transport and chemical evolution of species in the atmosphere and thus serves to relate emissions from specific sources to receptor concentrations.\(^\text{‡}\)

The model is first run with all air pollution emissions from different sources included. Then the emissions from the operating coal-fired power plants are eliminated, and the model is run again. The difference in pollution levels in the results of these two model runs is the share of pollution attributable to coal-fired power plants. To estimate air quality impacts of proposed new power plants, the emissions from these plants are added to the total current emissions from all sources, and the model is run with this new emission inventory.

**Health Impacts**

The assessment of health impacts from the coal-fired power plants followed the methods from Quantitative Health Risk Assessment for Particulate Matter\(^\text{7}\) of the United States Environmental Protection Agency (EPA). This report is based on a large-scale epidemiological study on health impacts of PM2.5, results from follow up studies of American Cancer Society, and additional proposals of research authors.\(^\text{8}\)

This research team has tracked medical histories and records on residence of 1.2 million Americans for 18 years. In the process, they were able to control a variety of confounding factors. The EPA has chosen such data as a foundation of report writing for following reasons:

1. Research period of applicable data has been extended to 18 years from 1999-2000 to 1982-2000, strengthening the influence of the research
2. Having various model types and thorough analysis of influence evaluation
3. Includes various ecological (sociological, economic, demographic) variables (considering the impacts of ecological variables on the relationship between rates on PM2.5 exposure and deaths)
4. In terms of PM2.5, a related analysis (centering on Los Angeles) is included in which spatial grade and the impacts of a responsive model are reflected is included
5. A large-scale data set including 1.2 million subjects and 156 Metropolitan Statistical Areas

Data on the mortality risks due to stroke, ischemic heart disease, lung cancer, chronic obstructive pulmonary disease, and other heart and lung diseases was referenced from the modeling section presenting data by nations from the Global Burden of Disease Study. Therefore, it was considered that there could be possible variations on factors such as population age structure and health conditions in different countries. The atmospheric model produces estimates of the total air pollution level at each grid location, and the share of the pollution that can be attributed to pollution emissions from coal-fired power plants in each country. Within the epidemiologic research of EPA, risk elements per 10 \(\mu g/\text{m}^3\) are applied to a yearly increase of PM2.5 produced by coal-fired power plants. The method of calculation on the number of premature deaths per cause and divisions (coffer clearance/grid) is as follows:

\[
\text{Given Mortality Rate} \times (1/\text{Hazard Ratio}) \times (\text{PM2.5 increase}/10\mu g/\text{m}^3) \times \text{Population}
\]
48

Hazard Ratio refers to the mortality ratio of a specific disease according to the yearly increase of 10\text{µg/m}^3 of PM2.5 exposure. For example, supposing 300 out of 10,000 people die from ischemic heart disease every year, most of the epidemiology research results would conclude that the PM2.5 level would increase the risk of cardiac disorder by 50% and 100 out of 100,000 will die from PM2.5 in the chosen region. Also, when supposing the coal-fired power plant’s PM2.5 contribution in the region is 10%, it could be interpreted that the same rate of deaths caused by PM2.5 is due to coal-fired power plants (10 deaths per 100,000 people). Applying this rate to the total population of the selected region will provide the total mortality rate.

The epidemiological approach used in the abovementioned research does not include the impact of PM hazardous levels. Therefore, health impacts of 50\text{µg/m}^3 and above are excluded from the report so that a conservative estimate has been drawn. The hazard ratio (HR) used to evaluate the influence on health is as follows:

<table>
<thead>
<tr>
<th>HR on 10\text{µg/m}^3 difference</th>
<th>Confident interval 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Heart and lung diseases Lung cancer</td>
<td>1.128</td>
</tr>
<tr>
<td>Ischemic heart disease Lung cancer</td>
<td>1.287</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>1.162</td>
</tr>
</tbody>
</table>

Population density in the study region

49

Damage Case Studies: Residents Living Next to Coal-Fired Power Plants

Air pollution from coal-fired power plants impacts the whole of South Korea. The most severe harm, however, is suffered by the neighboring residents of coal-fired plants. In this section, real-life case studies will be examined from South Chungcheong Province, where 47% of total domestic thermal power plants are located, and Yeongheung Thermal Power in Incheon city, which impacts the capital area the most directly.

Case Study 1: South Chungcheong Province

South Chungcheong is home to 47% of all domestic coal-fired power plants in Korea, including Boryeong Coal-Fired Power Plant and Seocheon Coal-Fired Power Plant of Korea Midland Power, Taean Coal-Fired Power Plant of Korea Western Power, and Dangjin Coal-Fired Power Plant of Korean East-West Power. The high concentration of power transmission facilities causes continuous problems for people living in the surrounding area, and a local newspaper article in July 2014 reported the impact on neighbouring resident’s health to be serious.

Testimony from Mr. Kim Jong-Ho, a resident living near the coal-fired Boryeong Thermal Power Complex

“We have been living in this village, now 2km away from Boryeong power plant, since the time of our ancestors. There is a high voltage tower which passes between the houses. When there are low pressure weather conditions with fog, rain, or snow, the dust and smell of gas from the burnt coal from the coal-fired power plant causes severe headaches and coughing. When it is at its worst, the headaches and nausea mean I am unable to sleep. When I filed a complaint, not even asking them to stop operating the power plant but asking for them to reduce the amount of dust and the smell of the gas, the employees threatened me and tried to placate me. For the past 20 years, all they have been saying is that they were "trying" and "testing." Whenever there has been some discussion to address a complaint with the relevant authority, this person would be replaced and conversation to have to be started.
over again, without making any progress on the matter. Making complaints to City Hall has only brought the same reply. Residents of the town are suffering from liver, lung, and stomach cancers without knowing the specific causes. I have two granddaughters. The older one was born prematurely while the younger one was born with a deformity. We can’t tell if this is because of the environment or the high-voltage pylons, but there are no inherited factors. I would like to know what is causing all these illnesses.”

Most of the residents living near coal-fired power plants interviewed by Greenpeace attested that they were suffering from psychosocial stress such as depression, panic and anxiety also pregnancies often end in miscarriage. According to the research on the health of South Chungcheong residents, conducted by the Environmental Health Center of Dankook University upon request of South Chungcheong Province, arsenic in urine has exceeded the exposure standard (400µg/l) in 19.2% (93 out of 482) of residents near four coal-fired plants within the province (Dangjin, Boryeong, Seocheon, Taean) and Dangjin Steel Plant. Moreover, an excessive level of mercury has been found in nine of the surveyed residents. The social costs related to air pollutants from power plants in South Chungcheong Province make up 37.5% of South Korea’s total domestic social costs (771.2 million KRW out of 2,058 billion KRW, 2010). However, the South Korean government has yet to agree to any compensation for these costs, nor countermeasures to ensure they do not continue. Instead, it is sticking to its plans to build more coal-fired power plants in the province.

Case Study 2: Yeongheung Coal-Fired Power Plant, Incheon City

The situation in Incheon City has many similarities with that of South Chungcheong. The current capacity of Yeongheung Coal-Fired Power Plant is 5,080MW, and there are plans to expand the plant by the addition of a 7th and 8th unit. According to the Clean Fuel Development Committee petition submitted to Incheon City in 2015, calling for the use of cleaner fuels in the new coal-fired power plant, a number of local residents have been suffering or died from thyroid or lung cancer as a result of their proximity to this coal-fired power plant. The petition also points out that, although regular health checkups have been carried out every two years, the lack of any organized management system has made it hard to investigate the actual damage being caused.

In addition to the impact on human health, sulfur oxides and nitrogen oxides emitted from plant chimneys have caused a decrease in local crop production and destroyed fish farms to an alarming degree, as a result of effluents discharged into the water. Coal dust left outside of waste disposal facilities and coal loading sites is carried by the wind, threatening neighboring areas, but this matter has been neglected by the coal-fired power plant site.

An even greater problem lies in the fact that Korea South-East Power is planning to use bituminous coal in units 7 and 8 of Yeongheung Power Station, in blatant disregard of the Special Act on the Improvement of Air Quality in the Seoul Metropolitan Area. An increase in coal-fired power generation in Incheon, which neighbors the metropolitan area of the country’s capital city, will affect even more people.

Will Particulate Matter Invade the Capital?

According to a report from the panel forum on Yeongheung Power Station carried out in the National Assembly of South Korea, the operation of the planned units 7 and 8 of Yeongheung will cause 42t of particulate matter to be dispersed into the atmosphere of Seoul every year. This is equal to the amount of particulate matter emitted by 127,000 diesel taxis in a year, which is nearly double the 70,000 taxis currently registered in the capital. Chemical reactions in the atmosphere will turn an additional 1,231t of sulfur oxides ($SO_x$) and 827t of nitrogen oxides ($NO_x$) into fine particulate matter. If the units were to be built as natural gas power plants, running on LNG, neither sulfur oxides nor particulate matter would be emitted, and only 393t of nitrogen oxides would be produced – a far less harmful impact on the local population. Atmospheric modeling carried out by Professor Soon-tae Kim at Ajou University’s Department of Environmental Engineering, has predicted that building Yeongheung units 7 and 8 as coal-fired power plants will affect the particulate
mater concentration level of the whole metropolitan area, including Seoul. Professor Kim stated that, “with Incheon City being close to Yeongheung island, an increase of fine particulate matter (PM2.5) by a concentration of up to an hourly maximum of 15.814 ɠ/m³ per hour and daily maximum of 5.389 ɠ/m³ is possible in some areas.” This possible daily concentration of fine particulate matter exceeds the suggested standard in 24 hours set by the World Health Organization (WHO, 25ug/m³) by five times.

Chairman Jong-ryul Yook of Yeongheung township’s Clean Fuel Development Committee stated, “Due to coal-fired power plants, local residents have been suffering damages to their health and livelihoods, so it is incomprehensible that Korea South-East Power continues to use coal, even in disregard of the law.” He also emphasized that “Across the world, the use of coal-fired power plants is decreasing. If we wish to keep the honor and pride we hold as the host country of the Green Climate Fund (GCF) secretariat, the use of bituminous coal in the new Unit 7 and 8 of Yeongheung Thermal Power Plant must be stopped.”

**Environmental Regulations Failing to Prevent Increasing Pollutant Emissions**

According to a document published in 2006 by former South Korean National Assembly member Hyeon-ki Kim, all of the power plant facilities of South Korea’s five largest power plant operators emitted pollutants exceeding the standard for acceptable emission levels during the four years between 2003 and 2006 (inclusive). Among the emitted pollutants were seriously harmful materials including sulfur oxides and nitrogen oxides, weighing 8,352t in total. However, the discharge fine imposed on excessive emissions was only 770 KRW/kg (70 US cents) for dust and 500KRW/kg (40 US cents) for sulfur oxides.

Recently, the situation has worsened. In 2013, Korea Western Power, which operates six power plants in the south-western area of South Korea, emitted 260t more nitrogen oxides than the standard acceptable level. This number was four times greater than the previous year, demonstrating the weakness of the air pollutant emission management system to control excessive, harmful discharges from power plants. Excess emissions of nitrogen oxides from Korean Southern Power were also five times larger than in 2012, and one and a half times larger in the case of Korean East-West Power.

Perversely, the total discharge penalty fee from excessive pollutant emissions imposed on the five companies in 2013 was only 26 million KRW (22,000 USD). In comparison to the damage wrought on the environment and health of local residents, let alone as a way to persuade companies to follow the standards, the figure is ridiculously low. Nitrogen oxides (NOx) are also not included on the list of penalized emissions, so the impact of these emissions - excess and otherwise - are not even included in the economic penalty system.

According to the revised Clean Air Conservation Act (2015), the Ministry of Environment should be regulating air pollutants emitted by workplaces. This Act requires mayors and governors to measure the air pollution levels of their districts on a regular basis and monitor the sources and quantities of air pollution. When pollutant emissions exceed the standard, a correction, suspension or closure order could be issued in line with Articles 33-35 of the Act, and penalty or fines can be imposed. The Act aims to ‘prevent air pollution which causes harm to people and the environment, and manage and preserve the atmospheric environment in a proper and sustainable manner, thereby to enable all people to live in a healthy and comfortable environment.’ Yet it also hides preferential provisions for power plants.
by Presidential Decree, such as where such suspension is likely to substantially impede the livelihood of residents and the national economy, including foreign credit, employment, commodity prices and public interest, the Mayor/Provincial Governor may impose penalty surcharges not exceeding 200 million won in lieu of the disposition to suspend operation.

In Article 37 (3), a coal-fired power plant is categorized as a ‘facility whose suspension of operation is deemed to considerably impede public interest.’ Therefore, although a coal-fired power plant may emit air pollutants exceeding regulatory limits, it remains exempt from the provisions laid out in Articles 33 through 35, and enforcing current law would mean only imposing a fine of 200 million KRW or less. This means that when air pollutants are produced in large quantities without proper refinement during coal-fired energy generation processes, coal power plants are privileged over general workplaces to be only lightly penalized by fines, instead of administrative actions such as work hour limitations or a closedown.

Such soft punishments lead to carelessness in managing air pollution reduction devices in coal power plants. A case in point is that of the thermal power plant in Boryeong, which built an ammonia measuring device worth 30 billion KRW to check if pollutants were being properly refined, yet did not use the device for nine years. The Korean government and power plant companies promote thermal power plants as ‘less’ harmful as they are equipped with desulfurization and denitrification systems, but in reality there is little assurance that these costly facilities are being operated to the correct, required standards.

Take Active Measures to Tackle Health Concerns

The Korean government should strengthen supervision over and penalties placed upon excessive pollutant discharges, and reinforce monitoring on air pollution emissions from coal-fired power plants. It is particularly necessary that the Ministry of Environment expands its role in the ongoing environmental impact assessment of coal-fired power plants, as well as carries out detailed damage investigations.

Furthermore, each power plant operator should regularly conduct research on the damage wrought to the health of residents and local environments in the areas surrounding their power plants. The results of this research should be fully disclosed, and active, long-term measures imposed to control and reduce further damage. The most crucial action, however, is to reconsider and retract the planned nationwide extension of coal-fired power plants in South Korea.
ASHKELON, ISR - SEP 03: The Rainbow Warrior during Greenpeace activists protest on Sep 08 2008, against Israel's plan to build a new electricity power plant fueled by coal in Ashkelon, Israel.

©ChameleonsEye
1. Recognize the Damage Inflicted by Coal-Fired Power Plants

Coal is a destructive and deadly resource: the main contributor to climate change and a major cause of air, water, and soil pollution. It is also deadly to human health. According to the data examined thus far, the fine particulate matter formed in coal-fired power plants presently in operation in South Korea is causing up to 1,100 (between 640 and 1600) premature deaths every year. If the planned new coal-fired power plants are completed by 2020, their operation is expected to increase the number of premature deaths to 1,900 (between 1,100 and 2,800) every year. Additionally, the exposure of hundreds of thousands of citizens to toxic particles, ozone, and heavy metals emitted by coal-fired power plants is causing irrevocable damage to health, the consequences of which will only be fully witnessed in the years to come.

Leading countries around the world are trying to reduce the number of coal-fired power plants in order to solve this problem. Disgracefully, a few countries, including South Korea, Japan, and some countries in South East Asia, are instead increasing the amount of coal-fired power plants inside their borders. In particular, the South Korean government is operating 11 coal-fired power plants - a total of 53 units - and in the process of constructing or planning to build an additional 13 plants - a total of 24 units. Such actions are damaging public health and breaking South Korea’s promise to the international community to reduce greenhouse gas emissions. In the 21st century, it is shameful to see the number of premature deaths increasing due to outdated coal-fired power plants. **South Korea must face up to the fatal harm caused by coal-fired power. It should end its retrograde energy policy and cancel plans to build new coal-fired power plants.**

2. Improve Air Quality Standards and Enforce Strict Regulations

Supervision and restriction on the pollutants emitted by coal-fired power plants must be improved. ‘The Environmental Impact Evaluation of Coal-Fired Power Plants’, presently controlled by the power companies and the Ministry of Industry, should be lead by the Ministry of Environment. In addition, an evaluation of the impacts on community health, environmental damage, and greenhouse gas...
emissions should be strengthened. Coal-fired power plants produce approximately 6% of the entire air pollutants emitted within South Korea as of 2011, including the matter formed through secondary reactions of fine particulate matter such as nitrogen oxide (60%) and sulfur dioxide (66%), as well as 3% of fine particulate matter (PM_{2.5}) and 3% of particulate matter (PM_{10}). This matter is also a cause of the secondary formation of further fine particulate matter through chemical reactions in the atmosphere. ‘The Prospect of 2024’s Fine Particulate Matters’ in the 2nd Seoul Metropolitan Air Quality Improvement Plan, published in 2014, predicts that the level of primary dust has been lowered since 2010, but due to the increase of secondary formation, the level of fine particulate matter pollution will not decrease greatly overall. Despite this alarming prediction, regulations to directly restrict the sources of emissions are not yet sufficient. Neither are cases of high concentration able to be sufficiently regulated. The emission of nitrogen oxides, the major precursor of secondary fine particulate matter, is not penalized, and no fine issued for this pollutant under the current law.

In 2012, the annual average concentration of fine particulate matter in South Korea was 24.6㎍/㎥, which is 2.5 times the WHO’s Air Quality Standard’s annual average concentration of 10㎍/㎥. South Korea started nationwide fine particulate matter forecasting in January 2015, but the measurement networks are so unevenly distributed that regional deviation is wide and it is not easy to calculate the substantial harms. The government should construct more measurement networks, in a systemized manner, across the nation. In the long-term, it should upgrade the air quality standard of fine particulate matter from the current WHO’s Interim Level 2 to the suggested Air Quality Guideline level. Furthermore, excess air pollution emissions must not be overlooked, and punishments and penalties enforced against power plants that violate the set emission standards. Reprimand and retribution should not simply consist of passive advice. Laws and regulations concerning air pollution must be enhanced and enforced in order to mitigate this dangerous problem, and make substantial improvements in public health.

3. Reduce Uneconomical Coal Consumption

Coal is touted as a cheap and efficient energy source, yet coal is neither cheap nor sustainable: more than a million people around the world die from the harmful effects of coal-fired power every year. Coal amounts for 44% of the world’s carbon dioxide emissions from fossil fuels, and contributes greatly to climate change. Amongst all the world’s contemporary industries, coal-fired power generation has the highest environmental impact cost, and East Asia’s expanding coal-fired power industry is expected to create a staggering environmental impact cost of 452.8 billion US dollars. These indicators prove that coal-fired power can never be a cheap nor sustainable way to generate power. From the moment the world established the convention on climate change and agreed to a gradual reduction of greenhouse gas emissions, South Korea’s persistent choice of coal-fired power is an embarrassment on the international stage. South Korea depends on imports for most of the bituminous coal it burns, making it vulnerable to fluctuations in foreign markets. International pressure to tackle climate change and reduce greenhouse gases will slowly diminish coal’s reputation, and the price of coal will increase. In contrast, renewable energy will gradually increase in use, and become cheaper. Greenpeace predicts that the price difference between renewable energy and coal will have reversed by the time all coal-fired power plants under construction or planned will be in operation by 2030. With such changes anticipated in the global coal market, South Korea’s energy market will weaken. South Korea’s plan to increase the number of coal-fired power plants is inappropriate in economic terms as well as in terms of energy independence.

4. Increase the Share of Renewable Energy

The number of coal-fired power plants should be reduced while electricity generation based on renewable energy should be increased. Presently, 40% of the electricity generated in South Korea is based on coal. The Korean government announced that the 6th Basic Plan for Long-term Electricity Supply and Demand enabled the current
new and renewable energy generation to amount to 3% (15,771GWh) as of 2013, but it is just 2.3% (14,982GWh) of the international standard. The government stated that it would raise the portion of new and renewable energy generation\(^1\) to 12.6% (91,340GWh) by 2027, but it is just 8% (61,996GWh) of the international standard. China promised that coal consumption would be reduced in order to cut down carbon dioxide by 2020 and replace 20% of primary energy sources with non-fossil fuels by 2030. Germany, whose solar energy potential is less than South Korea’s, has expanded its portion of renewable energy from 9.3% to 27.3% in total electricity consumption for the last 10 years.

Greenpeace’s Energy [R]Evolution Scenario concluded that South Korea would have no difficulty securing the technical availability and sites required to increase the portion of renewable energy to 60% by 2050, and to generate 100% of its electricity from renewable energy by the end of the 21st Century. With the whole world focused on reducing greenhouse gases, South Korea, the world’s 7th largest emitter of these gases, promised in 2009 to reduce its greenhouse gas emissions by 30% from the ‘business-as-usual’ level by 2020. Yet despite this promise to the international community, the government continues to go against the global trend by clinging on to nuclear energy and fossil fuels. It is not yet too late for South Korea to enter the rapidly growing global renewable energy market, but if it does not do so immediately it will lose its competitiveness and fall behind. For a sustainable future, South Korea must actively invest in the renewable energy market and implement an advanced energy policy to ensure a sustainable future.

\(^{1}\) South Korea’s own new and renewable energy. According to the IPCC, renewable energy is a form of energy from the sun, earth, physics, or biology. The energy comes from the source which (re)creates the same amount or more than a certain amount of the energy consumed. Yet the South Korean government’s style of ‘new and renewable energy’ involves even those energy sources converted from existing fossil fuels. The Korean government’s standard includes generation methods which destroy the natural environment and emit pollutants, and so they fail to meet the international definition of renewable energy.
Appendix

Types of Coal-Fired Power Plants

1. **Pulverized Coal-Fired (PCF) Power Plants**

   In these plants, coal is ground into a fine powder and blown into a boiler. It burns at between 1,300°C and 1,700°C, creating steam which drives a generator and turbine. This method is by far the most established and common of the three main types of coal-fired plants described here. PCF plants account for over 90% of the electricity produced from coal, and about 38% of the power generated from any source around the world. The bad news is that PCF plants are also horribly inefficient. Even the most efficient ones still waste half of the energy they produce: the worldwide average thermal efficiency of PCF plants is less than 32%, meaning that almost 70% of the energy is wasted. The lower the efficiency level, the more coal needs to be burnt to generate electricity, spewing out even more CO2 emissions.

   Ninety percent of the coal-fired power plants in the world use this type of technology.

2. **Fluidized bed combustion (FBC) plants**

   Here, coal is burned with air in a fluid bed, mixing gas and solids. This is done either at ambient (‘normal’ atmospheric) pressure (a method referred to as Atmospheric FBC) or under applied pressure (called Pressurized FBC), and at temperatures lower than those in PCF plants. The lower combustion temperatures in FBC systems cut the amount of NOx produced. As more than 95% of sulfur pollutants from the coal can be captured inside the boiler, FBC plants also produce less SO2. Despite these apparent advantages, FBC technology is often used with low quality coal, which together with lower thermal efficiencies means the amount of CO2 produced increases.

3. **Integrated Gasification Combined Cycle (IGCC) Plants**

   ‘Integrated Gasification Combined Cycle’ refers to the method used to turn coal from a solid to a gas, and then to burn this gas to produce steam to turn a turbine.

   The process used in IGCC plants involves two separate steps: First, coal is turned into gas through a controlled ‘shortage’ of air in an enclosed pressurized reactor. The resulting gas – a mixture of carbon monoxide (CO) and Hydrogen (H2) called Syngas – is then burned to drive a gas turbine. In the second step, the exhaust gas from step one is used to create steam, which drives a separate steam turbine.

   IGCC plants are the newest of the three types listed here, with average thermal efficiencies of between 40 and 50%. In 2014, IGCC for coal-based electricity production was in operation globally in three power plants in the US, three plants in Europe and one in Japan. In South Korea, The Korea Western Power is constructing IGCC plant in Tae’an. It is categorized as a source of ‘new energy’ in the group of ‘new renewable energy’ and seen to be an example of next generation, environmentally friendly energy. However, the electricity is still generated by burning coal, and most certainly emits air pollutants including NOx, SOx and particulate matters.

### South Korea’s Coal Imports in 2013

<table>
<thead>
<tr>
<th>Country</th>
<th>Bituminous Coal</th>
<th>Anthracite Coal</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>46,224</td>
<td>3,725</td>
<td>49,949</td>
<td>40%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>35,809</td>
<td>-</td>
<td>35,809</td>
<td>29%</td>
</tr>
<tr>
<td>Russia</td>
<td>10,152</td>
<td>1,787</td>
<td>11,939</td>
<td>12%</td>
</tr>
<tr>
<td>Canada</td>
<td>12,883</td>
<td>-</td>
<td>12,883</td>
<td>10%</td>
</tr>
<tr>
<td>USA</td>
<td>6,060</td>
<td>-</td>
<td>6,060</td>
<td>5%</td>
</tr>
<tr>
<td>China</td>
<td>1,487</td>
<td>1,422</td>
<td>2,909</td>
<td>2%</td>
</tr>
<tr>
<td>Vietnam</td>
<td>-</td>
<td>1,124</td>
<td>1,124</td>
<td>1%</td>
</tr>
<tr>
<td>Others</td>
<td>527</td>
<td>313</td>
<td>840</td>
<td>1%</td>
</tr>
<tr>
<td>South Africa</td>
<td>165</td>
<td>-</td>
<td>165</td>
<td>0%</td>
</tr>
<tr>
<td>Cyprus</td>
<td>-</td>
<td>46</td>
<td>46</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>-</td>
<td>124,704</td>
<td>100%</td>
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Source: Korean Coal Association
<table>
<thead>
<tr>
<th>No. Tier Unit (Metropolitan City &amp; Province)</th>
<th>And Far South Gyeongsang/Busan</th>
<th>Emission Source</th>
<th>Fuel</th>
<th>CO</th>
<th>NO₂</th>
<th>SO₂</th>
<th>TSP</th>
<th>PM10</th>
<th>PM2.5</th>
<th>VOC</th>
<th>NH₃</th>
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<tr>
<td>Busan</td>
<td>South Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>280,385</td>
<td>264,285</td>
<td>170,096</td>
<td>96,673</td>
<td>11,541</td>
<td>12,127</td>
<td>2,681</td>
<td>37</td>
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<tr>
<td>Daegu</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>922,243</td>
<td>932,249</td>
<td>521,385</td>
<td>246,907</td>
<td>26,533</td>
<td>20,794</td>
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<td>Public power plant</td>
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<td>3,938,491</td>
<td>316,038</td>
<td>246,330</td>
<td>21,035</td>
<td>16,597</td>
<td>21,503</td>
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<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
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<td>1,083,547</td>
<td>851,987</td>
<td>194,374</td>
<td>3,474</td>
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<tr>
<td>Gyeonggi Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>179,284</td>
<td>192,238</td>
<td>163,096</td>
<td>10,375</td>
<td>16,309</td>
<td>19,310</td>
<td>138</td>
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<tr>
<td>Gyeonggi Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>388,694</td>
<td>379,837</td>
<td>209,840</td>
<td>52,088</td>
<td>7,179</td>
<td>6,392</td>
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<td>1,932,526</td>
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<td>894,037</td>
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<td>13,658</td>
<td>20,892</td>
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<td>210,128</td>
<td>130,362</td>
<td>83,945</td>
<td>11,710</td>
<td>13,704</td>
<td>25</td>
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<td>Bituminous</td>
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<td>12,984</td>
<td>138,186</td>
<td>28,233</td>
<td>6,106</td>
<td>7,848</td>
<td>55</td>
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<td>South Chungcheong Province</td>
<td>Daegu</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>3,036,964</td>
<td>3,126,266</td>
<td>827,697</td>
<td>498,200</td>
<td>57,405</td>
<td>53,620</td>
<td>5,283</td>
<td>7.8</td>
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<td>South Chungcheong Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>628,677</td>
<td>758,599</td>
<td>643,797</td>
<td>16,390</td>
<td>1,459</td>
<td>1,396</td>
<td>0.06</td>
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<tr>
<td>South Chungcheong Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>91,281</td>
<td>2,020,505</td>
<td>108,359</td>
<td>16,946</td>
<td>21,480</td>
<td>21,716</td>
<td>223</td>
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<tr>
<td>South Chungcheong Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>224,955</td>
<td>234,305</td>
<td>235,835</td>
<td>40,317</td>
<td>16,976</td>
<td>21,480</td>
<td>21,716</td>
<td>223</td>
</tr>
<tr>
<td>South Chungcheong Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>2,080,501</td>
<td>1,975,317</td>
<td>782,670</td>
<td>239,037</td>
<td>18,637</td>
<td>14,520</td>
<td>4,653</td>
<td>530</td>
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<tr>
<td>North Jeolla Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>262,295</td>
<td>86,286</td>
<td>189,976</td>
<td>79,563</td>
<td>11,742</td>
<td>11,050</td>
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<td></td>
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<tr>
<td>North Jeolla Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>292</td>
<td>157</td>
<td>820</td>
<td>20</td>
<td>3</td>
<td>17</td>
<td>3</td>
<td></td>
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<tr>
<td>North Jeolla Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>31,252</td>
<td>7,963</td>
<td>215</td>
<td>12,230</td>
<td>7,125</td>
<td>6,105</td>
<td>4,974</td>
<td>0.06</td>
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<td>North Jeolla Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>4,78,991</td>
<td>7,86,915</td>
<td>130,520</td>
<td>246,330</td>
<td>246,330</td>
<td>246,330</td>
<td>23,982</td>
<td>19,309</td>
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<td>North Chungcheong Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>311,336</td>
<td>2,97,508</td>
<td>869,322</td>
<td>266,567</td>
<td>59,036</td>
<td>101,810</td>
<td>748</td>
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<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>3,386,555</td>
<td>3,812,714</td>
<td>870,512</td>
<td>75,357</td>
<td>664,908</td>
<td>1,08,305</td>
<td>960</td>
<td></td>
</tr>
<tr>
<td>South Chungcheong Province</td>
<td>Gyeongsang</td>
<td>Public power plant</td>
<td>Bituminous</td>
<td>3,192,639</td>
<td>3,275,768</td>
<td>1,149,315</td>
<td>21,352</td>
<td>1,459</td>
<td>1,396</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

**Fine Dust Forecast Ratings by Ministry of Environment**

<table>
<thead>
<tr>
<th>Matter</th>
<th>Unit</th>
<th>Period of Time to Measure the Concentration</th>
<th>Good</th>
<th>Moderate</th>
<th>Bad</th>
<th>Danger</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM10</td>
<td>µg/m³</td>
<td>- 24/48h</td>
<td>0-30</td>
<td>31-80</td>
<td>81-165</td>
<td>166+</td>
</tr>
<tr>
<td>PM2.5</td>
<td>µg/m³</td>
<td>24/48h</td>
<td>0-15</td>
<td>16-50</td>
<td>51-130</td>
<td>131+</td>
</tr>
</tbody>
</table>

**Behavioral Guidelines**

- **Sensitive**
  - No need to limit particular outdoor activities, but take care in what you do depending upon your physical condition.
  - Limit time spent outdoors and outdoor activity. In particular, those with asthma who may be affected should take care of the use of an inhaler frequently.
  - Stay indoors if possible. Consult with doctors on planning outdoor activities.
- **Ordinary**
  - Limit time spent outdoors and outdoor activity. In particular, those with sore eyes, a cough or sore throat should avoid outdoor activities.
  - Limit time spent outdoors and outdoor activities in particular, those with sore eyes, a cough or sore throat should avoid outdoor activities.

**Amount of Emission of Fine Particulate Matter (PM2.5)**

<table>
<thead>
<tr>
<th>Region</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seoul</td>
<td>2.723</td>
</tr>
<tr>
<td>All Nation</td>
<td>13.174</td>
</tr>
</tbody>
</table>

**Emission Source (Unit ton, %)**

- **Energy Industry’s Burning** 130 (0.6)
- **Non-Industry’s Burning** 1776 (3.1)
- **Manufacturer’s Burning** 101 (0.4)
- **Production Process** 8 (0.01)
- **Road Traffic Pollution Source** 78,682 (8.8)
- **Non-Road Traffic Pollution Source** 21,792 (1.3)
### Pollutants Emitted from Coal-Fired Power

**and Related Harm to Human Health**

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Related Harm to Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO2)</td>
<td>Secondary Impacts of Climate Change</td>
</tr>
<tr>
<td>Sulfur dioxide (SO2)</td>
<td>Possible impact on respiratory system, lung function, asthmatic exacerbation and chronic bronchitis, eye irritation and exacerbation of heart failure/asthenic strain/asthenic stroke</td>
</tr>
<tr>
<td><strong>High Volume Hazardous Air Pollutants</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Related Pollutants**

- **Nitrogen dioxide (NO2)**: Asthma pathogenesis and its exacerbation, chronic obstructive pulmonary disease, Deep vein thrombosis, Ischemic stroke
- **Particulate matter PM2.5, PM10.5**: Respiratory system asthma pathogenesis and its exacerbation, chronic obstructive pulmonary disease, lung cancer, cardiovascular disorder, abdominal pain, Acute myocardial infarction, Congestive Heart Failure, nervous system asthma, stroke
- **Ammonia (NH3)**: Respiratory system irritated, skin, and eye burned
- **Hydrogen Chloride and Fluoride (HCl, HF)**: Skin, eyes, nose, throat and respiratory system irritated
- **Organic Pollutants**
  - **Dioxins and furans**: Potential carcinogenic reproductive organs, endocrine & immune systems impaired, Dioxins accumulated in food chains
  - **Polycyclic aromatic hydrocarbons (PAHs)**: p(m)ential carcinogenic liver, kidney, and testis with unusual reaction; sperm impaired & reproduction weakened
- **Non-Methane Volatile Organic Compounds (VOCs)**
  - **Aromatic hydrocarbons**: Skin, eyes, nose, throat irritated, dyspnoea, lung dysfunction, slowdown of visual responses, memory impairment, gastrointestinal trouble, impacts on liver and kidneys, abnormal nerve system reaction, benzene is a strong carcinogen
  - **Aldehydes including formaldehyde**: Suspected carcinogenic eyes, nose, throat irritated symptoms on respiratory system
- **Heavy Metals**
  - **Mercury, in food as Methylmercury**: Brain, nervous system, kidney, and liver impaired
  - **Lead (Pb)**: Children's nervous system impaired, learning disability, dyslexia, and behavioral disorders; suspected material of damaging liver, a cause of cardiovascular disorders and anemia
  - **Antimony (Sb), Arsenic (As), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Nickel (Ni), Manganese (Mn)**: Carcinogenic lung, bladder, kidney, skin; Causes disorder in nerve system, cardiovascular, skin, respiration, and immune system; International Agency for Research on Cancer appointed arsenic and its compounds as a Group 1 carcinogen
- **Radioisotopes**
  - **Radium (Ra)**: Carcinogenic (lungs, bones), bronchial pneumonia, anemia, brain diseases
  - **Uranium (Ua)**: Carcinogenic (lungs, lymphatic system, nephritis

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**Article 8 (Air Pollution Alerts) of the Clean Air Conservation Act**

1. **The Mayor/Province governor may, when it is deemed that the degree of air pollution which exceeds the environmental standards for air as prescribed in Article 10 of the Framework Act on Environmental Policy (hereinafter referred to as the “environmental standards”) is feared to seriously harm the health and property of the residents or to the birth and breeding of animals and plants, issue an air pollution alert to the relevant area. In addition, the Mayor/Province governor shall cancel it as soon as the grounds on which the air pollution alert is issued cease to exist.**

2. **The Mayor/Province governor may, when it is deemed necessary to urgently reduce air pollution in an area in which an air pollution alert is issued, restrict the operation of automobiles, order for the curtailment of working hours in places of business, or take other measures in such area, within a fixed period of time.**

3. **A person who is subject to an order for the restriction on the operation of automobiles, the curtailment of working hours in places of business, etc. under paragraph (2) shall comply therewith, unless there is any justifiable reason otherwise.**
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Chapter 2

1 서울시가裤子for大气污染物报告(http://cleanair.seoul.go.kr/main.htm)


4 서울시가裤子for大气污染物报告(http://cleanair.seoul.go.kr/main.htm)

5 환경부,” 재고와 수도권 대기환경정화기본계획”, 2014.


7 Ibid.

8 9.10995% C1,006-1,031 PM2.5 가 10µg/m³ 증가할 때마다 조기 사망률이 0.9% 증가함 (95% 신뢰구간, 0.8-1.4% 오차범위)

9 1.02% C1,005-1,020 PM2.5 가 10µg/m³ 증가할 때마다 조기 사망률이 1.3% 증가함 (95% 신뢰구간, 0.5-2.1% 오차범위)

10 1.0015% C1,002-1,020 PM2.5 가 10µg/m³ 증가할 때마다 조기 사망률이 1% 증가함 (95% 신뢰구간, 0.2-2.0% 오차범위)


13 환경부,”알리미터해”, http://www.airkorea.or.kr

14 환경부,”알리미터해”, http://www.airkorea.or.kr

Chapter 3


4 Greenpeace, Silent Kilometers, 2013.

5 Platts(의자화점신(중국)를 재구성하는 방법으로 제안한 단일화 및 집중화에는 고려되어야만하기 허용(Configuration Fuel) 기준, Platts는 에너지, 에너지화학, 화학 및 석유부에 관한 정보 제공업체로, 상품 사양에 대한 기준 가격 명세도 제공한다.


10 이민호, “불량석의 발전 관련 사실에의한 환경부의 논의 월간신문”, (총116/연간분야, 2014)


Chapter k


Appendix

3.  서울시의 "사회적 기술적 솔루션"과 "가구형 에너지 전환"의 제도, 2010.

Inquiries
Written by
Yeunjin Kim, Researcher
Lauri Myllyvirta, Global Senior Campaigner

With the help of
Greenpeace, Hyegyeong Kim, Gyorgy Dalton, Marina Lou, Daul Jang
The Sunrise Project, Aviva Imhof, Jamie Hanson
The Yeongheung Committee for Clean Fuel Power, Jong-Ryul Yark
Korea Federation For Environmental Movements, Jieon Lee
Dangjin Korea Federation For Environmental Movements, Jongju Yu

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Contact
Seoul Office, Greenpeace East Asia
6th Floor, Cheongnyong Bld.,
Hangangdaero 287-gil, Yangsan-gu
Seoul, 140-759
Phone +82.2.3144.1994
Fax +82.2.6455.1995
www.greenpeace.org/korea
Greenpeace is an independent global campaigning organization that acts to change attitudes and behavior, to protect and conserve the environment and to promote peace.

Seoul Office, Greenpeace East Asia

6th Floor, Cheongnyong Bd., Hangangdaero 267-gil, Yongsan-gu, Seoul, 140-759
T. +82.2.3144.1994
F. +82.2.6455.1995
E. ENQUIRY.KR@GREENPEACE.ORG
H. WWW.GREENPEACE.ORG/KOREA

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