

# *How will reducing air pollution help the production of solar energy?*



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# Abstract

The overlying hypothesis of whether photovoltaic outputs are affected by air quality i.e. PM 2.5s are explored through secondary data from various locations such as Wuhan, Lombardy & London in order to obtain accurate patterns as a result of the COVID-19 lockdown during March 2020. This gave an ideal outlook where, most significantly in London & New York City a percentage decrease of ~27% PM 2.5 occurred corresponding with +25-50% average increase in solar energy output during relevant months hinting at  $PM\ 2.5 \propto 1/pv\ output$ . Which is then reinforced by the following data analysis of the locations Melbourne & Bateman Bay, New South Wales in relation to the Australian Bushfires lasting from December 19 to February 20, where graphs constructed using manipulated data showed a similar pattern in which a spike around the initial dates of 2020 corresponded with an average % decrease of ~15-20% in PV efficiency in both locations. This gave the hypothesis more validity to being accepted and is indeed an alternative hypothesis in conclusion since this negative relationship of both variables gave consistent readings from data manipulated and standardised without any forms of bias. Additionally, future primary data research will be conducted using a personal air quality monitor courtesy of the Leicester Education Business Company and STEM Learning which will be used as a form of follow-up and a contribution to local researchers.

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# 1. INTRODUCTION

Air quality is the extent to which the atmosphere is pollutant free, which is largely impacted by industrialized processes and fossil fuels on a day to day basis. This is characterised by particle pollutant concentrations in the air which is measured by PM2.5 and PM10 – where respective size micrometres of fine, inhalable particles are picked up by an air quality monitor.

With this project, we hope to cover different stimuli in the atmosphere, causes of peaks, and troughs in air pollutant concentrations. With a primary focus on lockdown during March 2020, as well as the Australian Bushfires during December 2019 - February 2020 and comparatively analyse solar panel data to these events to conclude on its effects on PV output.

This can help prevail the sheer significance of air quality at a global scale, with a hope to impact personal habits of readers, and highlight especially the impact air quality has as a major risk factor for chronic illnesses such as CVD and lung disease. This might spark conversations across all borders and bring people at a closer stage to sustainable and cleaner environments which can be fruitful to future generations.

## 1.1. Main Air Pollutants

Our primary focus lays on what creates a toxic polluted environment in the first place, whether it is induced by humans or naturally occurring. Although at higher relevance, anthropogenic factors seem to be controllable by governments at the very least. (EEA, s.d.)

To put it simply the following unnatural causes have made the greatest impact on the current air pollution state:

- Burning of fossil fuels during electricity generation, transport, in industrial processes such as cracking, burning of natural gasses, and even household fuels for food production, heating and leisure.
  - Contributing masses of particulates, toxic pollutants which in addition jeopardizes oceans' acidity levels, as well as producing dimming effects from Carbons produced during incomplete combustion:
  - $C_3H_8 + 2O_2 \rightarrow 3C + 4H_2O$  (+energy) where C is released as soot, where at times produces poisonous Carbon monoxides which cause serious health concerns by binding with Hb<sup>1</sup> reducing capacity of erythrocytes<sup>2</sup>. This is more than doubled if the fuel burned is coal – one of the worst polluting fuels.
  - Fossil fuels, and coal can produce VOCs<sup>3</sup>, CO and even large amounts of carcinogenic Arsenic – this can diffuse in water at 50 parts per billion, further causing cancer in 1 out of 100 people consuming this water.
- Agriculture and nitrogen-rich fertilizer use involved in production of agricultural ammonia, and many other aerosols which are linked with pulmonary diseases according to (AGU, 2016) estimated to cause at least 3.3m deaths per year globally.
- Methane production in masses is also a concern as grazing of cattle occurs in masses and is a greenhouse gas indirectly contributing to air pollution by enhancing effects of climate change.
  - In addition, fertilizers themselves contribute largely to surface runoff of nitrogen-based compounds poisoning bodies of water via eutrophication. Having serious wildlife concerns.
- Political instability is a major factor to be considered that indirectly has deteriorating effects due to wars, use of nuclear weapons and explosives largely seen across the Middle East, not to mention chemical weapons seen during the Iraq-Iran war in the 1980s. And even human error can have massive impacts on particulate pollution – such as the very recent Beirut explosion on 04/08/20. With its devastating toll, it may have also had widespread dust pollution, not to mention Ammonium nitrates being released into the atmosphere as that is thought to be the main cause. (Guglielmi, 2020)

<sup>1</sup> Hb also known as Haemoglobin, a globular protein responsible for carrying O<sub>2</sub> during respiration.

<sup>2</sup> Erythrocytes, also known as red blood cells.

<sup>3</sup> VOCs are known as volatile organic compounds such as coals and gasolines which are easily vaporised.

We can now focus on natural causes that although cannot be mitigated, but mentioning is significant in this context:

- Natural phenomena such as volcanic eruptions, and even sandstorms contribute largely to excess particle concentrations in the air and carbon particulates from volcanic ash which can more than block sunlight for days or even weeks following an eruption. Such as the cloud formed in Eyjafjallajökull, 2010 lasting for 7 days covering large areas of land (*Wikipedia, s.d.*). In addition to mass amounts of Nitrogen gasses.
- Wildfires which can be both natural and caused by humans are a hazard to air quality in the short term, releasing stored carbons in nature, intoxicating the air with Nitrogen oxides, Sulphur dioxides, CO<sub>2</sub> and Carbons. A recent example, which will be further analysed in this report is the Australian Wildfires of 2020 with PM2.5 levels reaching a peak of 400µg/m<sup>3</sup> which is one of the worst ever experienced according to WHO, this caused a multitude of respiratory health issues with 2027 hospitalized. (*Air Quality News, 2020*)
  - This is especially relevant in mass production of smog that in turn may reduce Solar energy efficiency.
- Natural disasters add to the blend as well, quite possibly increasing risks of industrial accidents, toxic gas/substance leaks. Although disasters such as Fukushima and Chernobyl aren't quite as relevant in terms of particulate pollution affecting PV output. It may be relevant to mention the effects of the devastating dust and debris spread throughout weather events.
- It was noted shockingly that pollutants in the air may have a reversed effect to reduce tropical storm frequency as a result of aerosols, however it is somewhat unreliable to take this subtle link and sources cited in such articles seem questionable. As other factors may come into play such as climate change and are not otherwise confirmed by the Met Office. (*The Guardian, 2013*)

## 1.2. Air Pollution and the effect on health

Next, we should consider the sheer importance of reducing air pollution in relation to its proven devastating effects on health, and pulmonary diseases.

- Air pollution is a major cause of premature death and disease. It is the single largest environmental health risk in Europe. Heart disease & stroke are one of the most common reasons for premature death highly attributable to air pollution, as well as lung diseases and cancers. (*EEA, 2020*)
  - Thus, it is considered as a carcinogenic factor by several Cancer research agencies – hence this research is very impactful for treatment of chronic diseases.
- More relevant to present day, following the COVID-19 pandemic it was noted that air pollution is seen to raise the risk of death by COVID when a team in the University of Birmingham “compared pollution levels and corona-virus casualties and calculated that an increase in fine particles of 1 microgram per cubic metre was linked with an increase of up to 15 COVID-19 cases, 4 hospital admissions and 3 deaths. Thus it is evident that the polluted areas had more of an influence in enhancing the effects of the COVID, moreover influencing the government to “adopt a new legally binding air pollution limit” and restrict polluting vehicles in clear air zones by local authorities. (*Webster, 2020*)
- A whopping annual global total of 412,000 premature deaths were attributed to be a result of PM 2.5s, showing the gravity of this issue. (*EEA, 2020*)

Since we are merely focussing on air quality so far, we should reinforce some basic knowledge on what the atmosphere is composed of and what polluted the air.

- As we are all already aware that the atmosphere surrounding the planet consists of 78% Nitrogen, 21% Oxygen and this very significant 1% of other gases. The atmosphere also includes pollutants and particles/particulates that gravitate and linger around for a quite long period of time after being released:

- Most of the time they are anthropogenic<sup>4</sup> but can also be natural as discussed previously, and can be classed by primary and secondary pollutants, and come in many different forms such as solid particles, liquid droplets, and gases.



- Primary pollutants are those that are emitted directly into the environment such as CO<sub>2</sub>, CO, VOCs and particulates directly from factories, agriculture and other exhausts.
- Secondary pollutants are those formed when primary pollutants interact with each other in the atmosphere such as O<sub>3</sub>, HNO<sub>3</sub> (Nitric Acid from the oxidation of Nitrogen oxides) and SO<sub>3</sub>.
- Main pollutants to be taken into account in this project are particulates (PM) which are 1<sup>o</sup> pollutants and VOCs – These are characterised as tiny pieces of solid matter in the air and can consist of many different chemicals such as C, S, N and metal compounds, ranging from sizes of <2.5 μm each which are measured as **PM2.5** particles which are very small and are small enough to pass into the blood supply, and <10 μm each which are **PM10s** and can be inhaled into deep parts of the lungs. (SEPA, s.d.) These measurements will be more relevant in the following section on collecting primary data via the air quality monitor.
- It is therefore of utmost importance to consider carbon particulate production since that is the reigning source of PMs which should be mitigated by authorities and contribute to physical blockage of sunlight thus the dimming of the ground-level atmosphere. Other than the other standing factor of humidity that might in response be a refracting or reflecting surface for sunlight.
- Humidity is quite affected by consistent hot weather, vaporising bodies of water in mass producing lingering water droplets on surfaces – thus is highly relevant in the overshadowing concept of climate change and how this consistency might affect solar energy production.

### 1.3. Basic facts on photovoltaic panels

However, before we come to conclusive topics of the factors that affect solar panel dimming – we should know the basic facts of solar energy and the different types of PV panels.

- Photovoltaic systems mainly consist of solar cells that generate current directly using sunlight, and typically convert this DC energy to AC using inverter technology. These cells are linked together to make up a solar panel which uses materials such as Silicon, and phosphorous layers and other parts creating an electric field and a negative charge. The photon of sunlight will then knock a free electron which is pushed out by the electric field. This flow of electrons can be turned into usable power using other components. (Dhar, 2017)
- There are 3 main types of solar panels that each have their pros and cons: Monocrystalline, Polycrystalline and Thin-film, of which it is evident that Monocrystalline is the one with the higher efficiency but coming at a higher cost. It is also said that efficiency of most solar panels is around an average of 15-20% stretching up to 50% in some cases. Thus, it is clear that energy is not as efficient to its full potential seeing there is an abundance of sunlight, and desperate need for renewables in

<sup>4</sup> Anthropogenic is something that originates as a result of human activity.

modern day energy production seeing as climate change is a proven global hazard to nature and humanity.

- Solar panels normally tend to residentially produce around 250-400W per hour per panel. Whereas more larger scale domestic projects can have a capacity of between 1-4kW. (*Yes Energy Solutions, s.d.*)

## 2. SCOPE

The overlying hypothesis of whether photovoltaic output is affected by air quality i.e. PM 2.5s is explored through secondary data from various locations such as Wuhan, Lombardy & London in order to obtain accurate patterns as a result of the COVID-19 lockdown during March 2020.

## 3. METHODOLOGY

The aim of the project was to research public information related to the air quality's stance on photovoltaic efficiency, thus it was highly important to consider various forms of secondary data sourced from the Internet, as well as a air quality monitor which was built using the Luftdaten website to coordinate with other sources and take an accurate average and make reliable conclusions.

Primarily, the focus when conducting this project was inched towards looking at different global catastrophes and events leading up to mass PM production and recently was met by the perfect opportunity of a global lockdown occurring during March 2020 as a result of the COVID-19 pandemic, instantly leading to lockdown of several locations such as Lombardy, Italy where cases seemed to reach a peak during this time thus allowing an instant shutdown of most businesses, forms of transport and even factories. Hence most anthropogenic factors were put to an end over this short period of time – this led to looking at data around this time and what effects this had on air quality.

It was fortunate to find a source of data such as AQICN.org allowing the tallying of data over the course of 2 years at Milano Senato, Lombardy, as well as Wuhan, China and Australian data figures. Using mean monthly figures allowed an initial comparative idea of the effects of lockdown and other major events occurring this year. It was particularly relevant to take recent figures as they are more likely to be known, and reliable due to more advanced systems as opposed to looking at secondary data from events such as Eyjafjallajokull, 2010. And simply due to issues of temporal validity and relevance in modern science - however it would be valuable to do such comparisons for additional confirmation.

Methods used during this report consisted of different measures such as mean averages, moving averages including various other statistical methods detailed further in this section. Whereas data was primarily sourced from AQCN as mentioned above and tallied over Excel sheets, it is deemed to be a reliable source regardless of its open-sourced system, it takes account of government given figures in some locations as well as provided sensor information from anonymous users.

It was essential that the Luftdaten website was our main source of information, however difficulties were met with the mass amounts of data provided, and issues with storage and handling of this myriad of data. Thus, proceeding to use of pre-obtained data from more easily accessible info in condensed forms was used which will be addressed further on.

### 3.1. Effects of lockdown on air quality

To gather data it was important to establish how air quality is measured, and what sources were available. Seeing that PM 2.5s and PM 10s were most relevant to this evaluation - AQICN.org.uk was used to tally data over a spreadsheet manually over the course of the years of 2019 and 2020, although concluding that Jan-Aug was the most appropriate time frame since a midway point of March was established when the COVID-19 was at its strictest. A before and after phase was allowed to see what effect this IV had, keeping in mind that the PM 2.5 figures used are simply an average Air Quality Index (AQI) scaled by the concentration of particulates given the health implications which has been assessed and advised by experts in this field:

AQI	Air Pollution Level	Health Implications	Cautionary Statement (for PM2.5)
0 - 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk	None
51 -100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
101-150	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
151-200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion
201-300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.
300+	Hazardous	Health alert: everyone may experience more serious health effects	Everyone should avoid all outdoor exertion

(AQICN, s.d.)

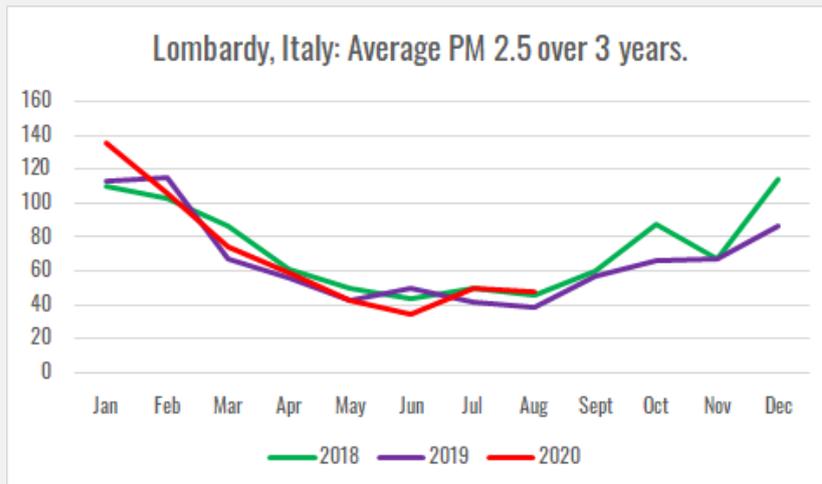
This daily PM 2.5 AQI measure is typically calculated by taking the 24-hour concentration average from midnight to midnight (Hylton, 2016), although the overall calculation may seem quite convoluted it can be characterised as a weighted average - more detailed info available [here](#).

A range of relevant locations were noted to identify where lockdown might have been more detrimental to get a more effective fluctuation as intended. And multiple locations were tackled to get an overall better sample validity.

- Milano Senato, Lombardy, Italy - national quarantine in place from 9th Mar, with local lockdowns in Lombardy as early as 21st Feb with over 60mil people affected. (Wikipedia, 2020) (AQICN, s.d.)
- Wuhan, China - lockdown taking place as early as 21st Jan with over 81,000 cases (Somerville, 2020) lasting for a few months, finally lifting on 8th Apr. (Wikipedia, 2020)
- London, England - starting around 23rd Mar, continuing for longer with multiple local lockdowns with over 320,000 cases as of 25/8. (Steed & Cavanagh, 2020) (Wikipedia, 2020)
- New York City, US - restrictions put in place between Mar-Apr.

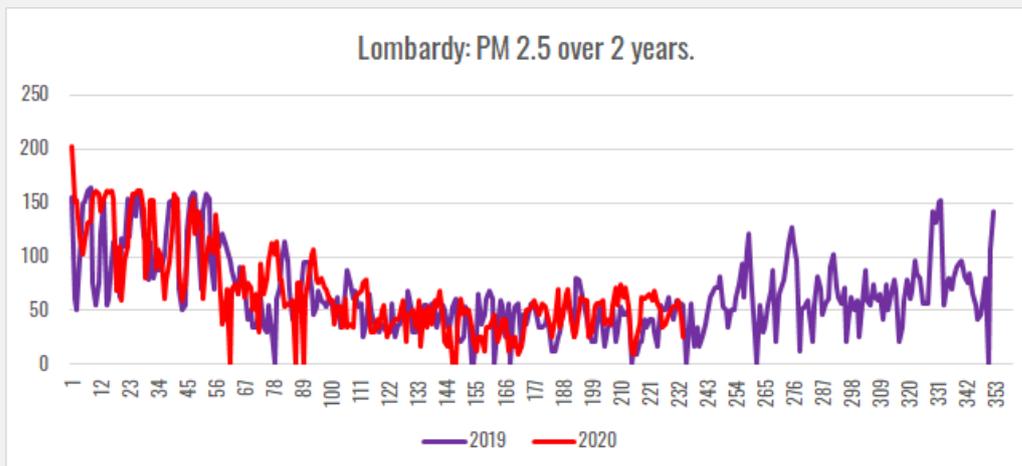
Upon establishing this, it was quick to piece together all the information obtained in an Excel spreadsheet and make necessary evaluations and discussions from graphs which were drawn:

- Data between locations were separated by years 2018-2020 which was felt relevant to get historical versatility thus used the =Average(x:y) tool to obtain mean PM 2.5 & 10 results for each month for all three years.



	A	B	C	D	E	F	G	H	I	J
1	Date	PM 2.5	PM 10							
2	05/01/2018		54		PM 2.5	Month/Year	2018	2019	2020	
3	06/01/2018	137	43			Jan	110.3461538	113.0333333	135.3333333	
4	07/01/2018	119	52			Feb	102.6666667	115.2857143	105.931034	
5	08/01/2018	109	26			Mar	86.85714286	67.53333333	73.8888889	
6	09/01/2018	59	19			Apr	61.23333333	56.03333333	59.1	
7	10/01/2018	38	30			May	49.8	42.4516129	42.2068966	
8	11/01/2018	78	46			Jun	43.86666667	49.8125	33.9333333	
9	12/01/2018	102	48			Jul	50.03333333	41.80645161	49.3870968	
10	13/01/2018	99	50			Aug	45.74193548	38.86666667	47.7391304	
11	14/01/2018	109	52			Sept	60.17241379	56.78571429		
12	15/01/2018	132	55			Oct	87.6	66		
13	16/01/2018	142	52			Nov	67.23333333	67.23333333		
14	17/01/2018	129	50			Dec	114.3666667	86.44827586		

- Then selected the data to create comparative line graphs such as shown above to identify clear patterns between months and the years involved in each instance. This made it easier to complete and segregate one of the variables in question which is the particle concentration in the air.
- For further analysis, it was useful to create a line graph using the entire data set to identify particular troughs and peaks within particular dates such as the 68th day as the critical point in the graph, and make these comparisons of how these fare against previous years - this gave a more staggered and fluctuating data representation.



## 3.2. Effects of natural events: Australian Fires

It was felt that a second independent variable comparison would be suitable and necessary in case lockdown in itself may not a similar effect on PV output, as it's not at a scale as large as this stimulus:

- The Australian fires occurring between Sept 2019 all the way up to May 2020, a large cluster of bushfires caused by multiple reasons ranging from lightning strikes, accidents and heavily enhanced by global warming - this event was at its worst from January-February leading to widespread disruption and loss of homes and habitats, having burnt approximately 18.6million hectares of land.
- In addition to contributing mass amounts of PMs which are hazardous to health, and led to multiple deaths as a result of severe lung conditions due to the smoky haze. And the AQI reached 12 times the hazardous level of 200 in December. (*Wikipedia, 2020*)
- This makes it a quite suitable variable to consider, since it is likely to present a quite significant effect on PM 2.5, as well as the PV output data which will be addressed in the next section.

For the Australian fires as well, data was gathered and downloaded from the AQICN website for the areas of New South Wales (Bateman Bay) and Melbourne which seem to present some of the most affected areas in Australia and will be the basis of this part of the analysis. It was quite clear upon cleaning up the data, that there is a quite visible IV as the fires around the time of Dec-Feb which will be discussed further in the corresponding section.

- Statistical methods and general tools used for this are similar to that for lockdown effects, where Excel sheets were used with the downloaded data from AQICN, and suitable graphs were created using the parameters that were wanted i.e. means.

### 3.3. PV Output

The next step upon tackling the first variable within this report, was to handle data which correlated with PM 2.5s and PM 10 that was regarding the PV output at these locations, at first it was difficult to find a reliable source of data since this was not as widely available on the internet, however a quite open-source web page [pvoutput.org](http://pvoutput.org) seemed to give hope to the search. It provided the needed data for the corresponding locations giving the Energy Generation figures in terms of kWh, as well as the Efficiency of this generation in kWh/kW.

The first hurdle to overcome was to find a downloadable base of data even if figures were directly obtainable from the statistics provided. Upon exploring the web page, stumbling upon the [Help](#) page seemed to give direction to some kind of API which they provide to the public. However, after an hour of searching through PVOutput forums, and endless misguided information, it was settled that without any sensor of our own, it was impossible to get access to this bank of data.

Thus settling on a method of inputting data manually into the same Excel sheet - which did not take long at all, it was deemed to be much more suitable since the data itself presented itself in both kWh and MWh, so the conversion of units was automatically done when going through.

Month ▼	Generated	Efficiency
<a href="#">Jul 20</a>	715.467kWh	4.368kWh/kW
<a href="#">Jun 20</a>	1.395MWh	3.953kWh/kW
<a href="#">May 20</a>	1.629MWh	4.169kWh/kW
<a href="#">Apr 20</a>	1.430MWh	3.782kWh/kW
<a href="#">Mar 20</a>	701.203kWh	2.140kWh/kW
<a href="#">Feb 20</a>	529.511kWh	1.751kWh/kW
<a href="#">Jan 20</a>	349.445kWh	1.387kWh/kW
<a href="#">Dec 19</a>	229.931kWh	0.793kWh/kW
<a href="#">Nov 19</a>	86.145kWh	0.684kWh/kW
<a href="#">Oct 19</a>	169.979kWh	1.927kWh/kW
<a href="#">Sep 19</a>	835.111kWh	2.882kWh/kW
<a href="#">Aug 19</a>	1.425MWh	3.899kWh/kW

	(kWh)			(kWh/kW)		
	Generation			Solar Energy Efficiency		
Year	2018	2019	2020	2018	2019	2020
Jan	439.3	401.7	349.5	1.125	1.386	1.387
Feb	537.6	780.9	529.5	1.524	2.214	1.751
Mar	591.9	1253	701.2	1.74	3.208	2.14
Apr	1139	1142	1430	3.013	3.021	3.782
May	1295	1501	1629	3.316	3.842	4.169
Jun	166	1771	1395	4.409	4.686	3.953
Jul	1798	1771	715.5	4.604	4.534	4.368
Aug	984	1425		2.892	3.899	
Sept	1054	835.1		2.883	2.882	
Oct	762.5	170		1.952	1.927	
Nov	264.3	86.1		0.699	0.684	
Dec	372.7	229.9		1.095	0.793	

It was also found that for some of the locations such as Wuhan, there was no suitable data available since most sensors registered were too far away from the intended location, and if these were used - then validity would be lacking in that instance. Hence, it was decided that air quality data itself was sufficient. Other locations which were not exactly corresponding with the air quality monitors were generalised to have the same or similar data values as they were close enough to the central location, this was the case for Melbourne & New South Wales (Bateman Bay). Some exceptions were also found in this set of data which will be evaluated and discussed further.

The PV data in hand, was compared directly with the air quality data obtained to see what effect the events have. It is however not possible to make correlations with this as there are 3 different variables including time to take into account.

### 3.4. Building a sensor

To enable future projects to gain primary data on local PM10 and PM2.5 emissions a simple sensor was built from basic components. The sensor was built using a design supported by Luftdaten and will be installed in the Leicester area in the future to help further work. The sensor came mostly pre-built, however had some parts that required piecing together such as "Arduino NodeMCU with Wifi", the Temperature, Pressure & Humidity sensor

as well as the "Laser Particle Counter" which measured PM10 and PM2.5 concentrations.. These pieces were connected with a useful information sheet which is available in the Appendix. After this mechanical part of the build was done, it was mounted in the box and connected to the wifi using a mobile device.



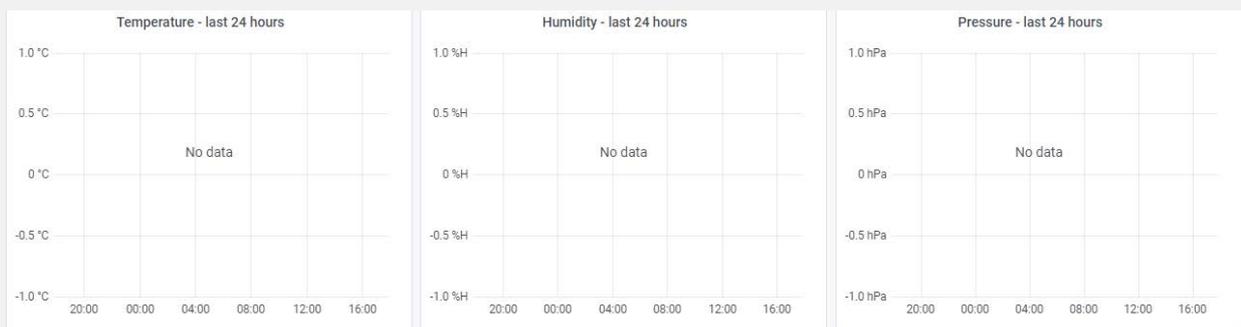
At first it showed difficulty in having contact with the third party device, however upon logging the IP address in the search bar - the gui quickly showed and allowed a WIFI password to be entered and after a few tries entering this, the monitor connected permanently to the wifi Hub. Thus after waiting 5 minutes for confirmation of this trial - it was deemed a successful run, as the monitor was already collecting data from its surroundings.



The data is available to be seen on the API website of PM Sensors which is interconnected with Luftdaten:  
<https://api-rrd.madavi.de/grafana/d/GUaL5aZMz/pm-sensors?orgId=1&theme=light&var-chipID=esp8266-5806178>



On the contrary, it was a letdown that the Temperature, Humidity & Pressure sensor was still showing no information at all, and upon moving around wires, and checking whether it was all correctly fitted, there was no difference made. So it was in the end concluded that the sensor itself may have been faulty. And since parameters given by it were not so relevant to this report, it was left as is.



If there was more funding, and time available to conduct this research, it would definitely be a useful sensor to include in more longer term projects that require this parameter.

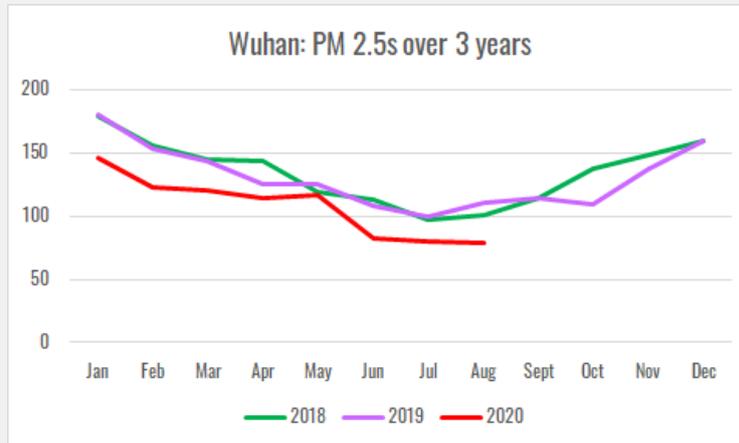
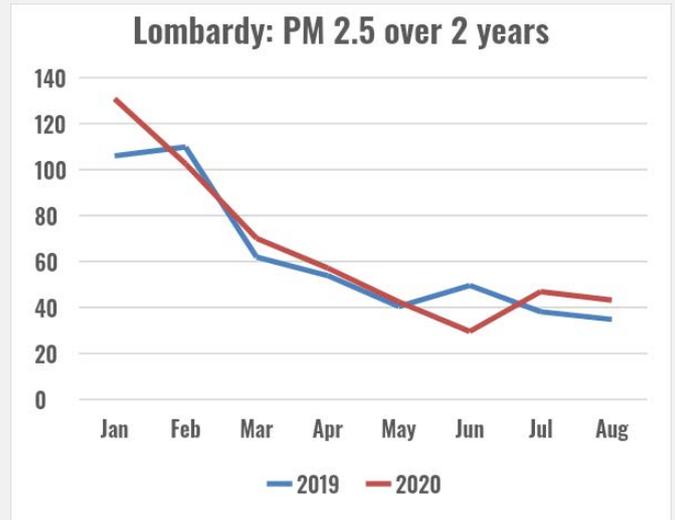
# 4. RESULTS AND DISCUSSION

## 4.1. COVID-19 lockdown and its effects

Comparing data from 2019 and 2020 from Lombardy, Italy, no clear difference was seen around times of March and April when lockdown was in place at its strictest. It's noticeable that the lower gradient of the line for Mar-Jun 2020 suggests air quality is in fact worse than the prior norm, and is a sharper peak when the seasonal pattern in past years is taken into consideration.

This was anticipated by other data which was pieced together regarding the city of Wuhan which is heavily relevant in this topic since the COVID-19 pandemic quickly affected this place, and was carefully handled by the Republic of China.

Data for 2020 gave quite mixed thoughts since the overall PM 2.5 & 10 figures seemed much lower than the previous years, even for the months of Jan-Feb. A slight peak was seen around March which seemed to suggest that it was possible that commotion and efforts to settle a lockdown was made, and as lockdown was in place much later following April vehicle use and other carbon producing activities were stopped, thus creating these significantly lower values between June and July. It's quite clear that something has caused this, since mitigation efforts for climate change might not have indeed made that big of a difference of 20-30 PM 2.5 AQI units.

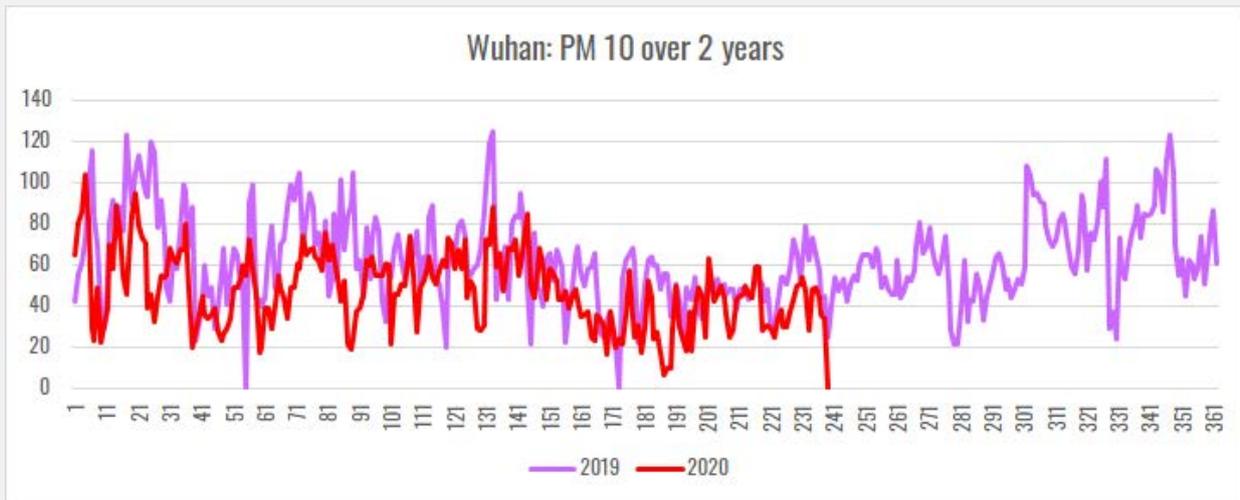


This is fairly significant when looking at the vast difference in annual PM 2.5 & 10 levels over the past 3 years, it's clear that since both 2018 & 2019 have similar averages compared to 108 in 2020.

However there might be a discrepancy between this implication, since data in 2020 only reflects Jan-Aug, and rising seasonal patterns around Oct-Dec are not considered when it might influence the average value being higher.

	2018	2019	2020
PM 2.5	134.7156	130.8173	108.0145
PM 10	66.42242	62.97924	47.19282

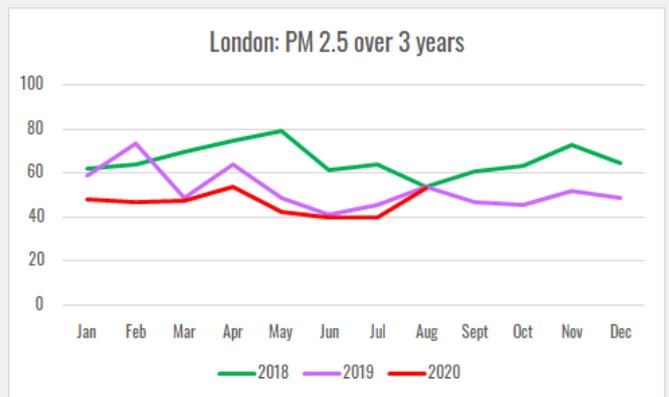
It's quite useful in turn, to take into account daily data to really magnify the possibly existing IV. Using daily average AQI it was noticeable that around the dates when lockdown was in place at its strictest - there was an increased surge of troughs when air quality improved compared to the previous years, especially evident when looking at PM 10s - suggesting more heavy pollutants release may have ceased more consistently:



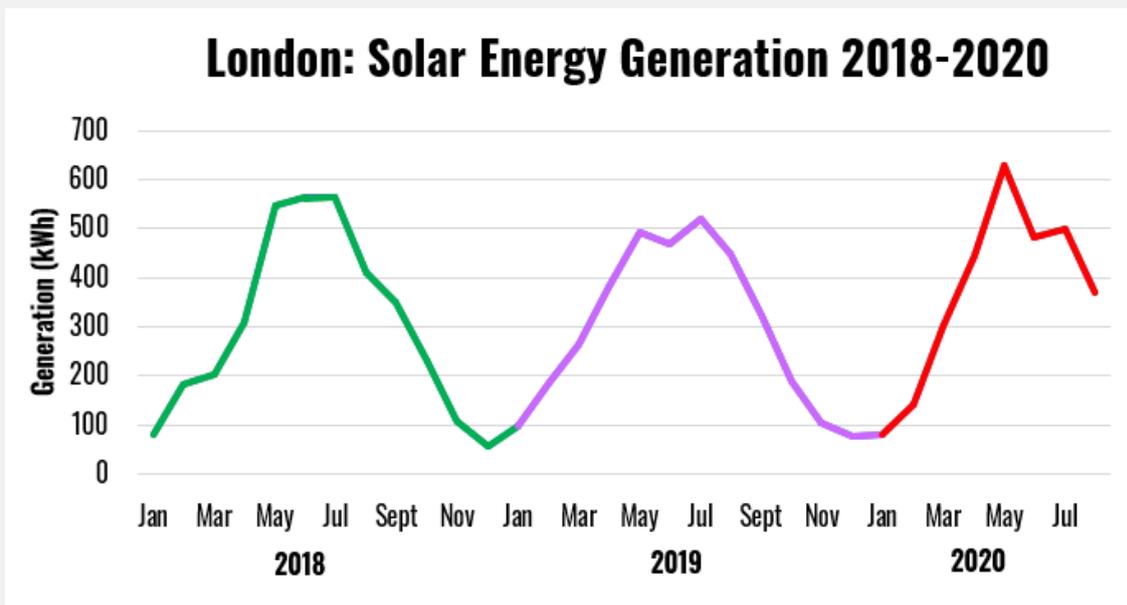
Peaks around days 81-91, 101 and in between 111 were quite distinctly low values from the previous norm. Showed how there may have been a physical change in the environment that could have caused it.

Although it is quite visible to see a difference in air quality throughout this lockdown period, pv output data was not available for Wuhan. Thus we will be looking at other locations to make more comparisons apart from this initial idea in the source of the virus, such as London, England where lockdown was put in place around March to April.

When looking at data in London - a quite similar pattern arises where the typical PM 2.5 levels are lower than all previous years, however this occurs more so in January-February as opposed to March, however there definitely is a decrease from Apr to May during 2020. The question is whether this decrease is simply a seasonal pattern since 2019 also has this, and so does 2018 even if the decrease is delayed up until mid-May. It's quite likely that it is, since research done into seasonality suggests lower emission levels during times of high temperature during May-Aug have lower emission levels as a result of local home furnaces and vice versa for winter months. (Cichowicz, R., Wielgosiński, G. & Fetter, W., 2017)



Instead it's more evident to obtain this pattern from solar data as shown below - which gives an explicit peak around the monthly average of March up until May suggesting an improvement in solar energy production has occurred compared to the previous year, since the gradients of the peak are larger in 2020, as well as the peak maximum value rising to 630 kWh compared to 519 kWh in just the previous year. Showing as much as an *increase of 16.3% since the past 2 years.*

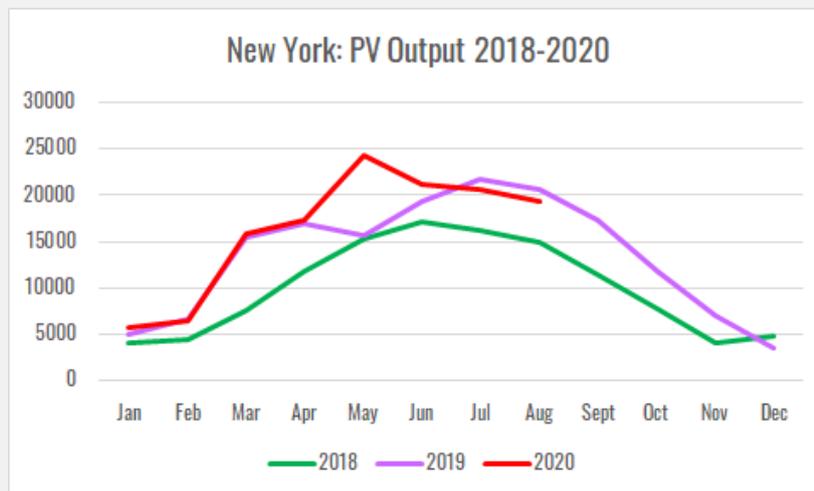
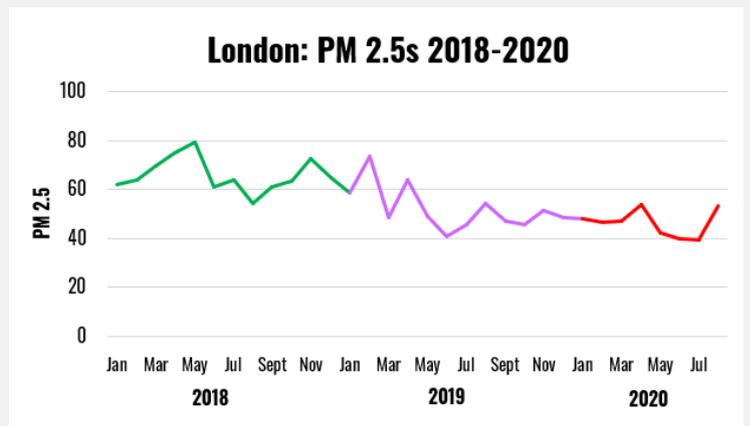


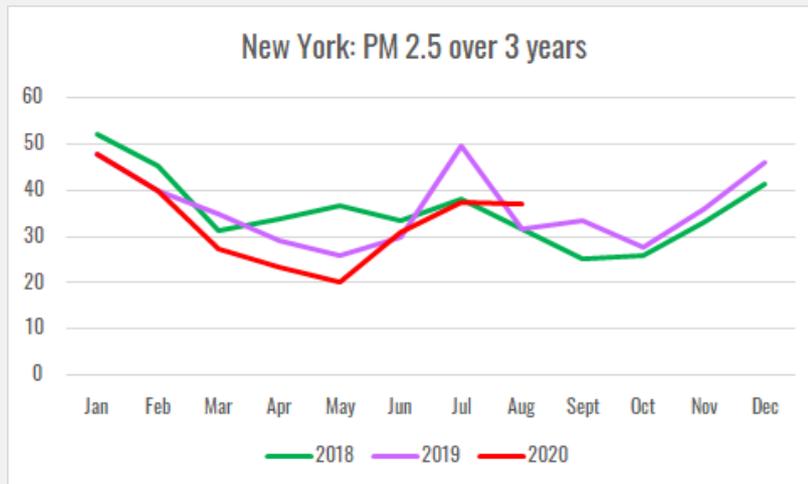
After taking solar output into account it's evident that lockdown might have influenced the peak around march, which is likely to be caused by a decrease in PM 2.5 - we can see a better representation of this below since the trough that occurs after the peak in march seems indicative of both peaks that are seen in the 2020 figures of PV output. This may be suitable evidence to show this pattern. However, it's vital to confirm with other possible locations - such as New York which will be our next target.

It is clear that lockdown in New York would be more persisting since there is a high influx of cases and COVID-19 deaths, thus perhaps hinting towards there being less commuting, and other polluting anthropogenic activities taking place.

Upon cleaning and graphing the data corresponding to NYC, it was pleasant to see that there was a clear inverse relationship that was not so visible in the previous locations:

- In NYC, it's explicit that the maximum PV Output value of 24.243 MWh corresponds directly with the minimum PM 2.5 AQI of 20.2 and is occurring at a very similar timeframe around May 2020, which may refer to a lagging response from the COVID-19 lockdown which was put in place just a month or 2 prior giving a quite possible conclusive statistic to agree with the overall hypothesis.
- It was also interesting to find quite high peaks around the 107th and 211th days of 2019 which gave the notion that there were other factors that were changing the PM 2.5 levels, although it is uncertain how the maximum peak around April, 17th was caused, but it's possible to link the one around July, 30th to particulates aroused and emitted due to hurricane seasons and local storms.



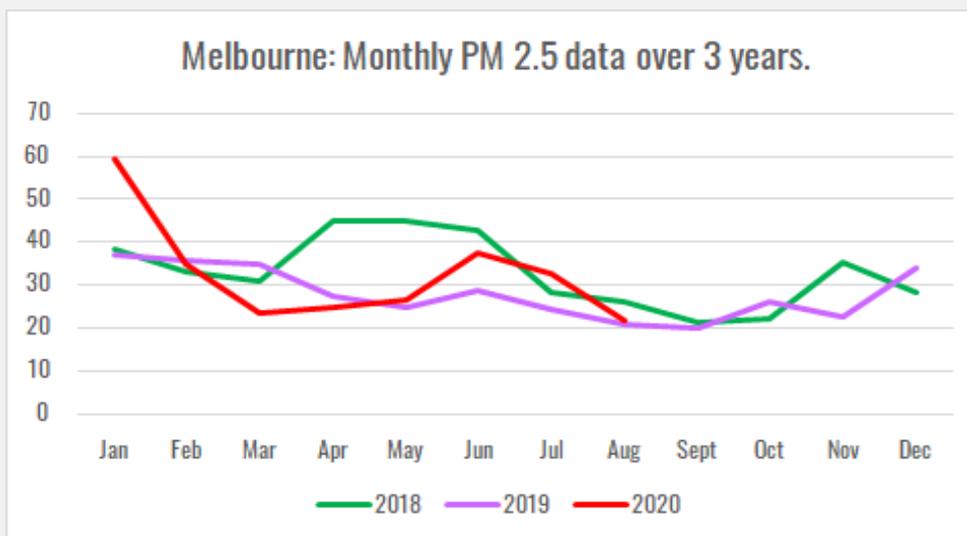


- It may be suitable therefore, to connote and accept the hypothesis that PV output is affected by the PM 2.5 levels in New York, keeping cautious of generalisations since other locations have not provided such concrete standings on this topic. This analysis will be evaluated further in the next section.

## 4.2. Effects of Australian Bushfires

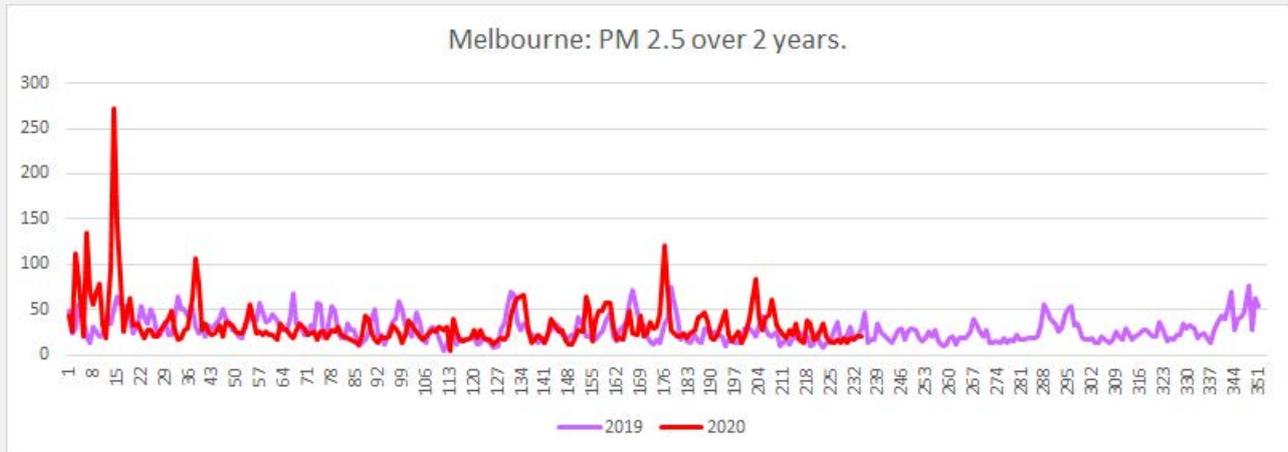
After having looked at the first stimuli, it's crucial to take a natural phenomena into account to see whether it has the same effect on PV output that lockdown has had. Thus it was decided that the Australian Bushfires of 2019-2020 provided a perfect scenario and likely strong particulate emission to show how it may affect solar energy production by dimming the amount of energy the panel receives.

Firstly, the impression gotten from the data obtained from monitors placed in the vicinity of Melbourne is that PM 2.5 levels sharply rise throughout January and December having multiple peaks, hence there is a quite large average value of 59.4 AQI units, compared to all other values in the dataset being in a range of 20-40. This is highly indicative of there being a factor present that caused this change - i.e. the bushfires release masses of PMs that are being detected.



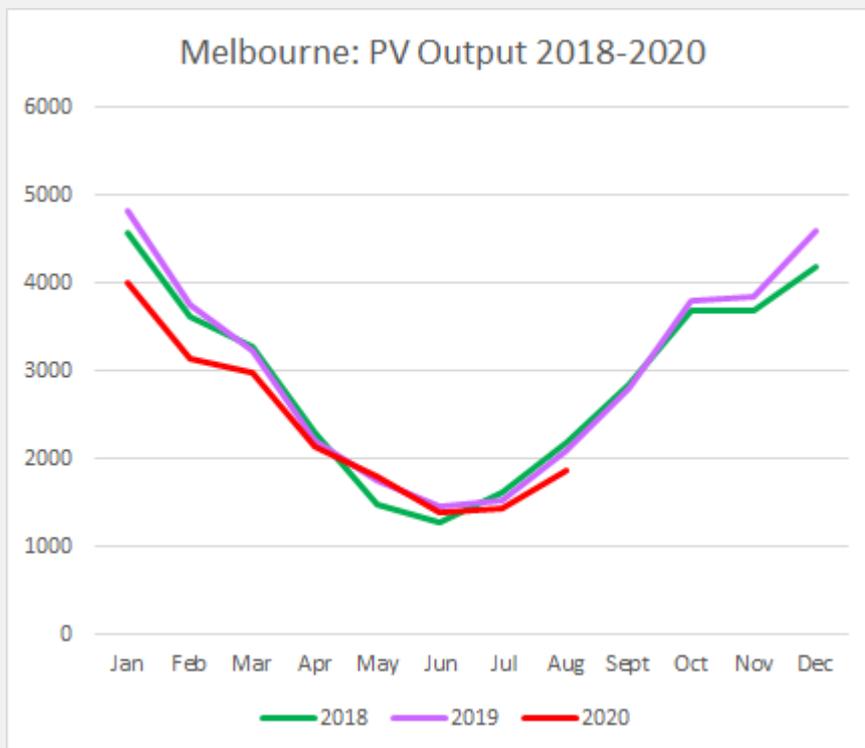
In addition, it is also the case that around March of 2020, there is an abnormally lower concentration of PM 2.5s which might be due to the COVID-19 lockdown, however in this case it might be unreliable to determine whether this change is simply because of the government's efforts to reduce air quality after the disaster, or any other possible reason.

When also looking at individual daily averages, it's important to mention how consistent these peaks were, that caused the average monthly peak of 59.4. It's visible around 2-3 smaller peaks in the first few days of January, then one of massive magnitude reaching 272 units on the 14th.



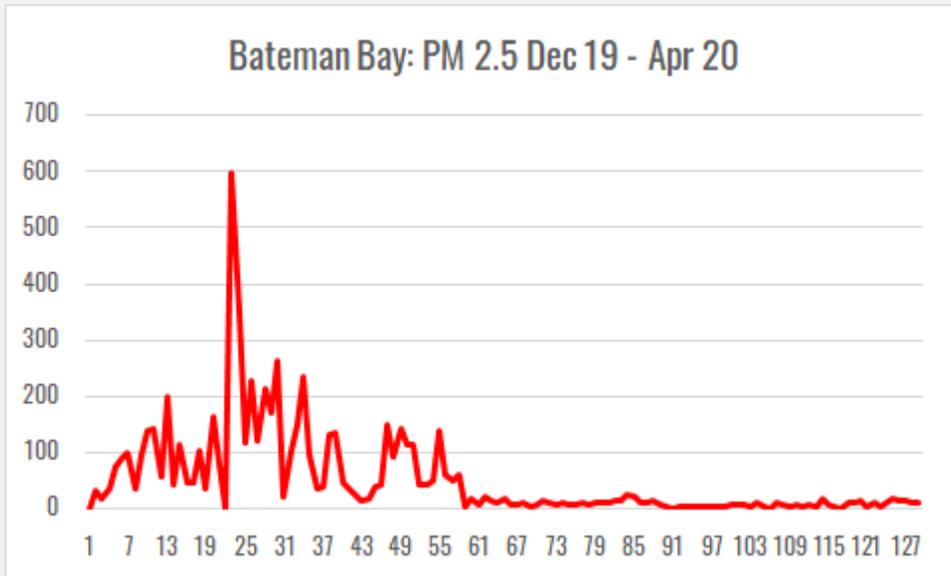
In turn, when comparing this data to PV Outputs, it's also explicit to see that figures from January are significantly apart in 2020 compared to the previous years with this pattern lasting up until February, and starting from November 2019 when the line distances away from the annual average. Where in the instance, the decrease is much more instant this year, than the past years. However it is rather difficult to use this data since bushfire seasons are quite abundant and the similarities in Dec-Feb may reflect them being synchronised to occur during the Australian summertime, and may instead show that the bushfires in 2020 may have been of greater magnitude.

This is also confirmed by sources regarding the bushfires, that the recent ones affecting NSW & Victoria are the worst to date. (BBC Newsround, 2020).

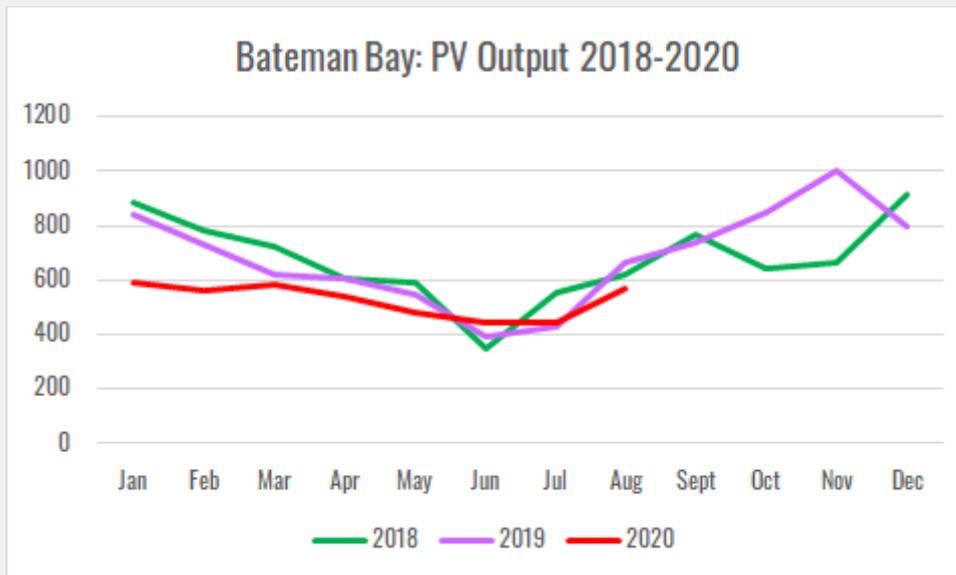


Thus it's clear that in Melbourne, bushfires may indeed decrease PV Output efficiency as a result of increased PM 2.5. Before making conclusions, it's important to take a larger sample size of locations, so analysis of data from New South Wales (Bateman Bay) was also crucial. Although only limited data from around the event is available, it is still useful to look at any underlying patterns.

It was also clear to see a similar pattern to that from Melbourne, so the data will be visible below as the conclusions made are fairly similar. There must be a cause allowing the PM 2.5 values to reach a whopping 599 on the 2nd January 2020, which can easily be linked to the bushfires to avoid repeating conclusions.



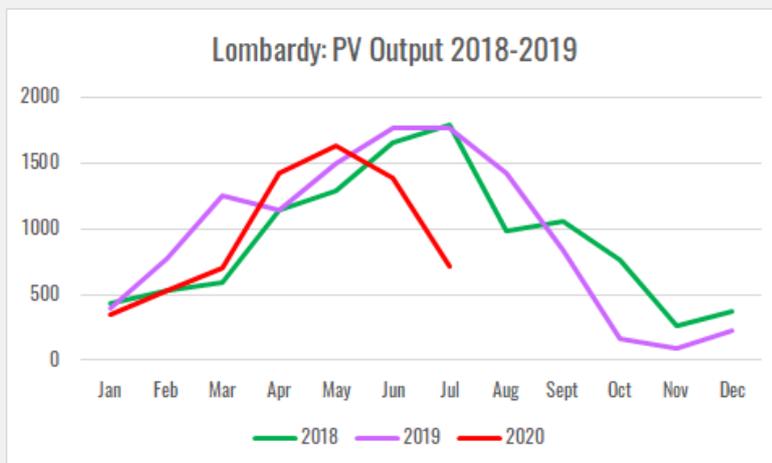
And when looking at PV Output, a very similar pattern is seen around the start of 2020 to that from Melbourne, suggesting that the conclusions made are reliable and have sample validity:



Thus it is clear that bushfires may decrease PV Output, where conclusions made regarding this will be made and evaluation in the following section.

### 4.3. Data Analysis

Furthermore, it is important to discuss the results found above, it is clearly detained that PM 2.5s have decreased as lockdown is in place, this in succession may cause PV Output to improve as for the positive correlation in the graphs seen in [section 4.1](#). More explicitly in London, UK and New York where a higher average is seen around April to May. In addition, Lombardy appears with a similar pattern, thus, I believe it is sufficient to have 3 different locations to give the same negative relationship between PV Output & PM 2.5 - hence allowing a conclusion to be made



This conclusion is reinforced by the data provided in [section 4.2](#) where the event named the Australian bushfires peaking in January 2020 - shows a similar negative relationship with a large peak of PM 2.5s in the initial dates of 2020, which is supported by PV output data which although might be limited by a surge in seasonal bushfires in the previous years - it's clear that solar energy generation does improve suggested by the troughs during January that differ by an average of around 600 kWh to previous years.

Thus allowing us to also conclude that solar energy generation is highly improved when air quality improves as well, looking from events that worsened air quality (Bushfires), as well as one that improved it (Covid-19).

It's interesting to see some percentage figures of by which degree solar energy production improved during the peaks of the corresponding event at each location:

Finding that both Lombardy and London both had quite similar percentage increases, which matched Melbourne and NSW which also had quite close values only distanced by 11% which may suggest there is consistency between the locations which may be affected by several other factors such as lockdown intensity, solar panel capacity and whether the solar panels were cleaned or underwent maintenance throughout the period. Thus, it's inconclusive whether it may reduce the validity of the sample since there are inconsistencies between locations, although it is effectively clear that a fluctuation is found, just not of the same magnitude.

Percentage Changes in PV Output	
Location	Percentage
Lombardy	20.50%
New York	56.55%
London	21.08%
Melbourne	-14.72%
Bateman Bay	-23.52%

Note: Percentage change calculation was standardised throughout the relevant months to increase validity.

## 5. EVALUATION

When evaluating this hypothesis named "How will reducing air pollution help the production of solar energy?" It's important to address the samples that were included in this project ranging from 6 different countries giving this great

generalisability that the conclusions made may be valid, and accurate. Where the data seemed to marry together well, presenting similar patterns such as a distant PM 2.5 & PV Output average from previous annual norms, which was seen in both London and New York. And in both Australian cities giving a large peak around January at both times, suggesting that the locations were both in sync with each other, and suitably reflect the conclusions made by each other.

Although, a fact that might limit the usefulness of the report may be the use of secondary data from open sources such as PVoutput.org where data providers themselves are anonymous and aren't funded by any government as opposed to AQICN as our source of data for PMs which sources data from official government websites such as [Defra \(UK Air\)](#) for the London data. (AQICN, s.d.). This gives more validity since it is from a legitimate source, however if compared with open sourced data which may be subject to bias or distortion - perhaps by incorrect placement by monitor owner - it may limit the validity this study has.

There quite a few things the study intended to cover at first, to use data that was from better sources that were available to us i.e. Luftdaten, however as the project neared its deadline, we decided it was best to use online sources that were more easily accessible since Luftdaten required masses of data organisation and cleaning, as well as heaps of storage space to handle this which was not quite possible with the resources available to us.

However if this research reaches wider demographics, it would be possible to fund further research into this subject of particulate matter in relation to PV output - and use more resources to allow an expert to handle this large amount of data. Which is what this piece of research intends in doing - to reach further audiences to inspire creative minds to help carry out research into this at a larger scale to raise awareness of renewables as well as the need to improve air quality.

This also does apply to the air quality monitor that was set up in [section 3.4](#), which was initially intended to collect data at a longer timeframe, however upon writing this report - it is my intention to keep this air quality monitor plugged in to collect data, as well as taking it to a larger institution for a better more open area to measure particulates i.e. my college as a need to provide data for the wider community to use at a longer term, for researchers who wish to study air quality in Leicester.

## 6. APPENDIX

### Data

The data cited in this report was obtained from the following two web pages : AQICN.org & PVoutput.org

- Lombardy: <https://aqicn.org/city/italy/lombardia/milano-senato/>  
<https://pvoutput.org/aggregate.jsp?id=32251&sid=28724&v=0&t=m>
- Wuhan: <https://aqicn.org/city/wuhan/>

- London: <https://aqicn.org/city/london/>  
<https://pvoutput.org/aggregate.jsp?id=6507&sid=5182&v=0&t=m>
- New York: <https://aqicn.org/city/usa/newyork/>  
<https://pvoutput.org/aggregate.jsp?id=32413&sid=29714&v=0&t=m>
- Melbourne: <https://aqicn.org/city/australia/melbourne/alphington/>  
<https://pvoutput.org/aggregate.jsp?id=46275&sid=42209&t=m>
- Bateman Bay: <https://aqicn.org/city/australia/nsw/bushfire-monitoring/batemans-bay/>  
<https://pvoutput.org/aggregate.jsp?id=45140&sid=41187&v=0&t=m>

RAW Data has been merged in one file with data that has been statistically manipulated, and graphed using Excel features, and is available [here](#).

## Supporting Resources

Document mentioned in [section 3.4](#) regarding building an air quality monitor provided and funded by Nuffield Foundation is linked [here](#).

Mind maps and additional background information available in PDF format [here](#).

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