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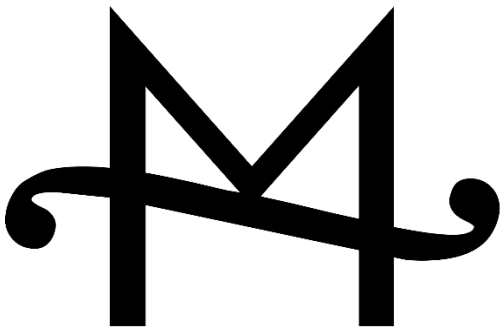

Research Topic : Global Recovery in Various Fields
Field : Exploration on How COVID-19 affects Carbon Emission in Asia
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Published by : Malaysian Actuarial Student Association (MASA)
Date of Publication: 21st September 2020

Website : **http://www.masassociation.org/**
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1 ABSTRACT

Most news is claiming how the skies are clearer since COVID-19 happened. This means that global recovery after COVID-19 not only affects the global economy but also gives impacts on the environment. During the lockdown, many regions in the world were under confinement and caused lesser flight schedules in Asia. Thus, carbon emissions have dropped in 2020 due to some of these reasons. As we know, Asia has been the largest carbon emitter in the world by the end of 2011. In this research, we will study how true the news is by investigating three countries from Asia – China, Japan and India by their respective main industries which are manufacturing, tourism, and agriculture. With the calculations of the daily average change in industry and power sectors, it is shown that there is a decrease in carbon emission for both China and India while Japan does not seem to have a significant drop in their carbon emission. All these three countries have their reasons for their changes respectively. As the carbon emissions changes, the air quality for each country is also affected. The use of two specific provinces for each country, China – Beijing, Wuhan; Japan - Sapporo, Osaka; India – Kolkata, Delhi, is further analysed to see the reasons of change in their air quality.

2 INTRODUCTION AND STATEMENT OF PROBLEM

'The crisis has shown us that we can't cut CO_2 emissions fast enough by simply shutting down, we need to do more. We need to invest in renewable energy, which can be good for the economy, which has suffered because of COVID-19. We have to spend a lot of money on the kind of clean, lean, mean green technologies that we need to decarbonise our planet. This can create more jobs, lead to more economic growth. It doesn't have to be a choice between the economy and emissions.' [1]

Global recovery in the environment field during the lockdown of COVID-19 pandemic gives a temporary impact on the reduction in carbon emission and air quality when comparing the previous years with the year 2020. The reasons for the drops in carbon emission may be due to the changes in travel restrictions which causes a decrease in flight schedules, where we will further analyse for various countries in Asia.

The comparison of carbon emission trend before and during COVID-19 will be visualised, and we will be analysing different Asian countries based on their main industry, i.e. China in the manufacturing industry, Japan in the tourism industry and India in the agriculture industry. The analysation can be related to the air quality and these can reflect whether the environment has recovered during this pandemic.

In this research, we will be focusing on how carbon emission been affected due to the lockdowns implemented during COVID-19; does the change in carbon emission depends on the industry that certain countries specialised. Also, we want to see whether there are any changes in the trend of carbon emission before, during and after COVID-19. Lastly, we investigate the relationship between carbon emission and air quality when carbon emission drops.

There is news published which caught our attention saying that the environment has improved due to the global lockdowns, whereby the reasons behind it may be linked to the changes of mobility in human due to travel restrictions and less usage of motor vehicles. This is one of the reasons why we are interested in carrying out this research, which is to investigate how true and to what extent is the published news in the reduction of carbon emission during this pandemic as well as whether other factors are affecting the carbon emissions.

Besides, in this research, we find that it is crucial to know how we can react to improve the environment by visualising the carbon emission trend in the sense that if there is a general decrease. We also want to see what we can do to continue this trend to improve the environment. If there is a general increase, we would like to find out actions that we can take to stop and the factors that drove the increase. If there is not much change in the trend, we will investigate the reason behind and any external factors that affect this result.

Moreover, when talking about global recovery, people often think about economic recovery but not environmental recovery. Therefore, we want to investigate from the side of the environment because it is equally important to the economy as our environment is precious.

[1] Time Out Tokyo. (2020). *The New Normal interview series: Covid-19 and the environment.* [online] Available at: https://www.timeout.com/tokyo/things-to-do/the-new-normal-interview-series-covid-19-and-the-environment [Accessed 8 Sep. 2020].

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By doing this research, we are more aware of the current situation of the environment with the knowledge that all of us can put efforts to improve the environment. As humans, we can reduce the carbon footprint that contributes to the reduction in carbon emission and improve the policies of a recovery plan to have better management of the environmental situation.

3 LIMITATIONS OF STUDY

There may be some possible limitations in this study. The first limitation is the **time constraint** as we only have a one-month period to conduct this research. Therefore, we only have a short time frame to collect data. Also, due to the COVID-19 situation, we are hardly interviewing people as there are many restrictions. Initially, we plan to research a few more Asian country other than China, India, and Japan, but we do not have enough time and data.

The second limitation concerns the **limited access to data**. We lack available and reliable data due to data privacy and protection. Most of the quality data need premium membership to access so we cannot afford to access it. Besides, most of our data source is from the internet, so it is difficult to identify the reliability of each data. Due to the limitations of data, there is one part of the research that we are unable to continue, which is the part where we want to see the trend of carbon emission from 2019 to 2020. We are unable to access or get any daily data for the whole of 2019 as we only have data until the end of June. Therefore, we can only see the changes from last year compared to 2020 in the first and second quarter. Also, we got an incomplete air quality index dataset, so we use PM 2.5 as the main indicator to represent the air quality index in each country.

Next, this research is subjected to the limitations of **insufficient sample size**. To generate supportive statistical evidence and valid research result, we will need a large sample size. The larger the sample, the more precise our conclusions will be. In our case, we need to find daily data to support our research and get sufficient data points. However, some of the daily data have repeated data in a specific period. When we visualize the data, we hardly see the trend because there is the lack of data points for the analysis. In the next research, we will need to check our data before we start to analyze them.

In a nutshell, these are the three limitations to the generalization of our results.

4 METHODOLOGY

This research aims to investigate the relationship between carbon emission and air quality during COVID-19. The research methods we will be using are both **quantitative and qualitative research**.

For quantitative research methods, it is the **use of secondary data** collected by various people or companies and data websites will be implied in this research. The reason for choosing this method is it is a standard method to conduct an investigation. It shows the validity where most of the data used are taken from official organizations. Also, there is reliability where the usability of data from websites is high. They were used by most data scientists and researchers. The data are collected from the depositories such as Power System Operation Corporation Limited (POSOCO), Carbon Monitor and Air Quality Open Data Platform.

For qualitative research methods, it is used for a deeper understanding of the numbers behind the data and the **resources used are from online articles, research or analysis by other researchers and authors**.[2] (McCombes, 2019) This method is suitable for secondary research after data analyzing and visualization. The data found are analyzed using different ways which are data visualization using Python, content analysis by categorizing and discussing the meaning behind the words, phrases, or sentences.

[2] McCombes, S., 2019. *How to Write Research Methodology in Four Steps / With Examples.* [online]. Scribbr. Available at: https://www.scribbr.com/dissertation/methodology/ [Accessed 3 August 2020].

5 LITERATURE REVIEW

Below are some researches, which are related to our topic, done by other groups of people:

1. **(Le Quéré, 2020)**[3] investigated the temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. In this report, they compiled government policies and activity data to investigate the reduction in CO_2 emissions. They found out that the daily global CO_2 emissions have fallen by 17% in early April 2020. Compared with the mean 2019 level, the changes are mostly because of surface transport. Emissions in each country reached -26% at their peak. The duration of the confinement will be the main impact of the drop in annual emissions. Thus, the emissions will float between -4% (if pre-pandemic conditions return by mid-June) and 7% (if worldwide restrictions remain until the end of 2020).

2. **(Qingqing Wang, 2020)**[4] found that the coronavirus pandemic reduced China's CO_2 emissions in short-term, while stimulus packages may lead to emissions growth in the medium- and long-term. They investigated how the coronavirus pandemic has caused reductions in coal, oil, and natural gas consumptions in China since January 2020. The results led to the conclusion that CO_2 emissions decreased by 18.7%. Even so, China's governments have released several stimulus packages to achieve the economic target for the 13th Five-Year-Plan. Therefore, COVID-19 may cause an increase in CO_2 emissions at a higher speed.

3. **(Xinbo Lian, 2020)**[5] investigated the impact of city lockdown on the air quality of COVID-19-hit of Wuhan city. They studied the changes in PM2.5, NO_2 and O_3 in Hubei Province one month before and after the lockdown and to further analyze the impact of human activities on atmospheric pollutant concentrations. They found out that the average monthly air quality index (AQI) in Wuhan was 33.9% lower after the lockdown. Besides, particulate matter (PM2.5) decreased by 36.9 % compared to the conditions before the lockdown. Nitrogen dioxide (NO_2) showed a decrease of 53.3% and ozone (O_3) increased by 116.6%. Also, O_3 pollution shows a highly negatively correlation with NO_2 concentration.

4. **(Sahar Safarian, 2020)**[6] studied the effect of COVID-19 on CO_2 emission globally. In this paper, they used a simple estimation model to assess the reduced CO_2 emissions in March 2020. By this indicator, they assume three scenarios based on the pandemic and distinct reduction percent of fossil fuels consumption in various sector in 2020. The three scenarios are the number of infected people increasing before peak region, the infectious growth rate reaches to peak region, and the growth rate falls after its peak. The carbon emission is estimated to be 34.4, 32.4 and 35.3 in three scenarios, respectively. As a consequence of COVID-19, CO_2 emissions worldwide in March 2020 has been 7% lower than the monthly average of this parameter in 2019.

[3] Le Quéré, C., Jackson, R.B., Jones, M.W. et al, 2020. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nat. Clim. Chang. 10, 647–653 (2020). https://doi.org/10.1038/s41558-020-0797-x [Accessed 1 September 2020].

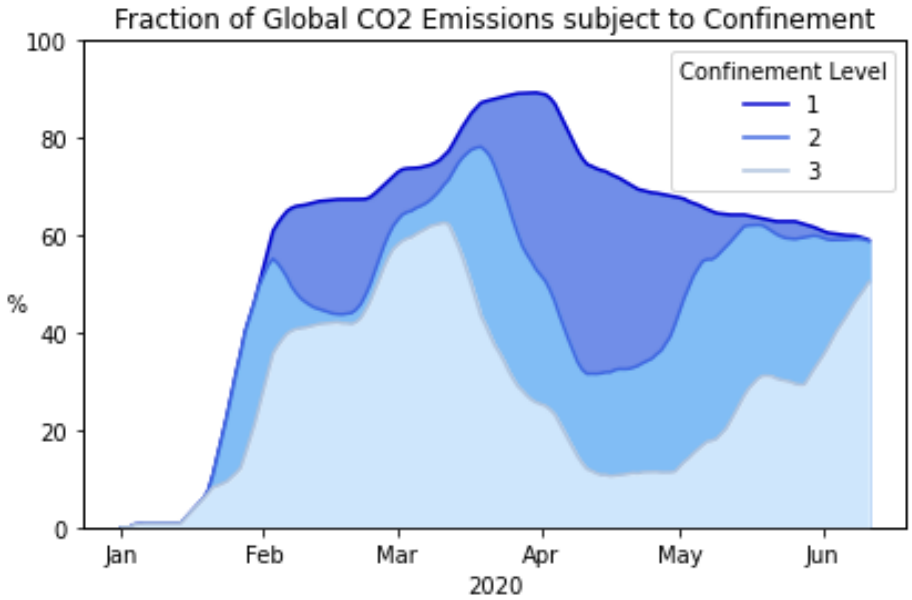
[4] Qingqing Wang, Mei Lu, Zimeng Bai, Ke Wang, 2020. Coronavirus pandemic reduced China's CO2 emissions in short-term, while stimulus packages may lead to emissions growth in medium- and long-term. https://doi.org/10.1016/j.apenergy.2020.115735 [Acceseed 1 September 2020].

[5] Xinbo Lian, Jianping Huang, Rujin Huang, Chuwei Liu, Lina Wang, Tinghan Zhang, 2020. Impact of city lockdown on the air quality of COVID-19-hit of Wuhan city. https://doi.org/10.1016/j.scitotenv.2020.140556 [Accessed 2 September 2020].

[6] Safarian, S., Unnthorsson, R. and Richter, C. (2020). Effect of Coronavirus Disease 2019 on CO2 Emission in the World. Aerosol Air Qual. Res. 20: 1197–1203. https://doi.org/10.4209/aaqr.2020.04.0151 [Accessed 2 September 2020].

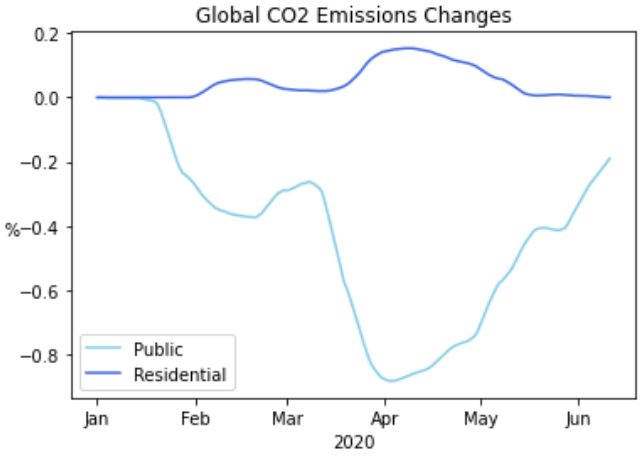
6.1 REASONS WHY CARBON EMISSION DROP IN 2020

Figure 1.1: More than 80% of region under confinement around April



Due to the outbreak of COVID-19, many countries have put their cities into lockdown. The population confined to the home, and the business operations are restricted. To see the restrictions all over the world, we use the confinement level index as a reference. Level 0 indicates no restrictions, and level 3 indicates significant restrictions. Therefore, we can see from Figure 1.1 that the confinement level of areas that emit carbon dioxide increased gradually when the COVID-19 pandemic started to spread rapidly through the continent. The confinement level has reached its peak around April, which more than 80% of areas emitting carbon dioxide are under confinement. This situation directly leads to a reduction in carbon emission globally. It is because people change their consumption habit and reduce their mobility.

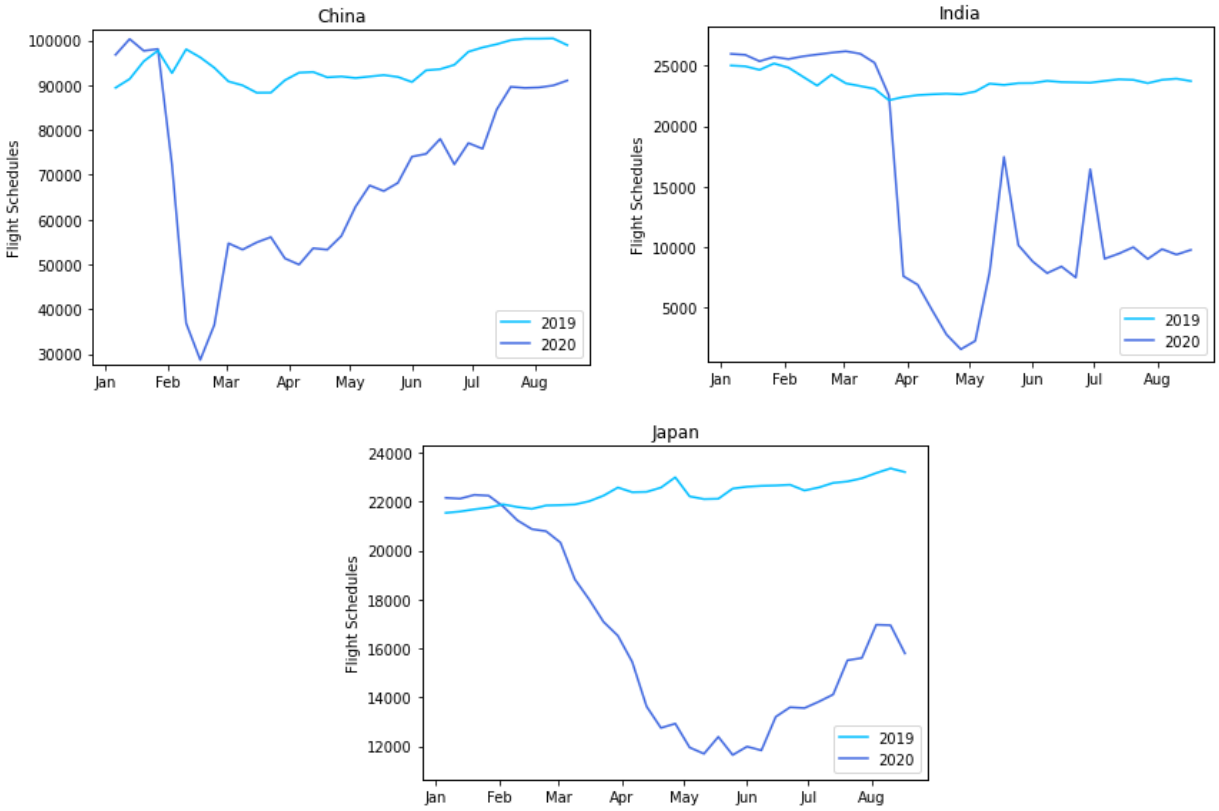
Figure 1.2: Increase in global carbon emission in residential



From Figure 1.2, we can see that the carbon emissions changes in the public have a significant reduction, but there is a slight increase in residential carbon emission. Both of the changes happened in around April, which shows the impact brought by the confinement to keep social distancing in each country. However, the rise of carbon emission in residential does not affect much to the reduction of carbon emission as the daily global CO_2 emissions have fallen by 17% in early April 2020 compare to the mean 2019 level.[7]

[7] Le Quéré, C., Jackson, R.B., Jones, M.W. et al. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nat. Clim. Chang. 10, 647–653 (2020). https://doi.org/10.1038/s41558-020-0797-x [Accessed 1 September 2020].

Figure 1.3: Drop in flight schedules in Asia



Apart from the lockdown and movement restrictions in cities, there are also travel bans all around the world. From Figure 1.3, we can see that there is a drastic drop in flight schedules in 2020 compared to 2019 due to the outbreak of coronavirus. Overall, three countries have shown sign of recovery around July. Overall, most of the countries are experiencing minor improvements or deteriorations in capacity each week as airlines look for changing demands or respond to enhanced lockdown measures.

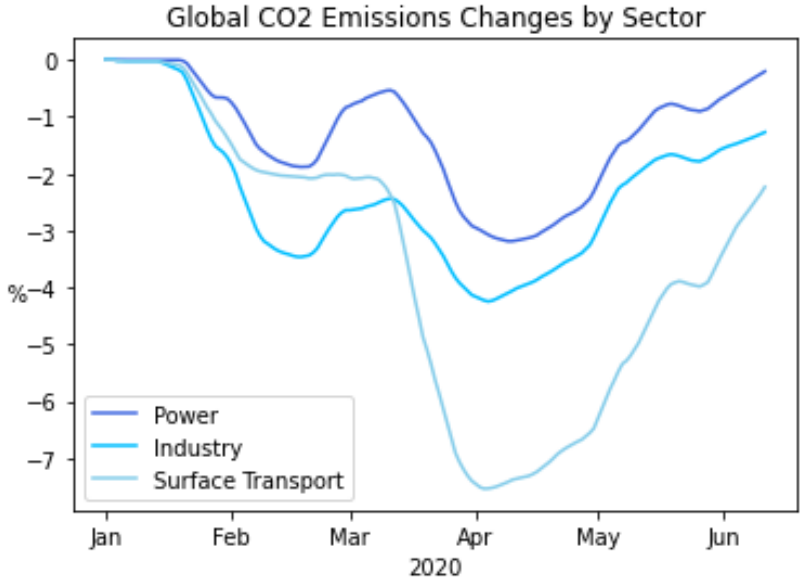
In China, the drop in flight schedule is nearly 70% in the first quarter of 2020, and it is mainly because China is the epicentre of coronavirus pandemic. The industry data provider OAG reports reductions of 50-90% in capacity on routes departing mainland China and a 60-70% reduction in domestic flights within the mainland from 10 until 24 February, compared with the week commencing 20 January.[8] Although the domestic capacity of China has recovered, the international flights are still down by over 90% until 24 August as there are still restrictions on international travel.[9]

In India, the worst drop happens in the week of 27 April, which is around -93.1% compared to last year. It is because India started its lockdown on the end of March and the travel restrictions continued with the closure of borders. In Japan, they experienced a drop between May and June, but it has risen again in July and show a signal of recovery.

[8] Lauri Myllyvirta, 2020. *Analysis: Coronavirus temporarily reduced China's CO2 emissions by a quarter.* [online]. Available at: https://www.carbonbrief.org/analysis-coronavirus-has-temporarily-reduced-chinas-co2-emissions-by-a-quarter [Accessed 1 September 2020].

[9] OAG, 2020. *How and When Will Aviation Recover from Covid-19?* [online]. Available at: https://www.oag.com/coronavirus-airline-schedules-data [Accessed 1 September 2020].

Figure 1.4: Drop in global carbon emission changes by sector



Besides the aviation sector mentioned in the part above, Figure 1.4 also shows that the sector which contributed most to the reduction of global carbon emission is surface transport such as public transport. It is because public transport is considered high risk due to the high density of passenger, especially for peak hours, so there is a higher chance of getting an infection from public surfaces. Public transport systems have ground to halt, and it contributes a lot to the drop in carbon emission.[10] (Hemant K. Suman, 2020) Apart from this, most of the people started working and studying at home. They seldom drive their vehicle as their movement is also restricted.

Following the land transportation, power and industry sector also experienced a drop in April 2020. As a result of the lockdown implemented, factory operation and manufacturing activities have forced to shut down. There is no doubt that manufacturing is one of the sectors that have taken a hit during the lockdown. They have faced problems like reducing the workforce or some absent teams as some rules need to follow during the pandemic. Also, there has been a disruption in supply chains and an aggressive decline in customer demand.[11] Therefore, the level of global emissions of power and industry sector was affected.

Although the emission has risen back after most of the countries loosen their lockdown restrictions, the manufacturing, transportation and travelling sector still need a period to return their production into the post-COVID level.

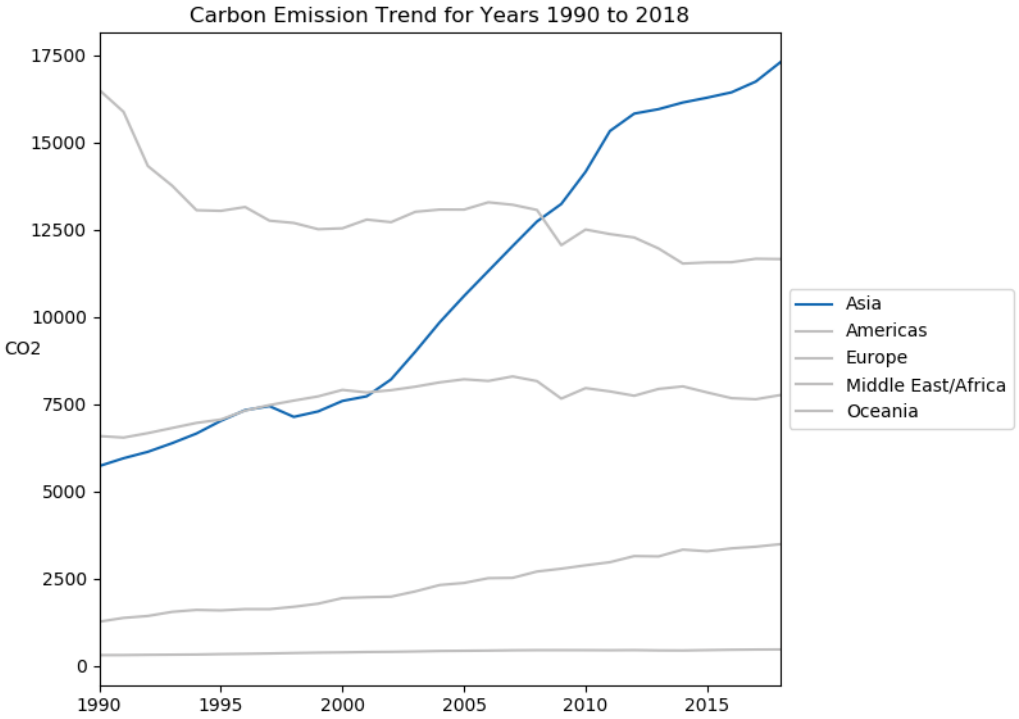
[10] Suman, H.K., Agarwal, A. & Bolia, N.B. Public Transport Operations After Lockdown: How to Make It Happen?. Trans Indian Natl. Acad. Eng. 5, 149–156 (2020). https://doi.org/10.1007/s41403-020-00121-x [Accessed 3 September 2020].

[11] Cristina Diaconu, 2020. *The Impact of Coronavirus Lockdown on the Manufacturing Sector.* [online]. Available at: https://www.memuk.org/manufacturing/the-impact-of-coronavirus-lockdown-on-the-manufacturing-sector-57696 [Accessed 3 September 2020].

6.2 CARBON EMISSION & AIR QUALITY IN CERTAIN ASIAN COUNTRIES BY INDUSTRIES

6.2.1 General Carbon Emission Trend before COVID-19

Figure 2.1: Asia - The largest emitter of carbon in the world



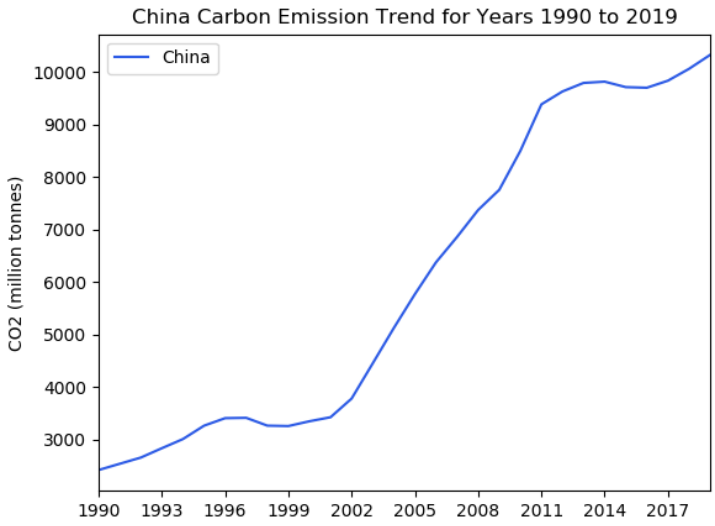
In 1994, Asia's gross domestic product became the largest in the world. Interestingly, though, Asia became the largest emitter of CO_2 one year before—in 1993—largely due to rapid economic growth in China. The chart above outlines this significant shift. In the past, the largest share of global emissions came from Europe and Northern America. But by the end of 2011, Asia dominated, contributing more than half of global carbon emissions.

6.2.2 China - Manufacturing

China is known as 'the World's Factory'. It is the world's largest manufacturer and exporter because of its strong business ecosystem and infrastructure and low taxes rates and duties. Also, thanks to its low labour cost and technically skilled workforce, it has been an attractive destination for manufacturing in recent decades.[12]

The industry was 39% of China's gross domestic product (GDP) in 2019. China had become the world's second-largest economy by 2010 with its national economy growing at an annual growth rate of above nine per cent for three decades in succession. [13] Besides, China outpaced the United States in factory output by the early 2000's. [14](Blacksmith International, 2019) One of the main reasons is China specialize in several different product categories. Aside from the technology industry, China also dominates in electrical machinery, clothing, automobile parts and so on. Among all the manufacturing branches, metallurgical and machine-building industries alone now account for about two-fifths of the total gross value of industrial output.[15] (C. Martin Wilbur, 2020) As a result of focusing on power and manufacturing industry, China's carbon emission has been rising for years before the COVID-19 pandemic.

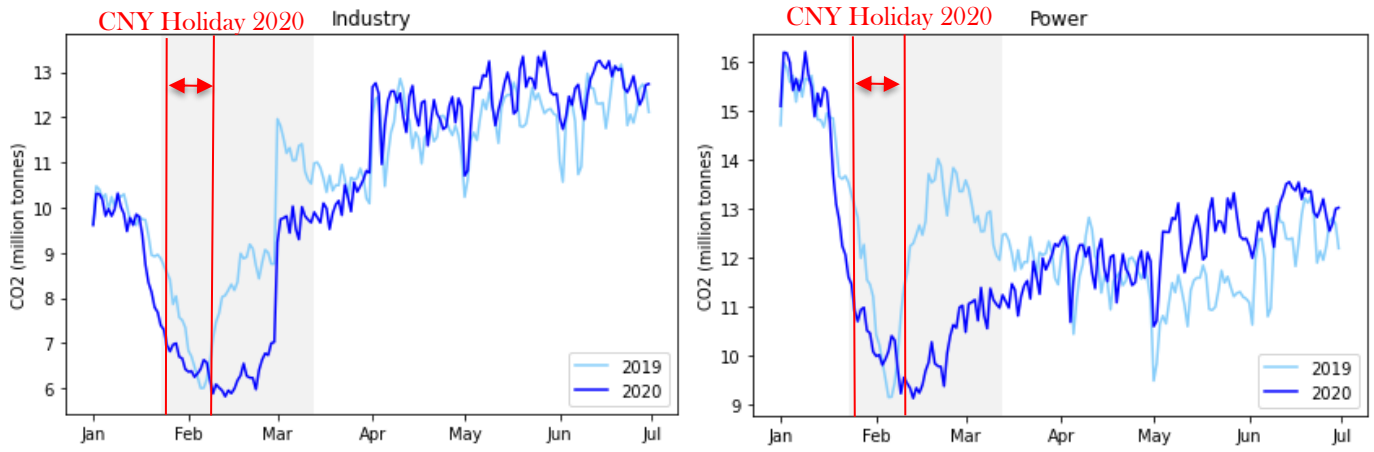
Figure 3.1: China- The world's top carbon emitter



China, one of the world's largest populations and for decades one of the fastest growing economies, China is far and away the world's top CO_2 emitter. Close to 10,000 million tonnes of CO_2 from burning fossil fuel were emitted by the superpower in 2017. Driving China's CO_2 emissions is the nation's massive coal production. China's generation of electricity from coal has dropped slightly from 75% in 1992 to 70% in 2015. Still, overall coal production has tripled since 2000 to nearly 4,000 million metric tons – approximately half of all global coal production.

[12] Asialink Business, n.d. *Manufacturing in China.* [online]. Available at: https://asialinkbusiness.com.au/china/business-practicalities-in-china/manufacturing-in-china?doNothing=1 [Accessed 3 September 2020].
[13] Statista, 2020. *China: distribution of gross domestic product (GDP) across economic sectors from 2009 to 2019.* [online]. Available at: https://www.statista.com/statistics/270325/distribution-of-gross-domestic-product-gdp-across-economic-sectors-in-china/ [Accessed 3 September 2020].
[14] Blacksmith International, 2019. *How Did China Become the World's Factory?* [online]. Available at: https://blacksmithint.com/how-did-china-become-the-worlds-factory/ [Accessed 3 September 2020].
[15] C. Martin Wilbur, David N. Keightley, 2020. China. [online]. Available at: https://www.britannica.com/place/China/Manufacturing [Accessed 3 September 2020].

Figure 3.2: Drop in carbon emission during the lockdown



The lockdown period in China is from 23rd January 2020 to 8th April 2020 as shaded in the graph above. Before the lockdown, the carbon emission level remains the same compare to last year. During the lockdown, the carbon emission of power and industry sector has a significant drop. It is because there are restrictions on manufacturing and most of the factories shut down. We can see from the table below, the average daily difference between the lockdown period in each sector is around -10%.

Sector	Average Daily Difference
Industry	-11.39%
Power	-10.41%

From the report published by KPMG China, manufacturers will typically ramp up production before the Lunar New Year every year to compensate for the decrease in productivity during the holiday. In addition, they often take time to return to pre-holiday levels as factory workers will extend their new Year holiday. Hence, some manufacturers may find their finished products will continue to meet the demand as the restart process remains. [16] This situation explains why the carbon emission before the COVID-19 is high the same as last year but drop in both years during Lunar New Year Holiday around February. In 2020, it took a longer time to recover and bounce back because of the interruption of coronavirus.

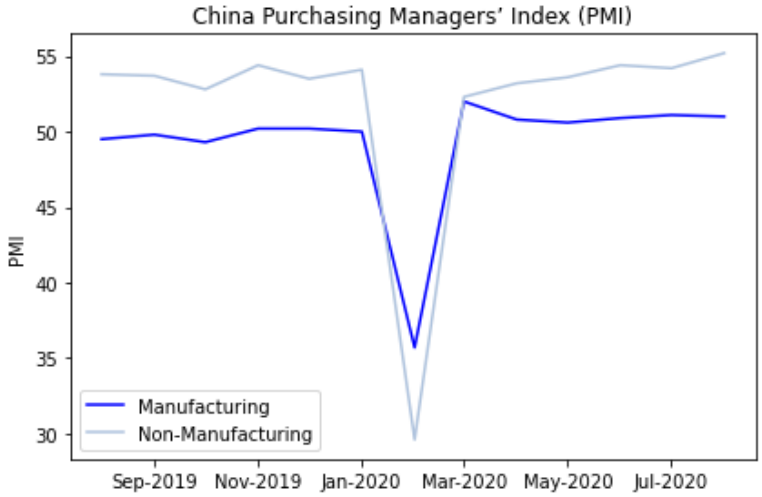
China has extended its Lunar New Year Holiday until 10th February 2020 to stop the spread of coronavirus. Factories began reopening on that day across the country with different rules and regulations across the country. Although they managed to restart their operation, they have faced problem in the workforce as most of the workers trapped in their hometown during the Chinese New Year holiday. The workers will need time to quarantine themselves for safety issue. The American Chamber of Commerce (AmCham) has surveyed 109 companies in the manufacturing powerhouse of the Shanghai region. They found that while two-thirds of factories were up and running by the end of last week, 78 per cent did not have enough workers to kick-start full production. At Foxconn plants that usually employ 16,000 and 20,000 workers in Zhengzhou

[16] KPMG China, 2020. *Rebooting manufacturing in mainland China.* [online]. Available at: https://home.kpmg/cn/en/home/insights/2020/02/rebooting-manufacturing-in-mainland-china.html [Accessed 7 September 2020]

and Shenzhen, only 10% were expected back to work last week, Reuters reported.[17] Besides, the factories also lack a face mask which leads to regulatory problems.

Therefore, the carbon emission in China was very low when the factories failed to pull their production back to the pre-COVID level in short. This situation has also caused a disruption in the global supply chain as manufacturers are now struggling to resume operations, with many workers unable to return due to continued travel restrictions.[18]

Figure 3.3: V-shape bounced back in PMI



As a result, China's official manufacturing purchasing managers' index (PMI) dropped to 35.7 in February from 50.0 in January, below the 38.8 figure reported in November 2008. Apart from that, the non-manufacturing index has plunged to 29.6 compared to 54.1 in January. [19] In the first quarter of 2020, China's GDP contracted by 6.8% from a year ago, which is also the first decline since at least 1992.[20]

However, the index bounced back quickly as we can see from figure 3.3, there is a V-Shape bounced back for both manufacturing and non-manufacturing PMI on March 2020. Although the regions under lockdown accounted for 90% of the country's exports, according to CNBC calculations of data accessed through Wind Information[21], most of them have loosened their restrictions and controls starting from 13 March 2020. From the joint report of consultancy Oliver Wyman and risk advisory Silk Road Associates, they mentioned that signs of recovery are to be seen across China when some school reopening, manufacturing PMI rebounding and people started travelling around. [22] In the report, they also said that the factories will need

[17] Finbarr Bermingham, 2020. *Coronavirus: American factories in China unable to staff production lines as lockdown continues.* South China Morning Post, [online]. 17 Feb. Available at: https://www.scmp.com/economy/china-economy/article/3050984/coronavirus-american-factories-china-unable-staff-production [Accessed 6 September 2020].

[18] Andrew Mullen and Orange Wang, 2020. *Coronavirus: China's factory activity plunges to all-time low, worse than global financial crisis, February data show.* [online]. Available at: https://www.scmp.com/economy/china-economy/article/3052985/coronavirus-chinas-factories-activity-plunges-all-time-low [Accessed 6 September 2020].

[19] National Bureau of Statistics of China, 2020. [online]. Available at: http://www.stats.gov.cn/english/PressRelease/202009/t20200901_1787004.html [Accessed 6 September 2020].

[20] Huileng Tan, 2020. *Slowing global demand due to coronavirus hits China's manufacturing sector in April, two sets of data show.* [online]. CNBC. Available at: https://www.cnbc.com/2020/04/30/china-reports-official-april-manufacturing-data-as-coronavirus-lockdowns-ease.html [Accessed 6 September 2020].

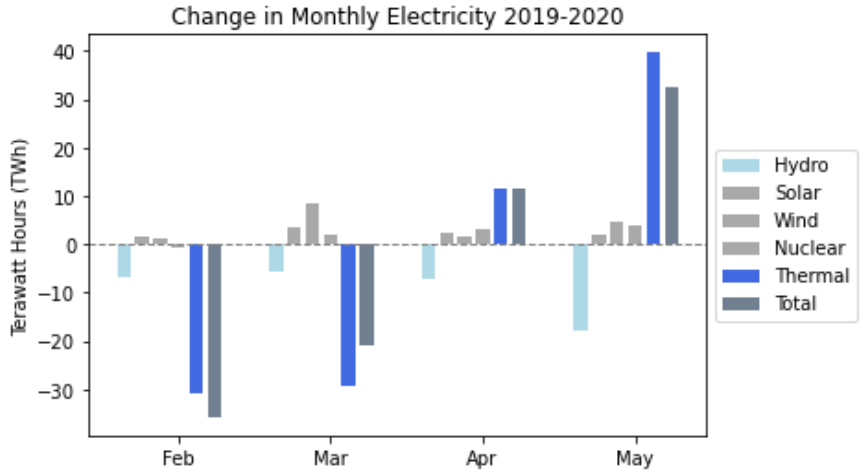
[21] Evelyn Cheng, 2020.*China may become one of many hubs as companies diversify manufacturing after coronavirus shock.* [online]. CNBC. Available at: https://www.cnbc.com/2020/05/25/china-one-of-many-manufacturing-hubs-in-a-post-coronavirus-world.html [Accessed 6 September 2020].

[22] Oliver Wyman and risk advisory Silk Road Associates, 2020. *WHAT MIGHT CHINA'S RECOVERY LOOK LIKE.* [online]. Available at: https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2020/may/what-might-china-s-recovery-look-like.pdf [Accessed 7 September 2020].

to increase production to meet the backlog of orders when the finished goods inventories are not enough. The V-shaped "bounce" indicates the manufacturing production in China has rebounded to levels seen before the COVID-19 pandemic.

Anyway, the drop in carbon emissions is also likely to vanish as Chinese industry ramps up again to offset its economic losses. According to a report by Carbon Brief, the increase in carbon emissions of power sector in May was mainly driven by coal power, cement, and other heavy industries. [23] These industries were bouncing back faster than other less emitting service and consumption sectors of the economy and prompted concerns about the global implications of a coal-heavy recovery in China.

Figure 3.4: High usage of non-renewable energy in May



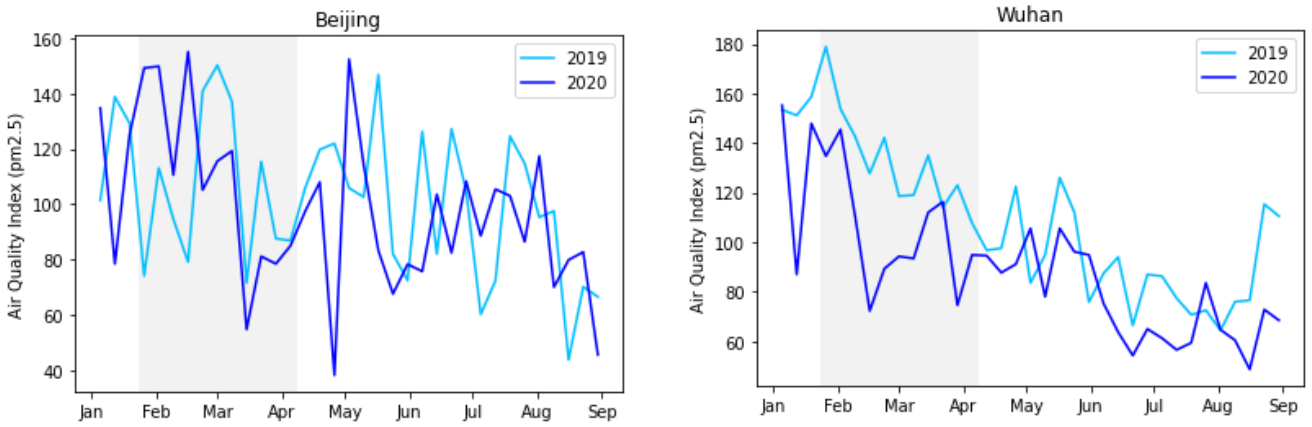
From figure 3.4, we can see that the 9% increase in thermal power generation is the biggest drives of the overall increase in CO_2 emissions in May. This mainly coal-fired power has rebounded much faster than overall power demand due to the weak installations of non-fossil energy and poor hydropower operating conditions this year. Although the nuclear, wind and solar power generation increased by 14%, 5% and 7% year-on-year in May respectively, it was insufficient enough to offset the 17% drop in hydropower.[24]

Consequently, the reasons for the rebound of carbon emissions in both industry and power sector is obvious when the emissions from power plants, industry and transport have been increasing. The coal consumption at five main power generating companies in eastern China rose above 2019 levels in early May. Cement and metals manufacturing rebounding in April, as the cement and non-ferrous output both increased 4% after the cement output falling 18% in March. Also, the steel output returned to growth after falling in March.[25]

[23] [23] Lauri Myllyvirta, 2020. *Analysis: China's CO2 emissions surged past pre-coronavirus levels in May.* [online]. Available at: https://www.carbonbrief.org/analysis-chinas-co2-emissions-surged-past-pre-coronavirus-levels-in-may?utm_content=bufferd871f&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer [Accessed 8 September 2020]

[25] CREA, 2020. *China's air pollution overshoots pre-crisis levels for the first time.* [online]. https://energyandcleanair.org/wp/wp-content/uploads/2020/05/China-air-pollution-rebound-final.pdf [Accessed 8 September 2020].

Figure 3.5: Air Quality Index (PM2.5) in China



Data from the Centre for Research on Energy and Clean Air (CREA) shows that the national average PM2.5 levels fell by 33% in the 30 day after 3rd February 2020. [26] The lockdowns had a dramatic impact on China's fossil fuel consumption and air quality. CO_2 emissions fell as shown in the part above with coal-fired power generation, cement manufacturing and oil consumption all plummeting. To investigate the relationship between the carbon emission and the air quality in China, we choose two main provinces from China and generate graphs using their PM 2.5 index.

Province	Average Daily Difference
Beijing	60.00%
Wuhan	-19.66%

Although the PM2.5 levels fell overall in China after the lockdown, not all cities have experienced improvements. In mid-February, Beijing saw a spike in pollution due to local weather patterns trapping air in the region.[27] Beijing has high air pollution due to its nature of the industry which are the coal-burning factories and geographical issue. It includes the largest concentration of iron and steel factories, and non-ferrous metals industries in the country with 14% of national thermal power generation.[28] Therefore, it becomes a victim of its topography as it is surrounded by mountains, ensuring that pollution was trapped within the city limits. During spring and summer, when the temperature and humidity levels rise, the winds bring the smog carrying pollutants from industrialized southern regions, so the air quality becomes even worse.

A research team led by Prof. Yele Sun from the Institute of Atmospheric Physics of the Chinese Academy of Sciences found that air pollution in Beijing during the COVID-19 lockdown was mainly due to different chemical responses of primary and secondary aerosols to changes in anthropogenic emissions.

[26] Centre for Research on Energy and Clean Air (CREA), 2020. *China's air pollution overshoots pre-crisis levels for the first time.* [online]. Available at: https://energyandcleanair.org/wp/wp-content/uploads/2020/05/China-air-pollution-rebound-final.pdf [Accessed 7 September 2020].

[27] Lauren Sommer, 2020. *Why China's Air Has Been Cleaner During The Coronavirus Outbreak.* [online]. Available at: https://www.npr.org/sections/goatsandsoda/2020/03/04/811019032/why-chinas-air-has-been-cleaner-during-the-coronavirus-outbreak [Accessed 7 September 2020].

[28] CREA, 2020. *Air Pollution in China 2019.* [online]. Available at: https://energyandcleanair.org/wp/wp-content/uploads/2020/01/CREA-brief-China2019.pdf [Accessed 7 September 2020].

"Primary gaseous and aerosol species responded directly to emission changes and decreased substantially by 30-50%", said Sun. "However, secondary aerosol species that are formed from oxidation of gaseous precursors and accounted for more than 70% of particulate matter remained small changes of less than 12%. Therefore, fine particle pollution hasn't been improved as expected." [29] (Newswise, 2020)

Conversely, Wuhan has a significantly better air quality than other provinces. It is because Wuhan is the epicenter of the coronavirus, and it has the longest lockdown period. Factories in Hubei are expected to remain shuttered for some time, as the top priority remains the controlling of the disease and the physical wellbeing of the population. Wuhan is the transportation and trade center of China. As they lack central heating and chemical industry, also any coal-fired enterprise that is rural biomass burning activities, vehicle emissions are the most crucial pollution source affecting the air quality in Wuhan.[30] Consequently, the air quality in Wuhan become better during the lockdown as transportation has the most restrictions to prevent the transmission of coronavirus.

[29] Newswise, 2020. A chemical cocktail of air pollution in Beijing, China during COVID-19 outbreak. Available at: https://www.newswise.com/coronavirus/a-chemical-cocktail-of-air-pollution-in-beijing-china-during-covid-19-outbreak/?article_id=734300 [Accessed 16 September 2020]

[30] Xinbo Lian, Jianping Huang, Rujin Huang, Chuwei Liu, Lina Wang, Tinghan Zhang, 2020. Impact of city lockdown on the air quality of COVID-19-hit of Wuhan city. https://doi.org/10.1016/j.scitotenv.2020.140556 [Accessed 2 September 2020].

6.2.3 Japan - Tourism

Japan is one of the leading tourism destinations in the APAC regions where it is the 4th largest travel economy in the world. The Japanese tourism industry has demonstrated sustainable growth during recent years. The number of international travellers coming to Japan more than tripled during the recent decade. As of 2017, about 29 million international travellers visited Japan – up from approximate 24 million foreign visitors registered in 2016. It is expected that about 40 million visitors will come to Japan in 2020 due to the Summer Olympics that are scheduled to be held in Tokyo. The most popular cities amid foreign travellers are Tokyo, Osaka, Kyoto, and Kobe. The total contribution of travel and tourism to the Japanese economy in 2017 was JPY37,136 billion, once all the direct, indirect, and induced benefits were taken into account. [31]

Factors driving this positive international visitor growth trend include the relaxation of visa requirements, extension of the consumption tax exemption system, ongoing Visit-Japan marketing and promotion projects and positive image of Japan overseas, expansion of airline networks, and closer cooperation between government agencies and the public and private sector, as well as the depreciation of the yen. [32]

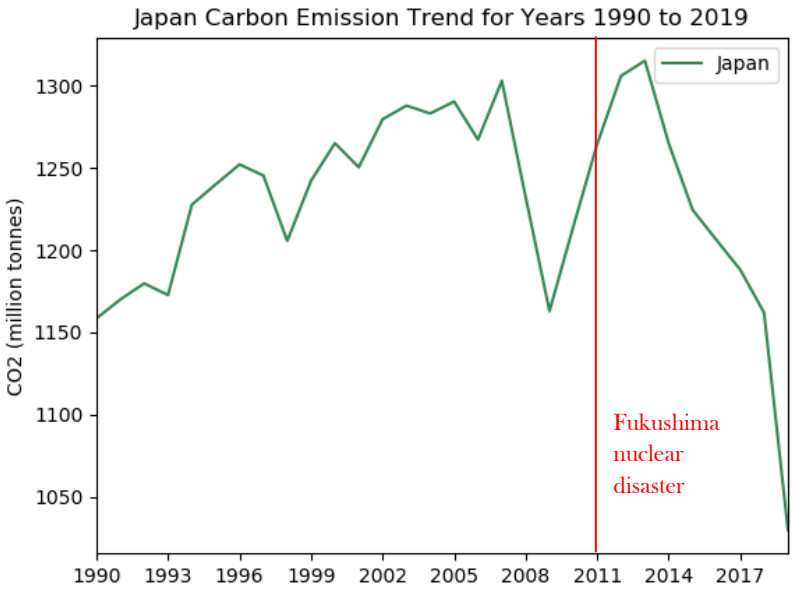
However, apart from Mainland China, Japan receives a high number of visitors from coronavirus-affected countries including South Korea, Taiwan, Hong Kong, Thailand, Singapore, Malaysia, and the Philippines. Tour cancellations from these countries are expected to cause a significant drop in foreign visitors to Japan in Q1 2020. Foreign visitors to Japan already declined by 1.1% in January 2020, compared to January 2019. A 59.4% fall in visitors from Korea was offset by an increase in visitors from Hong Kong, Singapore, Malaysia, Philippines, and Vietnam, which witnessed 33%-42% growth.[33]

[31] Tore, O., 2018. *Japan's Travel & Tourism supports 4.2 million jobs.* [online]. Available at: https://ftnnews.com/other-news/33974-japan-s-travel-tourism-supports-4-2-million-jobs [Accessed 2 September 2020].

[32] Japan, 2016. *OECD Tourism Trends and Policies 2016*, pp.212–217.

[33] Duddhu, P., 2020. *Japan coronavirus outbreak, updates, COVID-19 travel measures & impact.* [online]. Available at: https://www.pharmaceutical-technology.com/features/countries-with-coronavirus-japan-covid-19-impact-economy-travel-trade/ [Accessed 9 September 2020].

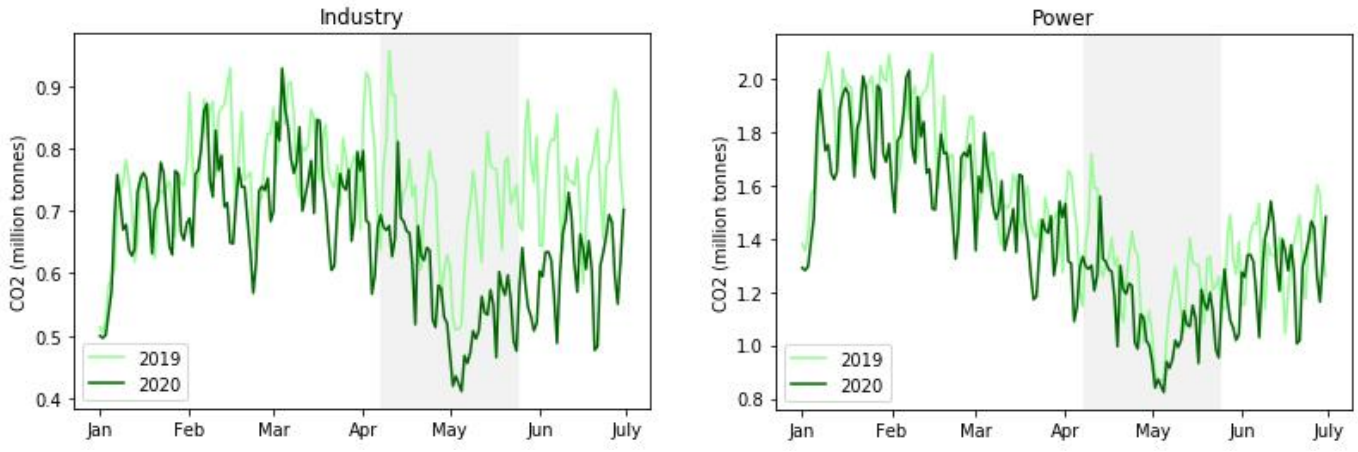
Figure 4.1: Decrease in carbon emission after the peak in Fukushima nuclear disaster



In Japan, the CO_2 emissions peaked in the three years following the 2011 Fukushima nuclear disaster, reaching 1,314 million tonnes of CO_2 in 2013. Emissions have since been reduced to pre-2011 levels as the country has increased its use of renewables – now about 5% of its energy mix. Still, Japan is heavily reliant on oil and is criticized for its promotion of coal and technology to reduce CO_2 emissions from coal.

Japan saw energy-related CO_2 emissions fall 4.3% to 1030 million tonnes in 2019, the fastest pace of decline since 2009 thanks to growing use of renewable energy and the gradual return of nuclear power as well as warmer winter. The power sector experienced the largest drop in emissions as reactors that had recently returned to operation contributed to a 40% increase in nuclear power output. This allowed Japan to reduce electricity generation from coal-, gas- and oil-fired power plants. It is the fifth straight annual decline and comes against a surge in global greenhouse emissions to a record last year.

Figure 4.2: Drop in carbon emission during lockdowns



The lockdown period for Japan as shown in the shaded region of Figure 4.2, April 7 - Prime Minister Shinzo Abe declares state of emergency for seven prefectures; May 25 - State of emergency lifted in remaining prefectures, Tokyo, Hokkaido, Chiba, Saitama, and Kanagawa.

Based on Figure 4.1, the average daily difference between 2019 and 2020 for industry and power sector in Japan are shown in the table below:

Sector	Average Daily Difference
Industry	-19.18%
Power	-8.89%

For the industry sector, the difference between 2019 and 2020 is not much but during and after the lockdown period, there was a slight decrease in year 2020 compared to 2019. For the power sector, the trend is almost same for both 2019 and 2020. The slight decrease and almost similar trend for carbon emission by both sectors maybe due to Japan has started practicing renewable energy since years before and aim to increase energy from renewables to 22-24% of the total by 2030.

Japan's government has announced it will phase out 90% of the country's old and inefficient coal-fired power generators, alongside the construction of "cleaner" high efficiency coal power by 2030. Minister for Economy, Trade, and Industry (METI) Hiroshi Kajiyama said coal-fired power will remain Japan's baseline electricity source, but 114 high CO_2 emitting coal power plants will be shut down to reduce overall carbon emissions. Japan currently has 140 coal power plants.[34] This leads to slight decrease in the power sector in 2020. With nuclear largely off the table and scepticism around renewables, Japanese officials have increasingly turned to natural gas and coal, over the objections of environmentalists and locals in many of the communities where new plants are planned.

To understand why Japan would turn to coal at this critical moment in history, we have to go back to 2011, when a magnitude 9 earthquake triggered a massive tsunami that towered more than 20 feet high and struck parts of Japan's Pacific coast.

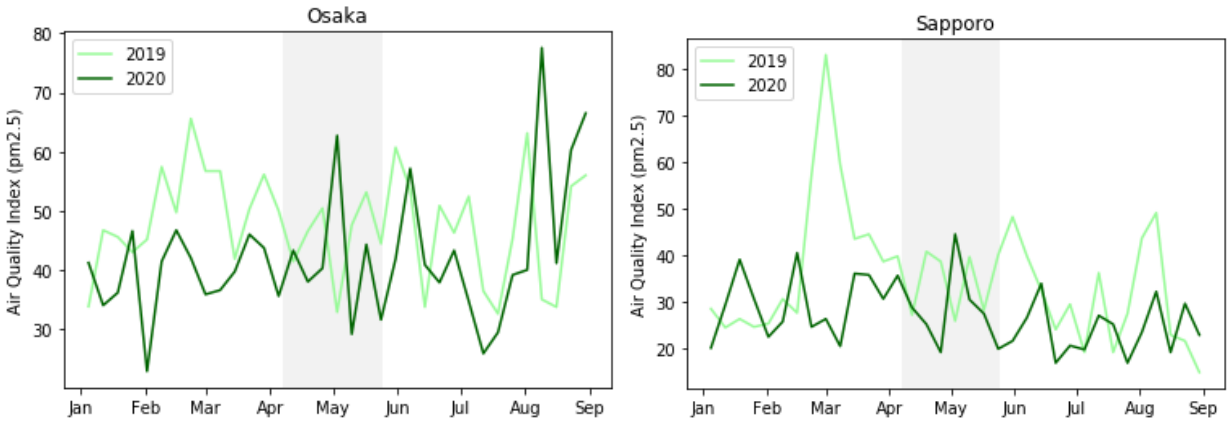
The reactors at the Fukushima Daiichi nuclear power plant automatically shut down in response to the earthquake, but the tsunami overtopped the plant's seawall, stalling the backup generators that were providing vital cooling to the idled reactors. The lost coolant led to meltdowns and explosions at the plant, releasing dangerous radioactive material.[35]

We can summarise that since Japan uses coal power plants as one of their main electricity sources, so as the lockdown implied there is less power used, thus the calculations show that power has smaller difference on average daily difference compare to industry sector.

[34] Siripala, T., 2020. *Japan Promotes 'Clean' Coal in the Battle Against Climate Change*. [online]. thediplomat.com. Available at: https://thediplomat.com/2020/07/japan-promotes-clean-coal-in-the-battle-against-climate-change/ [Accessed 7 September 2020].

[35] Irfan, U., 2020. Why the world's third-largest economy is still betting on coal. Vox. [online]. 19 Feb. Available at: https://www.vox.com/2020/2/18/21128205/climate-change-japan-coal-energy-emissions-pikachu [Accessed 8 September 2020].

Figure 4.3: Air Quality Index (PM 2.5) in Japan



Province	Average Daily Difference
Osaka	15.08%
Sapporo	-3.11%

Osaka city is at the centre of the second largest metropolitan area of Japan. Osaka metropolitan area covers 7,800 square kilometres within a radius of 50–60 km from the centre of Osaka. The population exceeds 10 million, making it one of the world's biggest metropolitan area. The area is known for its manufacturing technologies operated by small- and medium-sized enterprises. This area rarely experiences clear air conditions with a limited number of small particles, and often suffers high levels of pollution from particles emitted from diesel vehicles and industrial activities. [36] This is why the air quality is not getting better during the lockdown.

Sapporo is the fourth largest city in Japan by population, and the largest city on the northern Japanese island of Hokkaido. Located in Ishikari Subprefecture, it is the capital of Hokkaido Prefecture, and an ordinance-designated city of Japan. The tertiary sector dominates Sapporo's industry. Major industries include information technology, retail, and tourism, as Sapporo is a destination for winter sports and events and summer activities due to its cool climate.[37] The annual Sapporo Snow Festival drew 2.02 million visitors this year, down 716,000 from last year's record, 2.74 million, amid growing fears over the new coronavirus. The organizer had anticipated a sharp decline in festival attendance this year due to mass cancellations of hotel bookings following China's ban on overseas group travel.[38] As lesser tourists visit Sapporo this cause a decrease in the air quality due to lower manufacturing when comparing 2020 to 2019.

With all the reasons above, Japan's air quality does not have many changes during the COVID-19.

[36] Nakata, M., Sano, I., Mukai, S. and Holben, B., 2013. Spatial and Temporal Variations of Atmospheric Aerosol in Osaka. *Atmosphere*, 4(2), pp.157–168.

[37] Japan Products, n.d. *Sapporo Companies and Products*. [online]. Available at: http://japan-product.com/ad-category/japan-head-office/hokkaido-prefecture/sapporo-city-hokkaido-prefecture/#:~:text=The%20tertiary%20sector%20dominates%20Sapporo [Accessed 8 September 2020].

[38] The Japan Times, 2020. *Sapporo Snow Festival sees plunge in attendance amid coronavirus scare*. [online]. Available at: https://www.japantimes.co.jp/news/2020/02/12/national/sapporo-snow-festival-sees-plunge-attendance-amid-virus-scare/ [Accessed 9 September 2020].

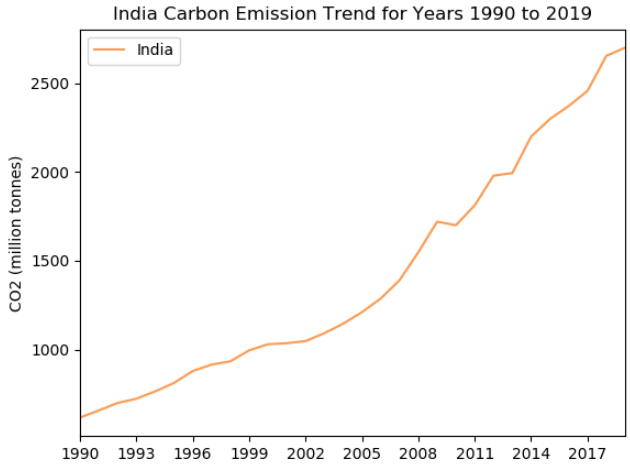
6.2.4 India - Agriculture

Agriculture is the main source of livelihood for about 58% of India's population. Gross Value Added (GVA) by agriculture, forestry and fishing was estimated at Rs 19.48 lakh crore (US$ 276.37 billion) in FY20(PE). Growth in GVA in agriculture and allied sectors stood at 4% in FY20. Due to having potential in value addition, the Indian food industry is also increasing their contribution to the world food trade every year. As the world's sixth largest, with retail, Indian's food and grocery market contributes 70% of the sales.[39]

By 2018, India is the third largest carbon emitter in the world.[40] Air pollution in India is a very serious issue, with India being one of the most polluted countries in terms of air quality. This is due to the high carbon emissions from industrial activities, crop burning and vehicles. The terrible air quality is one of the main cause of deaths in India due to respiratory diseases. Due to this concern, India launched the National Clean Air Programme in 2019 in order to control and reduce air pollution.[41] (Jaiswal, 2019)

As of 2020, the COVID-19 pandemic causes lockdowns all around the world, including India. It is said that air quality has improved significantly during the lockdown because of the halt in the country's economy. People are seeing blue skies and breathe cleaner air, which leads to less discomfort in their respiratory system and better breathing.[42] We will see to what extent this is true by analysing the carbon emissions and air quality in India, particularly during the lockdown period.

Figure 5.1: General increase in carbon emission since 1990



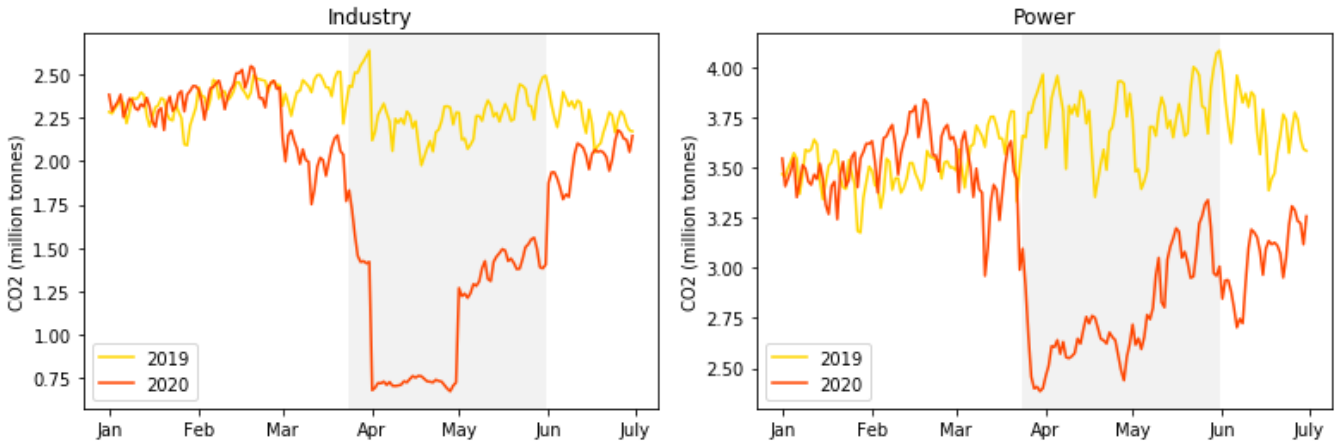
Carbon emission in India has been generally increasing since 1990. One of the reasons would be due to India's high reliance on coal as a source of electricity, for example, increasing from 68% of electricity production in 1992 to 75% in 2015.[43]

However, we can see a moderate growth of emissions in 2019 due to the stable electricity demand as well as strong growth in renewable energy, causing coal-fired electricity generation to drop for the first

[39] IBEF, 2020. *Agriculture in India: Information About Indian Agriculture & Its Importance.* [online]. Available at: https://www.ibef.org/industry/agriculture-india.aspx [Accessed 2 September 2020].
[40] Union of Concerned Scientists, 2020. *Each Country's Share of CO2 Emissions.* [online]. Available at: https://www.ucsusa.org/resources/each-countrys-share-co2-emissions [Accessed 9 September 2020].
[41] Natural Resources Defense Council (NRDC), 2019. *India Launches a National Clean Air Program.* [online]. Available at: https://www.nrdc.org/experts/anjali-jaiswal/india-launches-national-clean-air-program [Accessed 4 September 2020].
[42] Slater, J., 2020. *In India, life under coronavirus brings blue skies and clean air.* The Washington Post, [online] 11 Apr. Available at: https://www.washingtonpost.com/world/asia_pacific/india-coronavirus-delhi-clean-air-pollution/2020/04/10/ac23dd1e-783e-11ea-a311-adb1344719a9_story.html [Accessed 9 September 2020].
[43] C, T., 2019. *These countries produce the most CO2 emissions.* USA TODAY, [online]. 14 Jul. Available at: https://www.usatoday.com/story/money/2019/07/14/china-us-countries-that-produce-the-most-co-2-emissions/39548763/ [Accessed 3 Sep. 2020].

time since 1973. Regardless, this drop is offset by the dependence on fossil fuels in other sectors, such as transportation.[44]

Figure 5.2: Drop in carbon emission during lockdowns



During the lockdown period from 24th of March 2020 to 31st of May 2020 (grey region), there is a **significant drop in CO_2 emissions year-on-year**. This can be represented by the percentage of average daily difference, which is shown in the table below.

Sector	Average Daily Difference
Industry	-52.11%
Power	-26.29%

Drop for the industry sector is much higher than for power, possibly because most factories are closed during the lockdown period where most economy sectors are closed to reduce the transmission of the virus. Besides that, agriculture, fisheries, and construction were stopped during this period, which furthers contribute to the drop in carbon emission.

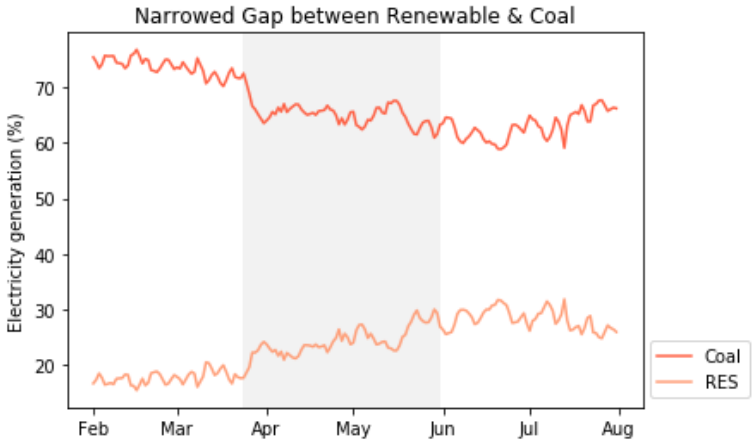
Lower drop for power is possibly due to the fact that there is still a need for electricity in daily operations of important economies and for daily routines, with more focus for renewable energy usage (wind, solar) than non-renewable energy (coal, oil). This is mainly because while the installation of wind turbines and solar panels may cost high, its operating cost is very low, Thus, renewables is a better source of energy in the long term, unlike fossil fuels, which cost more on a daily basis. Besides that, carbon emission rise starting from April because of the rising temperatures, encouraging the usage of air conditioning for cooling down during the summer season.

May is the month when the economy in India starts to reopen with the loosening of restrictions phase-by-phase. The reopening leads to the rise in demand for electricity to carry out the daily operations of the economy, which explains the rise in carbon emission after May for both sectors. The allowance for certain transportation also contributes to the increase in emissions too.

[44] IEA, 2020. *Global CO2 emissions in 2019*. [online]. Available at: https://www.iea.org/articles/global-co2-emissions-in-2019 [Accessed 4 Sep. 2020].

Even before the coronavirus hit the country, carbon emission has already been dropping due to the competition between renewables and non-renewables.[45] In fact, the gap between coal and renewable energy was narrowed further during the lockdown period, which can be visualised in Figure 5.3.

Figure 5.3: Narrowed gap between renewable & coal[46]



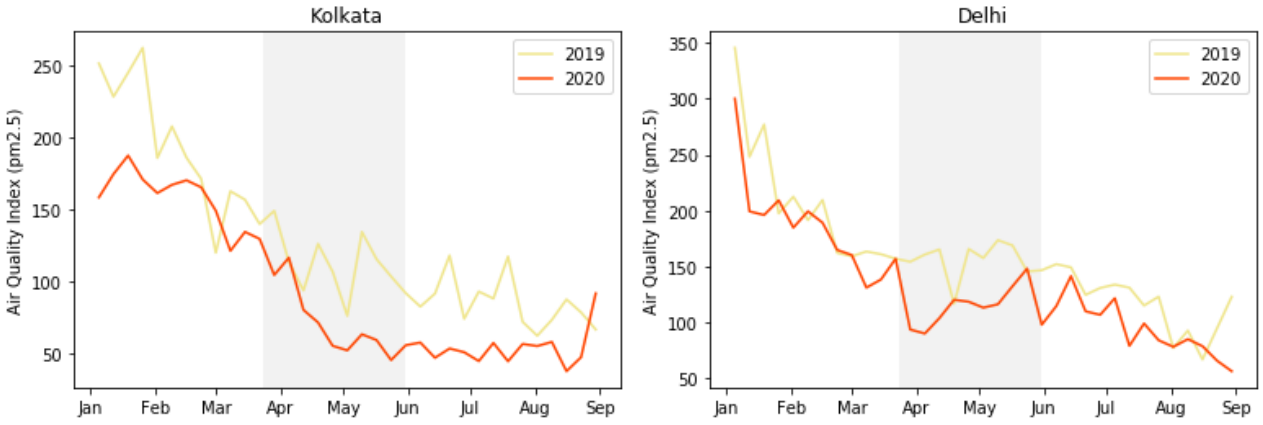
This narrowed gap is mainly due to the drop in demand for electricity because of the closure on most economic activities during the lockdown period (grey region). Despite the rise in the demand for electricity in the residential area (because people are stuck at home), this rise is insignificant compared to the drop in demand for electricity in large-scale industries (ie manufacturing). This narrowed gap also shows that coal remain below 70% of the mix for a few months since the start of the lockdown.

In late May, levels of electricity demand were recovering with the rising share of renewables in the mix, reflecting their seasonal availability. Then, the gap begins to widen around late June. This is due to the rising temperatures which further increases demand for electricity for cooling purposes. At the same time, the economy starts to recover in India, so the overall electricity demand increases, with coal increasing in the electricity mix and wind decreasing.[47] This shows that the effect of carbon emission reduction is only temporary (during lockdown) and easily affected by external factors (seasonal changes). This situation supports some analysts' prediction that the reduction in demand of the non-renewable energy will not last long especially once the country starts to reopen their economy.[48] Therefore, the government need to push their efforts in investing in renewables so that the supply is sufficient to cover for the rising electricity demand.

Overall, during the lockdown, demand for electricity drops due to restricted economic activities. Even if there was a demand, it is more favourable to use renewable energy due to its low operating cost which causes a change in the electricity mix with renewables increasing and coal decreasing. However, the drop in demand for coal is only temporary due to the rising electricity demand after May, which in turn, causes a rise in carbon emission close its 'normal' level.

[45][45] Rowlatt, J., 2020. *India's carbon emissions fall for first time in four decades.* BBC News, [online]. 12 May. Available at: https://www.bbc.com/news/world-asia-india-52614770 [Accessed 7 September 2020].
[46] Power System Operation Corporation Limited, 2020. *Daily Reports.* [online]. Available at: https://posoco.in/reports/daily-reports/ [Accessed 6 September 2020].
[47] IEA, 2020. *Covid-19 impact on electricity.* [online]. Available at: https://www.iea.org/reports/covid-19-impact-on-electricity [Accessed 4 September 2020].

Figure 5.3: Air Quality Index (PM 2.5) in India



States	Average Daily Difference
Kolkata	-34.34%
Delhi	-25.16%

The **trend of AQI is decreasing** for both 2019 & 2020 between January to September with a **significant drop year-on-year during the lockdown period**. The decreasing trend means that the lockdown is not the main reason the AQI decreases. However, the lockdown can be one of the factors that pushes the year-on-year drop. This is mainly because there were travel restrictions and most industries were closed during the lockdown, which led to the reduction of pollution level.[49]

Kolkata has a very significant drop in air quality index, which means high improvement in air quality, during the lockdown. Besides the decrease in motor vehicles on the road, another reason could be due to the Cyclone Amphan[50] that hit West Bengal around mid to end of May, which helped clear the pollutants in the area and so there is a drop in PM2.5 around that period.

For Delhi, about 11m of Delhi's registered cars were taken off the roads while factories and construction activities were stopped which lead to the AQI levels falling below 20.[51] The value 20 is referring to the NAQI that India uses which is different (and normally higher due to its strict characteristic) from the US EPA standard that is used for the visualisation in Figure 5.3. This explains why Delhi have better air quality during the lockdowns.

[49] Agencies, 2020. *Air quality improving in India as 130 bn people stay home amid lockdown.* Business Standard, [online]. 2 Apr. Available at: https://www.business-standard.com/article/current-affairs/air-quality-improves-significantly-across-india-amid-lockdown-cpcb-120040200831_1.html [Accessed 8 September 2020].

[50] PTI, 2020. *Kolkata air quality still good, but will fall after lockdown is lifted: environmentalists.* Deccan Herald, [online]. 27 May. Available at: https://www.deccanherald.com/national/east-and-northeast/kolkata-air-quality-still-good-but-will-fall-after-lockdown-is-lifted-environmentalists-842536.html [Accessed 9 September 2020].

[51] The Guardian, 2020. *'It's positively alpine!': Disbelief in big cities as air pollution falls.* [online]. Available at: https://www.theguardian.com/environment/2020/apr/11/positively-alpine-disbelief-air-pollution-falls-lockdown-coronavirus [Accessed 9 September 2020].

Overall, the lockdown has greatly improved India's air quality because of the significant drop in air pollutant from main contributors like vehicles, factories, crop-residue burning and construction activities. This shows how much carbon emission is caused by motor vehicles in India and how crucial it is for the said country to further improve their transportation system as well as for its people to consider other modes of transportation, such as walking and cycling. Besides that, the drop outside the lockdown period can be said to be due to climate change, such as the raining season and the cyclone in India, which helps in air circulation and remove the pollutants from the air.

7 CONCLUSIONS

Country	Main Industry	Industry Sector Average Daily Difference	Power Sector Average Daily Difference
China	Manufacturing	-11.39%	-10.41%
Japan	Tourism	-19.18%	-8.89%.
India	Agriculture	-52.11%	-26.29%

Surprisingly, China which focuses more on the manufacturing sector has the smallest average daily difference compared to Japan and India which focus on tourism and agriculture, during their respective lockdowns. This contrasts with our expectations that China would face a significant fall in carbon emissions. However, the smallest drop is mainly because China started their lockdowns during the Chinese New Year (CNY) season. Based on previous years, carbon emissions are normally low during the CNY period because factories will have rushed their production before the holidays and temporarily closed or limit their operations during the CNY season. Therefore, the drop for China is comparatively the lowest. Had the lockdown happened at a different time outside of CNY period, the difference may have been much larger than 10%. Even so, the fact that there is a drop of 10% shows that the lockdown does have some effect in decreasing carbon emissions in China.

However, due to emphasis on GDP targets following by construction and manufacturing projects, China's recoveries are foreseeable to be "dirty" with economic shocks followed by surges in fossil fuel consumption, air pollution and CO2 emissions. The increases in renewable energy, nuclear and natural gas use is only sufficient to slow down the growth in coal demand. Although we suppose the lockdown in China will reduce the carbon emission level and enhance the air quality, it seems like the double production after the lockdown to reach the GDP target has made the situation worse. Thus, the air quality improvements only can maintain in a short-term through heroic efforts and an enormous amount of expenditures in improving emissions controls, governance, and enforcement. We can see that China does put some efforts into reducing their air quality, such as switching thousands of industrial boilers and millions of households from coal to gas and electricity. There are limits on squeezing out air quality improvements since the fossil fuel use continues to incline, so the air quality gains slowed down but did not reverse. China has a long way to go in reducing carbon emissions and air pollution, with much of the population living in PM2.5 levels more than four times the WHO guideline. In the journey of recovery from the COVID-19 crisis, there are early warning signs that it is reversing air quality gains, with the national average of PM2.5, NO_2, SO_2 and ozone levels exceeding the levels at the same time in 2019.

Japan has a fairly high drop in carbon emission in the industry sector compared to the power sector. This is mainly because Japan has always been using renewable energy in the power sector, so the lockdown has a small effect in the decrease of carbon emissions in said sector, where some of the power generators in Japan are coal-fired generators. On the other hand, due to the lockdown, which led to the travel ban, tourism industry is on hold as lesser tourists travel to some of Japan's tourists' destinations. This leads to the drop in demand for items and services, particularly for the tourism industry. The drop in demand then causes the drop in the manufacturing activities which explains why there is a drop in carbon emission in the industry sector. However, in further analysis, the change in air quality is barely significant. This is because while the percentage drop is

present, when we compared with India and China, which has fairly high carbon emissions in the first place, the drop for Japan is very small and has little effect to the change in air quality. This can be further supported by noticing that Sapporo, a popular tourists' destination, have slight improve in air quality because their manufacturing activity is not as heavy as India and China. Besides that, the slight decrease in air quality index is also contributed by lesser vehicles because of reducing tourists.

India has the highest drop in carbon emissions for both among all the three countries. This is mainly because India still has a high dependence on fossils fuels, especially coal. However, despite that agriculture is one of the main industries in India, we cannot say the drop in carbon emissions is mainly due to the decrease in agricultural activities. This is mainly because motor vehicles and factories are the biggest contributors to carbon emission in India. Thus, when the lockdown was implemented, the drop is drastic as vehicles and factories were not allowed to operate without essential purposes. During the lockdown period, the increase in demand for renewables also cause the drop in carbon emission as renewables were more favorable in terms of environmental terms as well as operating costs. However, more efforts need to be done to control the usage of fossil fuels because when the economy reopened and electricity demand increases, there is still a dependency on fossil fuels to support the demand when renewables could not due to various factors (seasonal availability & high electricity demand). Even though agricultural activities may not be the biggest contributor to the carbon emissions, we cannot deny that crop-residue burning should be controlled to further reduce carbon emission in the air. This means there should be better management in the agriculture industry so that farmers can transition to the next planting season smoothly, but not at the cost of the environment.

The lockdown has a significant effect in dropping the carbon emissions and improving air quality in the three countries. On the surface, it may seem like carbon emissions in India, representing the agriculture industry, is heavily affected by the lockdown. This indirectly means that agriculture is the highest contributor to the carbon emission in India. However, upon further analysis, the agriculture industry is not the main contributor to carbon emission, but vehicles, factories and construction activities are. In fact, China could have been the country most affected during the lockdown for their carbon emission but their lockdown clashes with the CNY period which has already contribute to the drop in carbon emissions. This means the lockdown only served to decrease carbon emission by a small amount than it would have, had the lockdown period been out of the CNY season. As for Japan, the drop is not too significant and the drop is only because of the travel ban, where tourists, both local and international, cannot freely travel to most of the tourist's destinations in Japan. With the decrease in number of tourists, there is low demand for certain products, particularly those that would have been normally sold for tourism, and thus, this leads to low manufacturing and eventually, lower carbon emissions. At the same time, Japan being a country that mainly uses renewable energy is also another reason why the drop is not significant as the lockdown has little effect on the carbon emissions. Yet, at the same time, for cities that have focus on manufacturing industry, this industry continues to operate, which offsets the improvement in air quality for certain areas.

As a conclusion, there are various factors affecting carbon emissions and it's not just the lockdown, but the industrial activities, seasonal changes and when lockdown happens. All the countries need to reconsider their situation when it comes to the environment. There is a great need to further improve transportation system and use better and cleaner fuels. Besides that, there is also a need to balance any manufacturing activities, to support the demand of the people and for the country's economy while not compromising the needs of the

environment, particularly the air. This is because a clean air is extremely important for the people to stay healthy, which also means less risk in getting COVID-19 that causes respiratory problems.

8 APPENDICES

Appendix 1: Confinement Level Index[32]

Level	Description	Policy examples
0	No restrictions	
1	Policies targeted at long distance travel or groups of individuals where outbreak first nucleates	- Isolation of sick or symptomatic individuals - Self-quarantine of travellers arriving from affected countries - Screening passengers at transport hubs - Ban of mass gatherings >5000 - Closure of selected national borders & restricted international travel - Citizen repatriation
2	Regional policies that restrict entire city/region or ~50% of society from normal daily routines	- Closure of all national borders - Mandatory closure of schools, universities, public buildings, religious/cultural buildings, restaurants, bars, and other non-essential businesses, within a city or region - Ban public gathering >100 and social distancing >2m - Perhaps also accompanied by recommended closures at a broader or national level - Mandatory night curfew
3	National policies that significantly restrict the daily routine of all but key workers, ~80% of workforce.	- Mandatory national 'lockdown' requiring household confinement of all but keyworkers - Ban public gathering >2 and social distancing >2m

Appendix 2: Formula for Calculating Average Percentage of Daily Difference

- Daily difference (%) = $\frac{MtCO2\ in\ 2020 - MtCO2\ in\ 2019}{MtCO2\ in\ 2019} \times 100$
- Average daily difference (%) = $\frac{\sum(Daily\ difference)}{Number\ of\ days\ of\ lockdown}$

[32] Le Quéré, C., et al., 2020. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nature Climate Change. https://doi.org/10.1038/s41558-020-0797-x.

Appendix 3: Lockdown Timeline in China[53][54]

Lockdown Period: 23 January 2020– 8 April 2020

Date	Situation
30 December 2020	The health commission in Wuhan notifies local hospitals of a "pneumonia of unclear cause" and asks them to report any related information of suspicious cases in the past week.
31 December 2020	Chinese officials confirm they are investigating 27 cases of viral pneumonia and dispatch a team of health experts to the region.
1 January 2020	Chinese authorities shut down Huanan Seafood Wholesale Market, the location of a number of cases and a potential source of the virus.
23 January 2020	Chinese authorities enforce a partial lockdown of transport in and out of Wuhan and some nearby cities (Huang gang, Ezhou).
24 January 2020	Travel restrictions implemented in other 10 cities in Hubei.[55]
25 January 2020	30 Provinces in China is under Regulation on the Urgent Handling of Public Health Emergencies.[56]
26 January 2020	The Chinese government imposes a temporary ban on the trade in wild animals throughout the country, which is later made permanent.
31 January 2020 – 9 February 2020	More than 207 provinces and cities in China is under lockdown. They extend their Chinese New Year holiday and most of the non-essential enterprises closed.[57]
13 February 2020	The Chinese government has issued extension of order to shut down all non-essential companies, including manufacturing plants, in Hubei Province until at least 24:00 20 February.[58]
20 February 2020	The Chinese government has issued extension of order to shut down all non-essential companies, including manufacturing plants, and all schools in Hubei Province until at least 24:00 10 March.[59]
13 March 2020	Huangshi and Qianjiang removes their controls and permit on road traffics. [60][61]

[53] CNN, 2020. *Coronavirus Outbreak Timeline Fast Facts.* [online]. Available at: https://edition.cnn.com/2020/02/06/health/wuhan-coronavirus-timeline-fast-facts/index.html [Accessed 5 September 2020].

[54] BBC, 2020. Coronavirus: *What did China do about early outbreak?* [online]. Available at: https://www.bbc.com/news/world-52573137 [Accessed 5 September 2020].

[55] BBC, 2020. *武汉肺炎："封城"防疫是怎么操作的？到底有没有用？* [online]. Available at: https://www.bbc.com/zhongwen/simp/chinese-news-51232433 [Accessed 6 September 2020].

[56] Caixin, 2020. *全国 30 省份启动重大突发公共卫生事件一级响应.* [online]. Available at: http://m.china.caixin.com/m/2020-01-25/101508214.html [Accessed 6 September 2020].

[57] China Briefing, 2020. *China's Extended Lunar New Year Holiday Schedule.* [online]. Available at: https://www.china-briefing.com/news/china-extends-lunar-new-year-holiday-february-2-shanghai-february-9-contain-coronavirus-outbreak/ [Accessed 6 September 2020].

[58] Huanqiu, 2020. *湖北继续延迟复工开学：企业不早于 2 月 20 日 24 时前复工.* [online]. Available at: http://baijiahao.baidu.com/s?id=1658402162460563869 [Accessed 6 September 2020].

[59] News.cn, 2020. *湖北：除疫情防控必需外各类企业不早于3月10日复工.* [online]. Available at: http://www.xinhuanet.com/2020-02/20/c_1125603476.htm [Accessed 6 September 2020].

[60] Sina, 2020. *湖北黄石：解除市区交通管制，停办通行证.* [online]. Available at: https://news.sina.com.cn/c/2020-03-13/doc-iimxyqwa0259279.shtml [Accessed 6 September 2020].

[61] Sina, 2020. *湖北潜江市民燃放烟花庆祝解封.* [online]. Available at: https://news.sina.cn/2020-03-13/detail-iimxxstf8849211.d.html?vt=4&pos=8&cid=56261 [Accessed 6 September 2020].

14 March 2020	Only Wuhan remains a high-risk area. The rest of the province is considered medium- or "low-risk areas". Any low-risk township-level divisions, in addition to those medium- and high-risk divisions with no confirmed active cases, could lift their blockades and other mobility controls. Besides Huangshi and Qianjiang, Yichang, Huanggang, Suizhou, Xiantao, Jingzhou, Jingmen, Shiyan, Xiangyang, Tianmen and Shennongjia had announced "measures to lessen controls" and for industries to incrementally resume work and production.[62]
17 March 2020	Jingzhou removes it controls and permit on road traffics and residential area.[63]
19 March 2020	At a news conference, officials from China's National Health Commission report no new locally transmitted coronavirus cases for the first time since the pandemic began.
25 March 2020	China to lift travel restrictions in Hubei after months of coronavirus lockdown except for Wuhan.[64]
8 April 2020	Wuhan lifts its lockdown and resumes all transportation.[65]
23 May 2020	China reports no new symptomatic coronavirus cases, the first time since the beginning of the outbreak in December.
2 June 2020	Wuhan's Health Commission announces that it has completed coronavirus tests on 9.9 million of its residents with no new confirmed cases found.

[62] CNA, 2020. *湖北封閉式管理鬆綁　低風險鄉鎮社區全數解禁*. [online]. Available at: https://www.cna.com.tw/news/acn/202003140249.aspx [Accessed 6 September 2020].

[63] Yicai, 2020. *湖北荆州：17 日起小区有序解封*. [online]. Available at: https://www.yicai.com/news/100550418.html [Accessed 6 September 2020].

[64] Helen Davidson, 2020. *China to lift travel restrictions in Hubei after months of coronavirus lockdown.* [online]. Available at: https://www.theguardian.com/world/2020/mar/24/china-to-lift-travel-restrictions-in-hubei-after-months-of-coronavirus-lockdown [Accessed 6 September 2020].

[65] Bloomberg, 2020. *China to Lift Lockdown Over Virus Epicenter Wuhan on April 8.* [online]. Available at: https://www.bloomberg.com/news/articles/2020-03-24/china-to-lift-lockdown-over-virus-epicenter-wuhan-on-april-8 [Accessed 6 September 2020].

Appendix 4: Lockdown Timeline in Japan

Date	Situations
January 16th 2020	Japan's first case of a novel coronavirus was confirmed, with the Japanese Ministry of Health, Labor, and Welfare informing the World Health Organization that the affected had travelled to Wuhan, China. It was the second case of COVID-19 in Asia outside of China.
February 4th 2020	Japanese authorities announced the quarantine of the Diamond Princess cruise ship in Yokohoma due to confirmed cases in passengers on the vessel. Put under quarantine for two weeks, at least 705 people contracted the virus.
February 27th 2020	Dr. Norio Ohmagari, director of the Disease Control and Prevention Center at the government's National Center for Global Health and Medicine, admits quarantine measures aboard the Princess Diamond were not perfect.
March 24th 2020	Abe announces an agreement with the International Olympic Committee to postpone the 2020 Summer Olympics in Tokyo to 2021.
April 7th 2020	Abe declares a month-long state of emergency for Tokyo and six other prefectures in the face of a rise of cases. By that time, Japan had reached 3,906 confirmed cases, double the amount from the previous week. "The declaration will depend largely on voluntary compliance, and Mr. Abe emphasized that it was not a lockdown, and that public transit would continue. Prefectural governors can only request that people work from home and avoid going out."
April 16th 2020	Abe expands the state of emergency nationwide, and announces plans for stimulus funds of 100,000 yen (approx. $930) each for Japanese citizens.
April 27th 2020	Tokyo reports its lowest daily level of new coronavirus cases in more than three weeks despite its relaxed measures (in comparison to the penalty-induced lockdown measures of other foreign nations) and a low level of less than 10,000 tests per day. Thus far, Japan has reported 13, 385 infections and 351 deaths nationwide. Following Abe's announcement of a state of emergency, pedestrian numbers had fallen sharply in city centres.
May 14th 2020	Abe lifts the state of emergency imposed in 39 out of 47 prefectures, announcing that the nation's rate of infection has decreased to one seventh of its peak. The state of emergency is still imposed in regions like Tokyo, Osaka, and Hokkaido where new cases are still emerging daily. Abe expressed his hopes that the state of emergency could be lifted in the remaining regions by May 31st.[66]

[66] Xue, F., 2020. *Japan's Response to the Coronavirus: A Timeline of Major Events | East Asia Center*. [online]. eastasiacenter.as.virginia.edu. Available at: https://eastasiacenter.as.virginia.edu/news/japans-response-coronavirus-timeline-major-events [Accessed 6 September 2020].

Appendix 5: Lockdown Timeline in India

PHASE	START	END	GUIDELINES
14-hour Voluntary curfew[67]	22nd March 2020	22nd March 2020	
National Lockdown for 21 days (Lockdown 1.0)	24th March 2020	14th April 2020	- Schools, offices, factories, parks, temples, railways & airspaces are closed - Businesses that provide essential services are allowed to open[68]
Extension + conditional relaxation from April 20 (Lockdown 2.0)	15th April 2020	3rd May 2020	- Agricultural businesses & public work programmes can be reopened[69] - Vehicles carrying cargo are allowed to operate - Banks can reopen
Lockdown 3.0	4th May 2020	17th May 2020	- Districts are split into three zones (Red, Green & Orange)[70] - No movement between 7pm-7am besides for essential purposes - Private sector offices can work with 33% staff
Lockdown 4.0	18th May 2020	31st May 2020	- All shops except malls & containment zones can open[71] - Buses, auto-rickshaws & cabs can operate - Delivery of essential & non-essential items are allowed through online shopping platforms - Restaurants can function but only for take-away

[67] PTI, 2020. *India to observe 'Janata curfew' on Sunday amid spurt in Coronavirus cases.* The Economic Times, [online]. 22 Mar. Available at: https://economictimes.indiatimes.com/news/politics-and-nation/india-to-observe-janata-curfew-on-sunday-amid-spurt-in-coronavirus-cases/articleshow/74750784.cms?from=mdr [Accessed 2 September 2020].

[68] Singh, K. D., et al., 2020. *India, Day 1: World's Largest Coronavirus Lockdown Begins.* The New York Times, [online]. 25 Mar. Available at: https://www.nytimes.com/2020/03/25/world/asia/india-lockdown-coronavirus.html [Accessed 7 September 2020].

[69] *Coronavirus lockdown guidelines: What has India changed under new rules?* BBC News, [online] 15 Apr. Available at: https://www.bbc.com/news/world-asia-india-52290761 [Accessed 7 September 2020].

[70] newsworld24, 2020. *Lockdown Extension till May 17: Read MHA guidelines.* News World 24, [online]. 1 May. Available at: https://www.newsworld24.in/2020/05/lockdown-extension-till-may-17-read-mha-guidelines.html [Accessed 7 September 2020].

[71] *India lockdown 4.0 guidelines | What's allowed and what's not?* The Hindu Net Desk, [online]. 18 May. Available at: https://www.thehindu.com/news/national/lockdown-40-guidelines-whats-allowed-and-whats-not/article31609394.ece [Accessed 7 September 2020].

			- Weddings & funerals cannot have more than 50 & 20 guests respectively
Unlock 1.0 (Lockdown 5.0)	1st June 2020	30th June 2020	- Night curfew changed to 9pm-5am[72] - Hotels, shopping malls & religious places can open
Unlock 2.0	1st July 2020	31st July 2020	- Educational institutions remain closed - No large gatherings - Night curfew (10pm-5am) - National Directives for COVID-19 Management to be followed - Lockdown limited to Containment Zones[73]
Unlock 3.0	1st August 2020	31st August 2020	- Movement at night removed[74] - Yoga institutes & gyms can reopen
Unlock 4.0	1st September 2020	30st September 2020	- Social/Academic/Sports/Religious gatherings are allowed up to 100 people only with mandatory wearing of face masks, social distancing, provision for thermal scanning & hand wash/sanitizer from 21st Sept 2020 - Open air theatres allowed to open from 21st Sept 2020

[72] Express Web Desk, 2020. *Lockdown 5.0 guidelines: What's allowed, what's not from June 1.* The Indian Express, [online]. 31 May. Available at: https://indianexpress.com/article/india/lockdown-5-0-guidelines-6434777/ [Accessed 7 September 2020].

[73] Express Web Desk, 2020. *Unlock 2.0 guidelines: Full list of what is allowed, and what is not.* The Indian Express, [online]. 30 Jun. Available at: https://indianexpress.com/article/india/india-unlock-2-guidelines-rules-what-is-allowed-coronavirus-6482192/ [Accessed 4 September 2020].

[74] Express Web Desk, 2020. *Unlock 3.0 guidelines: Full list of what is allowed, and what is not.* The Indian Express, [online]. 30 Jul. Available at: https://indianexpress.com/article/india/unlock-3-0-guidelines-rules-whats-allowed-whats-not-6529596/ [Accessed 7 September 2020].

Appendix 6: Links of Codes

Reason why carbon emission drop in 2020 (Confinement Level, Carbon Emission Changes by Sector, Flight Schedule)
https://drive.google.com/drive/folders/1nnZN8fdFwxQ-DfPNkgMLe_dE_ZEihOEY?usp=sharing

General carbon emission trend worldwide (1990-2018)
https://drive.google.com/drive/folders/1scOyrxdVloH3XuZXB5Q-cvHzw3QsK-Ib?usp=sharing

China (Carbon emission changes in industry and power sector, China PMI, Electricity Changes, Air Quality)
https://drive.google.com/drive/folders/1QiiUtrTxRMgxgpuTzqNdd0u85S2H7Nag?usp=sharing

Japan (Carbon emission changes in industry and power sector, Air Quality)
https://drive.google.com/drive/folders/18iXzthXMHiDFO0_qJzJsDsuQP26OfX7r?usp=sharing

India (Carbon emission changes in industry and power sector, Change in electricity mix, Air Quality)
https://drive.google.com/drive/folders/1096U4Wk9FJvQIiC5cW-CjpWhTePWlsq5?usp=sharing

9 GLOSSARY

NO	WORD / PHRASE	DEFINITION
1	Gross value added	Value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry or sector; gross value added is the source from which the primary incomes of the SNA are generated and is therefore carried forward into the primary distribution of income account[75]
2	Made in China 2025	A plan announced in 2015 to upgrade and modernize China's manufacturing in 10 key sectors through extensive government assistance in order to make China a major global player in these sectors.[76]
3	Particulate matter smaller than 2.5 micrometres in diameter (PM 2.5)	PM2.5 is the most dangerous air pollutant globally. PM2.5 is emitted from coal, oil and biomass combustion, industrial processes such as cement production, as well as from road and construction dust and from deserts during dust storms. Around half of PM2.5 in the air is formed from SO2 and NOx emissions, mainly from fossil fuel combustion and ammonia, predominantly from agriculture, industry, and vehicles.[77]
4	Carbon dioxide (CO_2) emissions	Are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.
5	Air Quality Index (AQI)	A nationally uniform index for reporting and forecasting daily air quality. It is used to report on the four most common ambient air pollutants that are regulated under the Clean Air Act: ground-level ozone, particle pollution (PM10 and PM2.5), carbon monoxide (CO), and sulfur dioxide (SO2). The AQI focuses on health effects that may be experienced within a few hours or days after breathing polluted air.[78]

[75] Organisation for Economic Co-operation and Development (OECD), 2001. *Gross Value Added.* [online]. Available at: https://stats.oecd.org/glossary/detail.asp?ID=1184#:~:text=Gross%20value%20added%20is%20the,carried%20forward%20into%20the%20primary [Accessed 2 September 2020]

[76] Everycrsreport.com, 2019. China's Economic Rise: History, Trends, Challenges, and Implications for the United States. [online]. Available at: https://www.everycrsreport.com/reports/RL33534.html [Accessed 3 September 2020]

[77] CREA, 2020. Air Pollution in China 2019. [online]. Available at: https://energyandcleanair.org/wp/wp-content/uploads/2020/01/CREA-brief-China2019.pdf [Accessed 7 September 2020]

[78] United States Environmental Protection Agency (EPA). *Glossary for Air Pollution terms in Particle Pollution and Your Patients' Health.* [online]. Available at: https://www.epa.gov/pmcourse/glossary-air-pollution-terms-particle-pollution-and-your-patients-health [Accessed 8 September 2020]

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