

## Article

# The environmental impact of SARS-CoV-2: an assessment of the health risks of air pollution during the pandemic

Serafin Corral <sup>1,\*</sup>, Jesús Hernández Hernández <sup>2</sup> and José Luis Rivero Ceballos <sup>3</sup>

<sup>1</sup> Dept. Applied Economics and Quantitative Methods; Instituto Universitario de Desarrollo Regional, University of La Laguna; scorral@ull.edu.es

<sup>2</sup> Dept. Geography; Instituto Universitario de Desarrollo Regional, University of La Laguna; jfhdez@ull.edu.es

<sup>3</sup> Dept. Applied Economics and Quantitative Methods, University of La Laguna; jlrivero@ull.edu.es

\* Correspondence: scorral@ull.edu.es

**Abstract:** This article analyses the environmental impact of the measures imposed during the SARS-CoV-2 pandemic. We compare the evolution of atmospheric pollution levels in recent years and during lockdown, and assess the effects of the decrease in mobility and changes in patterns and lifestyles during the latter period. Thus, the reduction in the risk to human health brought about by the improvement of air quality during the months of confinement through the use of dose-response functions is estimated. The focus of the case study is the island of Tenerife. The island of Tenerife has been selected because it can serve as an example for other sites in Europe. We distinguish between the three areas with the highest population concentrations: the Metropolitan, Southern, and Northern areas. The impacts of air pollution and its relationship with changes in consumption and activity patterns are clearly distinguishable. Therefore, the lessons learned can be easily extrapolated to other areas, in both island and mainland contexts.

**Keywords:** Environmental impact; atmospheric pollution; lifestyle changes; health effects; SARS-CoV-2 pandemic.

## 1. Introduction

The SARS-CoV-2 virus has had an unprecedented global impact, affecting almost every country in the world. This is the sixth time that a global health emergency has been declared under the International Health Regulations, although it is by far the most serious to date. Most countries have tried to combat the propagation of the virus with mass screening tests and have imposed public measures of social distancing. These measures have prioritized the protection of people's health and the avoidance of contagion, and they have had indirect impacts on the environment. While the effects of the pandemic on the economy, education, health and social and individual behaviour have been the subject of numerous analyses, the impacts on the natural environment have received less attention.

The earliest studies anticipated a positive impact on the environment due to the implementation of measures that restricted mobility and imposed social distancing, and climate experts predicted that greenhouse gas (GHG) emissions might fall to levels not seen since World War II [1]. Indeed, the introduction of these measures in Spain had a dramatic effect on the country's economic activity. Power stations and factories reduced their production drastically and vehicle use also fell to levels not seen in years. This led in turn to a large fall in the concentrations of nitrogen dioxide (NO<sub>2</sub>) and of particles with a diameter of less than 2.5 µm (PM<sub>2.5</sub>), two of the pollutants with the greatest impact on health. The reduction in the use of private and public transport and in normal commercial activities also caused a fall in noise levels.

At the time of writing, the horizons of the extension or the reactivation of the pandemic in this second wave, and in the foreseeable subsequent waves, are unknown. What seems clear is that until treatments or vaccines provide a general response to the virus its effects will continue to be felt intensely in most countries of the world, and restrictive measures of greater or lesser scope will remain mandatory.

The purpose of this article is to present an in-depth analysis the indirect impacts of the measures imposed during SARS-CoV-2 on the environment. We also estimate the effects on human health of the improvement of air quality during the months of confinement through the use of dose-response functions. Taking the island of Tenerife as an example, we study the evolution of the levels of pollutant deposition, comparing the monthly values pre-SARS-CoV-2 with those observed during confinement in order to establish whether the measures taken have led to differences in air quality.

Tenerife is chosen for this case study because, as an island, it is an ideal setting for the study of the relationships between lifestyles, pollutant deposition and risks to human health. It has high levels of deposition, due to the use of non-renewable sources to generate power and the high volume of private traffic with an outdated automotive fleet. These sources of pollutant emission have been directly affected by the isolation measures taken to combat COVID.

In this paper we also assess the risk to human health caused by different levels of pollutant deposition. We examine how these values may have been altered by the containment measures, the modification of the general public's behaviour, and the changes in economic activity.

## 2. The global impact of the lockdown measures

The containment measures adopted by many countries in 2020, and the restrictions on the production and consumption of goods and services that they have entailed, have generated the largest global economic crisis since the end of World War II. We stress that we use the term "economic crisis" in its usual sense, that is, a moment in which production shows a fall in value measured in terms of GDP. We emphasize this point because our aim is to assess the link between the economic crisis and the effects on the environment, which in some circumstances may be a better indicator than GDP of the well-being of a society.

These two objectives, maintaining economic growth and protecting environmental quality, may prove to be incompatible. While the current economic crisis produces major disruption, its effects on certain aspects of the environment may paradoxically have positive consequences for people's well-being. So, it is important to distinguish between effects on GDP and effects on the environment. In our view, an examination of this dramatic situation can shed light on a conflict that goes to the very heart of economic development.

[2] warned that "the pandemic represents the largest economic shock the world economy has witnessed in decades, causing a collapse in global activity." The pandemic has had a huge impact on well-being in terms of health and income, and has reduced the employment opportunities of a large part of the population. But, at the same time, the negative growth of the economy and the restrictions on mobility have led to improvements in environmental indicators. Unfortunately, the experience of these past months has drawn attention to the contradictions underlying the objectives of economic growth, full employment, and social welfare. It has been shown that modern-day societies with their current organizational structures have great difficulties in maximizing all three objectives at the same time.

Take, for example, the European Green Deal of December 2019. The Commission Communication states forcefully that it "resets the Commission's commitment to tackling climate and environmental-related challenges that is this generation's defining task." [3]. The strong wording of the message stresses the importance of seeing the environmental question as one of the priority objectives of the societies of the twenty-first century. So, it is essential to examine the relationships of environmental indicators alongside indicators of economic growth and employment, especially at a time when the contradictions between them seem to be so evident.

Countries have responded by restricting activity and mobility in a variety of ways. Some have reacted by passing drastic measures; others, over time, have adapted their restrictions. These measures (especially the confinement) had unprecedented repercussions for economic activity. The indicator that probably best summarizes its impact is the evolution of quarterly GDP, a statistic that allows a simple comparison in the whole of the European Union.

Table 1 shows the variation in GDP in the EU-27 countries in the second quarter of 2020 compared to the previous quarter. This makes it possible to assess most of the variation, since the second quarter includes a few weeks at the end of March when countries adopted their own strategies, in which the cessation of activity already affects the GDP of the first quarter.

**Table 1.** Quarterly variation in GDP in EU countries between the first and second trimesters (2020)

	Quarterly variation		Quarterly variation
Spain	-18.5	Bulgaria	-10.0
Croatia	-14.9	Germany	-9.7
Hungary	-14.5	Slovenia	-9.6
Greece	-14.0	Poland	-8.9
Portugal	-13.9	Czech Rep.	-8.7
France	-13.8	Netherlands	-8.5
Italy	-12.8	Slovakia	-8.3
Romania	-12.3	Sweden	-8.3
Belgium	-12.2	Denmark	-6.9
Eurozone	-11.8	Latvia	-6.5
Cyprus	-11.6	Ireland	-6.1
Malta	-11.6	Estonia	-5.6
EU-27	-11.4	Lithuania	-5.5
Austria	-10.4	Finland	-4.5

**Source:** Eurostat

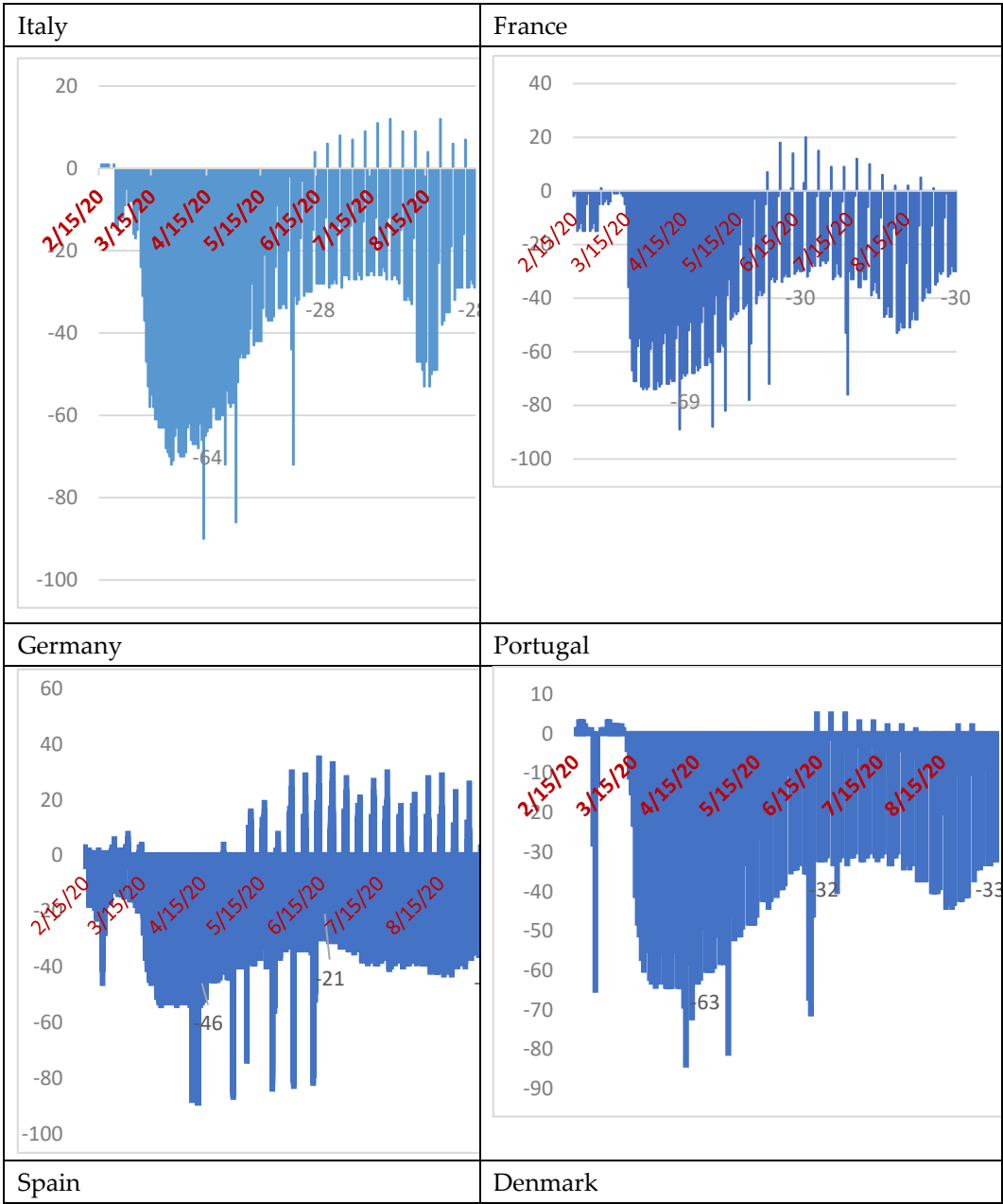
The case study of the Canary Islands presented here will assess data at regional level, using the estimates made by the Canary Island Institute of Statistics (ISTAC). The data show that in the second quarter of 2020 the islands recorded a reduction in interannual GDP of 36.2%. This figure, the highest since records with disaggregated data began, was 60% higher than the average for the whole of Spain, which was 22.1%. According to this estimate, the impact was almost as serious as in Spain's other tourist archipelago, the Balearics, whose regional government reported a fall of 40.5%.

Although practically all sectors of the Canary Island economy were affected by the pandemic and the health control measures imposed, this high impact on GDP seems to be clearly linked to the relative weight of tourism. In this regard, restrictions on mobility and measures of social distancing, and especially in the period of confinement, have had devastating effects on supply, demand, and on all tourism-related activity.

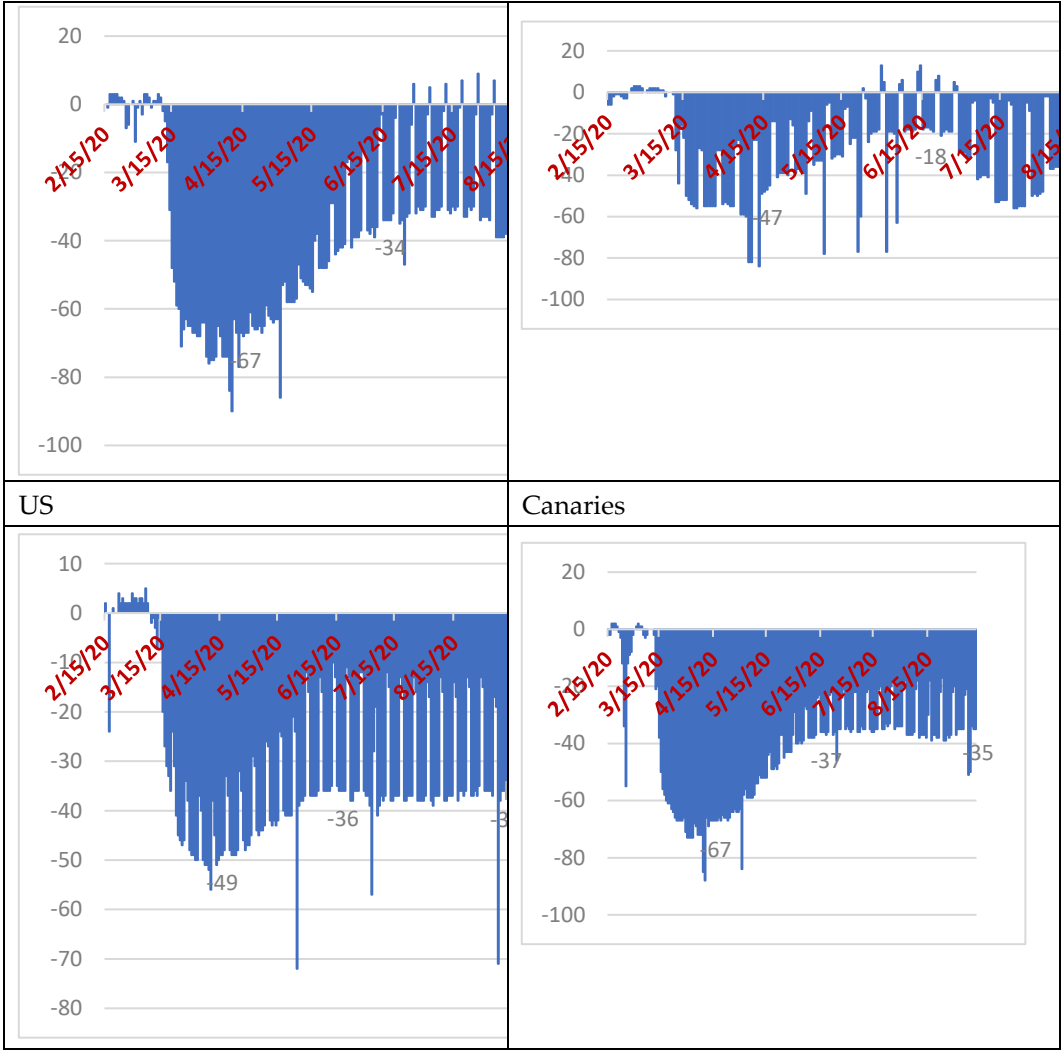
Although we lack indicators such as those traditionally used in economic analysis such as GDP, there are others that can help us to reliably quantify the effect of these changes. Specifically, the following charts display indicators of the evolution of workplace attendance in several major EU countries: Italy, France, Spain, Portugal and Germany, as

well as the US and the Canary Islands, based on the statistics generated by Google from its multiple users of geolocatable terminals<sup>1</sup>.

**Chart 1.** Percentage changes in workplace attendance (January-September)



1 Daily mobility is measured as the percentage of daily change with respect to the average of the five weeks in January. Google describes its methodology in the following link: [covid19mobility/answer/9825414?hl=es&ref\\_topic=9822927](https://www.google.com/covid19/mobility/answer/9825414?hl=es&ref_topic=9822927)



Source: Google

These eight examples of the evolution of mobility offer some interesting comparisons if we take three representative days of the lockdown, at the beginning, in the middle and at the end (for now) of the period. Table 2 shows the differences in mobility in various EU countries, the US, and the Canary Islands. The results suggest that the measures to reduce mobility, and specifically the lockdown, led to a large reduction at the first time point analysed – around two-thirds in the countries like Italy, France, Portugal and Spain which took the most drastic measures. However, at the other two time points the figures in most cases are relatively homogeneous (with reductions in mobility of around a third, except for Germany and Denmark), despite the changes in the patterns of restrictions. It is too early to be able to establish causal links between the factors and to identify the ones with the greatest influence, even though the extension and maintenance of working from home seems to have been decisive.

Table 2. Differences in relative mobility. EU countries, US and Canary Islands (three time points)

	April 16	June 18	September 11
Italy	-64	-28	-28
France	-69	-30	-30
Germany	-46	-21	-32
Portugal	-63	-32	-33

Spain	-67	-34	-39
Denmark	-47	-18	-21
US	-49	-36	-34
Canaries	-67	-37	-35

The reduction of mobility seems to be one of the trends that is now becoming consolidated. Time will tell whether other factors such as the paralysis of the labour market and the spread of working from home continue at levels that influence the still very significant reduction in work-related mobility.

### 3. Impact of environmental pollution on human health

Economic activity has been dramatically affected and radical changes have been seen in a short period of time. The discussion of the impact on mobility and economic activity in the previous section gives an idea of these changes. We now turn to the environment, focusing specifically on air pollution and its effect on human health and examining the new environmental scenarios and the priorities of public policies. Pollution does not respect borders: transported by wind and water, it damages environments far away from its place of origin [4, 5], specifically in relation to air pollution, the World Health Organization stated that “potentially harmful gases and particles are being sent into the atmosphere on a global scale and in increasing quantities, generating negative effects on human health and the natural environment”. [6, 7].

Air pollution is another expression of this new global phenomenon, in which complex relationships are established between the emission of pollutants, atmospheric processes and the effect on the various recipients. Air pollution can cause health problems ranging from mild respiratory difficulties to asthma attacks, potentially leading to long-term lesions in the lungs. It also affects the natural environment, where the consequences observed in the short term remain severe over longer periods [8, 5, 9, 10, 11, 6, 12].

[5] establishes that the sectors mainly responsible for air pollutant emissions in Europe are (1) transport, both road and non-road (air transport, rail, sea and river traffic); (2) commercial, institutional and households; (3) the production and distribution of energy; (4) industry – divided into energy use in industry and industrial processes and product use; (5) agriculture; and (6) waste, which includes landfills, waste incineration with heat recovery, and open burning of waste.

The National Emission Ceilings (NEC) directive imposes maximum limits for the emissions of five key air pollutants – nitrogen oxides, sulphur dioxide, volatile organic compounds other than methane, ammonia and fine particulate matter – which harm human health and the environment (table 3).

**Table 3.** Air quality: EU norms and WHO guidelines

Pollutant	Period	WHO guidelines µg/m <sup>3</sup>	Thresholds in the guidelines on ambient air quality µg/m <sup>3</sup>	Nº of times in a year that the EU thresholds may be exceeded
NO <sub>2</sub>	1 year	40	40	-
	1 hour	200	200	18
O <sub>3</sub>	8 hours	100	120	25
PM <sub>10</sub>	1 year	20	40	-
	24 hours	50(a)	50	35
PM <sub>2.5</sub>	1 year	10	25	-

	24 hours	25	-	-
SO2	24 hours	20	125	3
	1 hour	-	350	24
	10 mins	500	-	-

(a) The WHO recommends using the 99th percentile (3 days/year). **Source:** [13]

The present study focuses on certain specific effects of pollution: those that condition human health, and in particular premature mortality, overall mortality, and the costs associated with mortality and morbidity. Studies such as the reports by [13, 14] have shown that the total external costs due to mortality exceed those deriving from morbidity. These reports also estimate premature mortality levels related to air pollution, based on PM, NO<sub>2</sub> and O<sub>3</sub>.

Air pollution is one of the leading causes of premature death and disease, and is currently the greatest risk to environmental health in Europe [15, 16, 17], causing around 400,000 premature deaths per year across the continent [5]. The health effects of air pollution range from subclinical (inflammation) to severe states such as aggravation of existing conditions and ultimately death. Although air pollution affects the entire population, certain groups such as children, the elderly, pregnant women and people with pre-existing health problems are more susceptible to its effects [8].

Exposure to air pollution may have other adverse health effects, such as increased premature mortality and morbidity due to respiratory and cardiovascular diseases [13, 12].

4. Methodologies for assessing population exposure to air pollution

A large body of research has analysed the physical and economic effects of pollution. Due to the wide range of polluting sources, inputs and agents many different methodologies have been devised for its analysis, some focusing more on the physical evaluation of the impacts and others on their economic repercussions.

The acute and chronic effects of air pollution on human health have also been studied in recent decades. Many studies have presented overviews of previous research. The pioneering works of [18] focused on mortality, but also included other effects; [19] performed a meta-analysis of acute mortality studies; and [20] compiled a large number of investigations. For their part, [21, 22, 23] considered both chronic and acute effects.

Health impacts can be quantified using a range of metrics, which reflect morbidity (for example, an increase in the number of hospitalizations, lost work days, etc.) or mortality (for example, the number of premature deaths). Calculating the exposure of the population to air pollution is crucial to an assessment of its impacts [24].

Most studies of the effects of pollution differentiate between some or all of the following three phases:

- Identification of sources of pollution and polluting agents.
- Identification of impacts.
- Evaluation of impacts.

[8, 5] have calculated mortality attributable to exposure to air pollution since 2014. The methodology used (and the results) can be found in the series of reports entitled Air Quality in Europe. The study focuses on the assessment of air pollution levels, demographics, and the relationship between the two. Specifically, the reports use the pollutant values recorded by Air Quality Control stations in specific areas, mainly in cities, and then analyse these values using the legal standards established by the EU and the WHO guidelines for air quality in urban areas.

Dose-response relationships are commonly used to estimate and evaluate the risks to human health from exposure to air pollutants. These relationships have been established through epidemiological studies and represent the association between a population, the concentration of an air pollutant to which it is exposed, and the risk to health.



Concentration-response functions quantify the health impact per unit concentration of air pollutant [15]. The dose-response function can be defined as the representation of the changes in a recipient ( $y$ ) due to a certain concentration of contaminating agent ( $x$ ).

$$y = f_{\text{impact}}(x)$$

The term “dose” refers to the amount of pollutant that the recipient receives, which does not necessarily coincide with the exposure; it represents the measurement of the levels of pollutants found in the recipient’s environment [25, 24]. In theory, the effects are more closely related to doses, but in reality, it is easier to measure exposure; in fact, in many cases “dose-response” really means “exposure-response”.<sup>2</sup>

In this analysis, we use the concentration-response functions defined by [12], which are based on relative risks. The relative risks capture the increase in mortality that can be attributed to a given increase in the concentration of air pollutants. Relative risks are defined at the population level (as statistical averages) and cannot be assigned to specific individuals. In the case of mortality, therefore, it is not possible to identify which individual cases are caused by air pollution [15, 26].

After determining the dose-response functions we will apply them to the case study, and relate them to the deposition values recorded in order to estimate the impacts of pollution.

With the concentration map provided by the monitoring stations, and taking into account the population groups (mainly based on age) exposed to these levels of contamination, the relative risk is estimated from the concentration-response functions defined by epidemiological studies. This allows an estimation of the mortality and morbidity risks in a region in a given period and the levels of deposition recorded by the monitoring stations.

However, the application of these analyses presents certain limitations that must be borne in mind. By their nature, estimates of human mortality or morbidity are subject to various levels of uncertainty, with regard both to the deposition values recorded and to the dose-response functions. For example, the location of the stations is not always ideal; similarly, operational problems may mean that the data recorded are not sufficiently reliable. As for the dose-response functions, in most cases they are linear and are not specifically defined for the populations to which they are to be applied. Further, most epidemiological studies cannot exclude other factors that may also have an impact on mortality, such as smoking, diet, or other lifestyle issues. Lastly, air pollution is a complex mix of various agents; the health impacts of certain pollutants may overlap, and the premature deaths attributed to each pollutant cannot simply be added up together.

In view of the above, the objective of this study is not to provide a precise quantification of the deaths associated with pollution, but rather to obtain a set of data that can help to reflect on the importance of measures favouring the reduction of atmospheric pollution for the improvement of population health.

## 5. Evaluation of the effects of air pollution on the island of Tenerife

As a result of a series of climatological and geographical factors, the Canary Islands export more pollution than they receive. In the case of Tenerife this natural convection is favoured by the island’s orography, with an almost vertical relief (its surface area is 2,034 sq. km and its highest point 3,718 m), which forces the north north-easterly trade winds coming in from the sea to move upwards and thus disperse polluting particles and gases more quickly. While this wind regime is maintained, pollutant emissions are projected outside the urban area.

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<sup>2</sup> These functions can be determined through the observation of the effects on the environment under natural conditions (e.g., the development of dose-response functions for certain diseases, contrasting the levels of pollutant deposition with the number of hospitalizations for a given period). Experimentation under controlled conditions is also used to determine dose-response relationships (an example would be the study of the effects on the tree population through the use of controlled plots).



The main sources of pollution in Tenerife are the Las Caletillas and Granadilla thermal power stations and the various forms of transport: air, sea, and above all road traffic.<sup>3</sup> In normal atmospheric conditions, the pollution produced in the islands (with the exception of the pollutants that go directly into the soil, such as fertilizers, pesticides, and wastewater) is for the most part dispersed and is carried away from the archipelago by the atmosphere and the ocean. It does not produce an instantaneous and direct impact on the island ecosystems, but its contribution to the increase in the levels of global pollution is a matter of concern.

In this study three areas have been defined that correspond to the nuclei with the highest economic activity and population, and therefore the highest number of urban and interurban displacements. In the “Metropolitan” area, corresponding to Santa Cruz and La Laguna, the main pollutant source is urban and interurban road traffic, and, in times of what is known as “southern weather” (described above), the Las Caletillas thermal power station.

The “Southern” area encompasses the tourist and residential centres of the south of the island where the dense population, air and land traffic, and the island’s second thermal power station are the main sources of pollution. Finally, the “Northern” area is home to most of the residential and tourist areas of the North of the Island.

5.1 Evaluation of electricity consumption in Tenerife and the influence of Covid-19

Restrictions on mobility due to the Covid-19 pandemic have also had a significant impact on energy consumption patterns. This initial evaluation document analyses these repercussions on electricity consumption focusing on three areas corresponding to the three main urban agglomerations of Tenerife, and assessing the variations in consumption after the declaration of lockdown on March 16, 2020.

Electricity generation is one of the main sources of GHG emissions, especially CO<sub>2</sub>. According to the latest regional calculation available, dating from 2017 [27], total GHG emissions in the Canary Islands amounted to 13.59 million tons of CO<sub>2</sub>-eq, of which the vast majority, 11.81 million tons, were CO<sub>2</sub>. In 2017, the thermal power stations were responsible for 44.23% of the total emissions, while the transport sector accounted for 38.8%.

In Tenerife, and indeed throughout the Canary Islands, the proportion of GHG emissions resulting from electricity generation with respect to all emissions is much higher than in the rest of Spain. In the same year 2017, GHGs deriving from electricity generation in Spain as a whole amounted to 18.8% of the total, and in subsequent years the figure has fallen further (to 13.5% in 2019).

The limitation of mobility, the reduction or cessation of activities characterized by high levels of energy consumption such as tourism and the lockdown itself have significantly affected electricity production and consumption. The data available confirm this: first, electricity production in the archipelago recorded a significant decrease in the months following the pandemic (Table 4).

**Table 4.** Evolution of gross electricity production in the Canary Islands and Tenerife: monthly and annual variations, January-September 2020

	Canaries			Tenerife		
	MWH	%/previous month	%/ previous year	MWH	%/previous month	%/previous year
January	712,351	2.4%	-0.8%	270,359	2.2%	-3.5%
February	622,618	-12.6%	-2.9%	234,392	-13.3%	-4.8%
March	594,726	-4.5%	-8.6%	227,739	-2.8%	-8.1%

<sup>3</sup> Maritime traffic is responsible for emissions and depositions of significant amounts of heavy metals, but their analysis is not the object of this study.

April	499,687	-16.0%	-22.1%	196,869	-13.6%	-22.7%
May	512,561	2.6%	-19.0%	197,673	0.4%	-19.8%
June	502,631	-1.9%	-22.7%	190,531	-3.6%	-25.9%
July	531,228	5.7%	-12.5%	201,834	5.9%	-13.3%
August	547,167	3.0%	-13.4%	202,376	0.3%	-13.2%
September	599,867	9.6%	-9.3%	230,305	13.8%	-9.3%

Source: ISTAC

The table shows a significant reduction in electricity production coinciding with the period of confinement (March 16 to June 9), both in Tenerife and in the Canary Islands as a whole. The comparison with regard to the months of April to June in the previous year shows reductions of between 20% and 25%.

This decrease in the production of electrical energy also brought down CO<sub>2</sub> emissions. Tables 5 and 6 show the comparative results of CO<sub>2</sub> emissions by the island's power stations according to the type of generation technology used in two periods: March 2020 (Table 5), when a large reduction in emissions is observed from the start of the confinement (on March 15); and in the month of April 2020 in relation to the same month of 2019 (Table 6).

**Table 5.** CO<sub>2</sub> emissions according to system of electricity generation in Tenerife, March 2020

	Tonnes of CO <sub>2</sub> emitted according to type of technology used				
March 2020	Diesel motor diesel	Gas turbine	Combined cycle	Steam turbine	Total
Monthly total	6,267.5	5,866.9	87,618.2	51,545.7	149,668.2
Mean 1-15 (A)	215.0	278.8	2,674.9	1,882.3	5,051.0
Mean 16-31 (B)	190.2	105.3	2,968.4	1,457.0	4,619.0
(B-A)/A: Δ (%)	-12%	-62%	11%	-23%	-9%

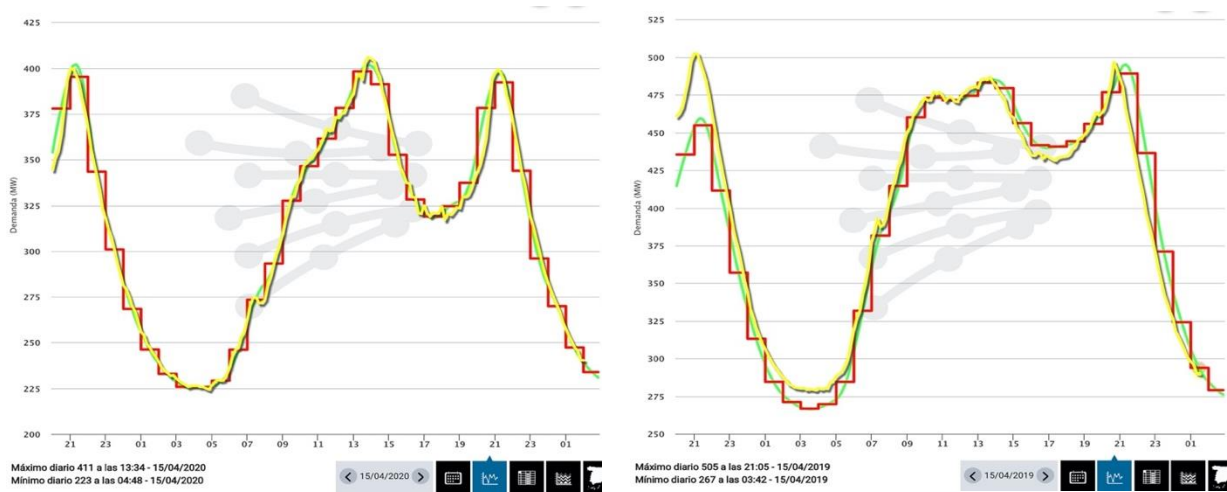
**Table 6.** Average daily emissions for April 2019 and April 2020 according to type of generation technology in the electricity system of Tenerife

	Diesel motor	Gas turbine	Combined cycle	Steam turbine	Total
Daily mean April 2019 (a)	341.2	493.9	2,308.9	2,998.6	6,142.6
Daily mean April 2020 (b)	276.6	136.0	2,635.6	1,231.6	4,279.8
Δ 2020/2019 (%)	-18.9%	-72.5%	14.1%	-58.9%	-30.3%

Source: Red Eléctrica Española-REE (Spanish Electricity Network)

Table 6 also shows that the significant reduction in emissions was concentrated in the technologies that pollute the most, due to the reductions in peak energy demand (around 30% in April 2020 compared with April 2019). The figures below (chart 2) display data from the Spanish Electricity Network, showing a reduction in peak demand of around 20% between Wednesday, April 15, 2019 and Monday, April 15, 2020.

**Chart 2.** Energy Demand in April 15 2020 and April 15, 2019.



Source: Red Eléctrica Española-REE (Spanish Electricity Network))

These changes in production levels were accompanied by changes in consumption levels. The averages of the previous years were established for comparison with the behaviour observed during the lockdown and the subsequent de-escalation (table 7).

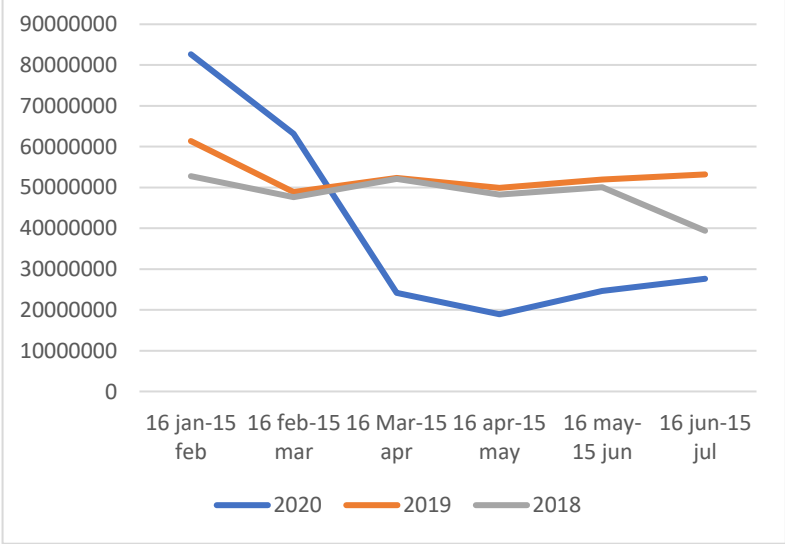
Table 7 Energy consumption according to area during the COVID-19 pandemic

Period	Metropolitan (KWH)	Northern (KWH)	Southern (KWH)
16 Jan-15 Feb	84,676,337	17,505,344	82,652,583
16 Feb-15 Mar	70,263,179	14,388,101	63,153,896
16 Mar-15 Apr	56,685,396	8,160,402	24,161,694
16 Apr-15 May	54,081,245	6,447,861	18,930,523
16 May-15 Jun	64,908,119	7,333,147	24,675,182
16 Jun-15 Jul	67,872,257	7,795,529	27,659,330

Source: DATADIS

Chart 3 shows the immediate and continued impact of the reduction in consumption in the Southern area: a fall of more than 60% at the start of lockdown compared to the immediately preceding period, after which the curve flattens out.

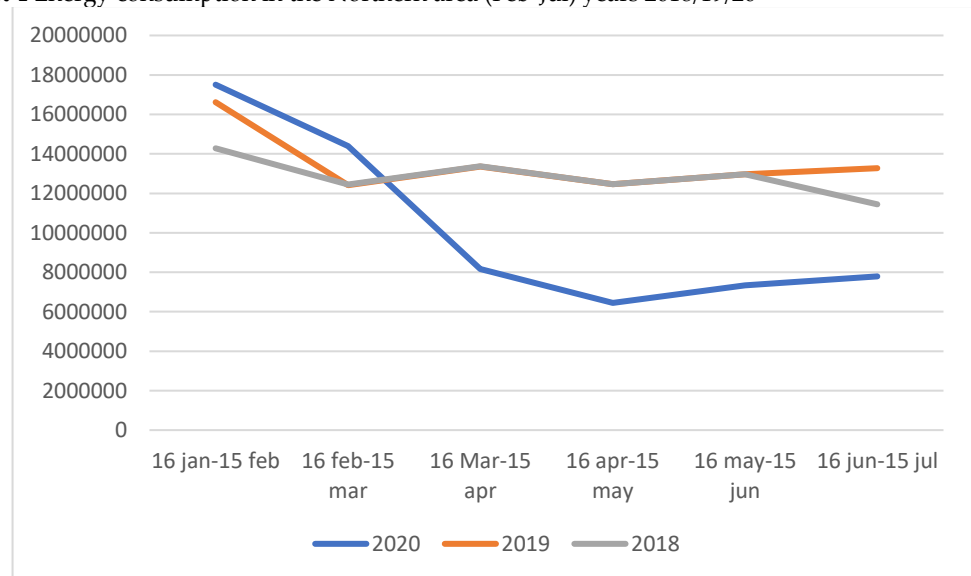
Chart 3 Energy consumption in the Southern area (Feb-Jul) years 2018/19/20



Source: DATADIS

In the Northern area of Puerto de la Cruz (Chart 4), the decreases were very significant but were nevertheless lower than those recorded in the Southern area. The reduction in the first period was just over 40% in relation to the immediately preceding month, and the average decrease in relation to the same periods of previous years was almost 50%.

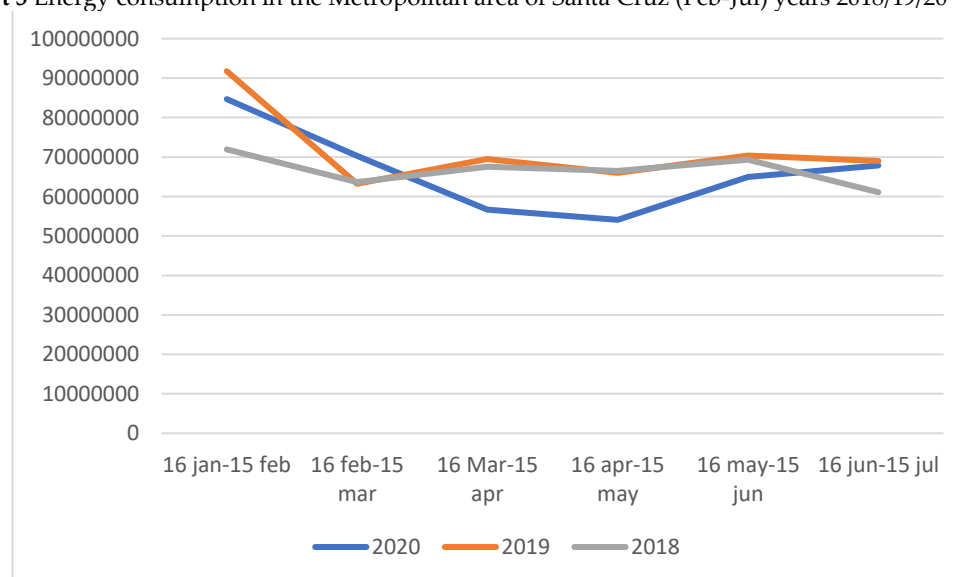
**Chart 4** Energy consumption in the Northern area (Feb-Jul) years 2018/19/20



Source: DATADIS

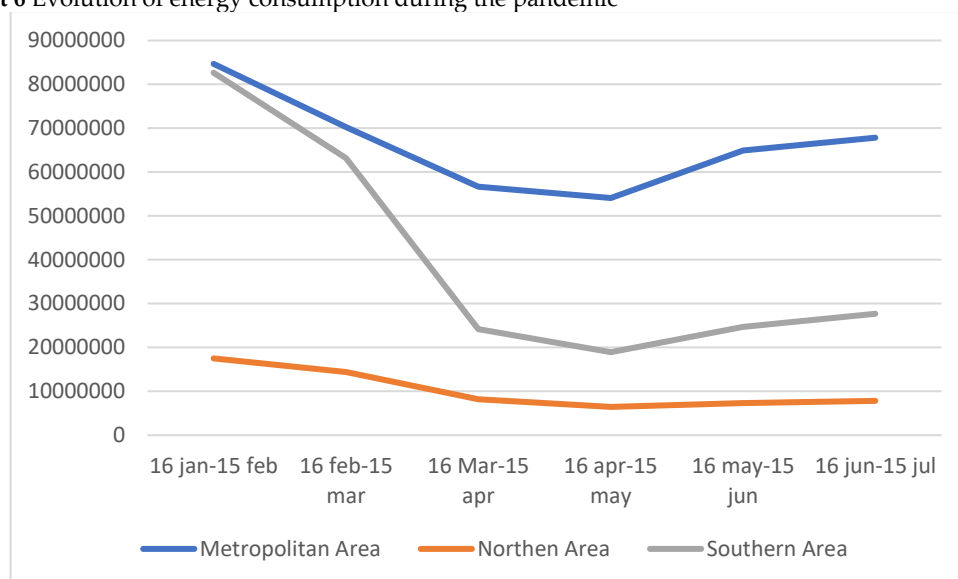
Finally, in the Metropolitan area the reduction was much lower than in the areas where tourist activity is significant or dominant (Chart 5). The decrease with respect to the immediately previous period did not reach 20%, while, in relation to the same periods of previous years, the highest recording (a reduction of 18.4% in the period April 16-May 15) is less than a third of that recorded in the tourism-dominated Southern area. In fact, at the end of the period, there was even a slight increase compared with previous years.

**Chart 5** Energy consumption in the Metropolitan area of Santa Cruz (Feb-Jul) years 2018/19/20



Source: DATADIS

In summary, then, the decrease in consumption is clear (Chart 6). This is due fundamentally to the fact that more than 90% of electricity generation is carried out through highly polluting non-renewable sources.

**Chart 6** Evolution of energy consumption during the pandemic

Source: DATADIS

## 5.2. An evaluation of the effects of air pollution on the island of Tenerife

These changes in patterns and lifestyles have significantly modified the levels of pollutant emission and deposition in the islands. In order to analyse the impact of these reductions, we used the values of pollutant deposition recorded by the Canary Islands Air Quality Surveillance Network. They cover the Metropolitan area of Sta. Cruz de Tenerife - S. Cristóbal de La Laguna, with an approximate population of 360,000 inhabitants, the Southern area with some 176,000 inhabitants and Northern area with 66,000. The values used are the daily averages based on hourly values; in the interests of health protection, the regulations establish hourly, daily and annual limits. Table 8 displays the most important information for the years 2018 and 2019. These data will later be used to study whether the confinement measures have had an effect on the levels of deposition in the areas under analysis.

**Table 8.** Average annual levels of the main atmospheric pollutants in the three study areas

2018	Annual average		
	PM10	PM2.5	NO2
Metropolitan	17	7	19
Northern Tenerife	16	n/a	7
Southern Tenerife	24	10	10
2019	Annual average		
	PM10	PM2.5	NO2
Metropolitan (Santa Cruz De Tenerife - La Laguna)	22	8	16
Northern Tenerife	12	n/a	5
Southern Tenerife	27	8	10

In 2018, the pollutants with the greatest impact were PM10 and PM2.5. At some point, most of the stations on the island recorded annual or daily mean values for PM10 above the WHO recommendations. The legal assessment of these excess values is pending, since the proportion of the emissions due to natural causes (for example, the dust blown over to the islands from Africa) still has to be calculated, but it is clear that a major part of this pollution comes from road and maritime traffic and from the thermal power stations. As

for PM<sub>2.5</sub> particles, the Vuelta de los Pájaros (Metropolitan) and La Guancha-Candelaria (Southern) stations registered values above the daily averages recommended by the WHO, with 19 and 17 excess recordings respectively, although neither surpassed the annual limit of 25 µg/m<sup>3</sup> established by the legislation.

Sulphur dioxide (SO<sub>2</sub>) presented high concentrations at the four stations southwest of the city of Santa Cruz de Tenerife – Candelaria, La Guancha, Barranco Hondo and Calatillas – which, respectively, exceeded the average daily concentration recommended by the WHO on 51, 44, 37 and 28 occasions. The levels of this pollutant have fallen since the economic crisis of 2008, especially after the suspension of activities at the CEPESA oil refinery in 2014.

With regard to nitrogen dioxide (NO<sub>2</sub>), two of the stations located in Santa Cruz de Tenerife exceeded the hourly limit value of 200 µg/m<sup>3</sup> established by the regulations on four occasions –well below the maximum of 18 permitted by the legislation. During 2019, the annual limit of 40 µg/m<sup>3</sup> was not exceeded; the highest value (33 µg/m<sup>3</sup>) was recorded at the Hacienda de Santa Cruz de Tenerife station.

In 2019, PM<sub>10</sub> and PM<sub>2.5</sub> were once again the pollutants with the highest deposition values, followed at some distance by sulphur dioxide and tropospheric ozone. All the stations recorded annual or daily mean values for PM<sub>10</sub> above the figures recommended by the WHO. Two stations in the Metropolitan area and one in the Southern exceeded the daily limit values established in the regulations (50 µg/m<sup>3</sup>) on more than the 35 days permitted. The worst values were recorded at the Casa Cuna station, next to the entry to the city of Santa Cruz on the TF-5 North motorway, where the daily limit value was exceeded on 70 occasions. Three stations in the Southern area that measure PM<sub>2.5</sub> particles exceeded the daily mean value recommended by the WHO on three occasions, although none surpassed the annual limit value of 25 µg/m<sup>3</sup> established by the legislation.

Sulphur dioxide presented high concentrations at the four stations to the southwest of the city of Santa Cruz de Tenerife, previously mentioned, which exceeded the average daily concentration recommended by the WHO on 38, 37, 33 and 16 occasions.

As for NO<sub>2</sub>, in 2019 two of the stations located in the Metropolitan area again exceeded the hourly limit value of 200 µg/m<sup>3</sup> established by the regulations on four occasions, well below the maximum of 18 allowed by the legislation. During 2019, the annual limit of 40 µg/m<sup>3</sup> established in the regulations was not exceeded; the maximum value (35 µg/m<sup>3</sup>) was recorded at the Hacienda de Santa Cruz de Tenerife station.

In general, then, Tenerife presents certain specific foci of pollution, such as thermoelectric power stations, the Santa Cruz de Tenerife refinery (until 2014), maritime traffic at the harbours, and road traffic in the metropolitan area. The pollution generated in these sites spreads throughout the rest of the islands. An added problem that is specific to the Canary Islands is its proximity to Africa; the high levels of PM<sub>10</sub> particles are due to the frequent arrival of dust from the Sahara.

The period chosen to study the incidence of the measures against SARS-COV-19 runs from 2018 to September 2020, in order to reduce meteorological biases and to extend the analysis beyond the months of confinement alone. The comparison with 2018 allows an appreciation of the most evident changes, since the levels of deposition of the pollutants analysed in 2019 were in general higher than those of 2018. Thus, the reductions in the months of March and April were dramatic (Table 9), with falls of more than 27% and 24% respectively for NO<sub>2</sub> compared with 2018, and falls of 9% and 17% for PM<sub>10</sub>.

**Table 9.** Variations in NO<sub>2</sub> and PM<sub>10</sub> levels in Sta. Cruz de Tenerife (years 2018 and 2020)

NO <sub>2</sub>												
2018	Dec-18	Nov-18	Oct-18	Sep-18	Aug-18	Jul-18	Jun-18	May-18	Apr-18	Mar-18	Feb-18	Jan-18
	28.5	14.3	14.6	11.2	11.6	8	7	9.8	8.8	16.1	15.2	22.40
2020				Sep-20	Aug-20	Jul-20	Jun-20	May-20	Apr-20	Mar-20	Feb-20	Jan-20
				12.7	10.7	11.2	11.3	11.7	6.7	11.8	27.5	25.20

Difference (%)				13%	-8%	40%	61%	19%	-24%	-27%	81%	13%
PM10												
2018	Dec-18	Nov-18	Oct-18	Sep-18	Aug-18	Jul-18	Jun-18	May-18	Apr-18	Mar-18	Feb-18	Jan-18
	29.8	6.6	10.7	20.5	17.6	10.8	7.3	8.8	7.8	13.5	8.2	8.3
2020				Sep-20	Aug-20	Jul-20	Jun-20	May-20	Apr-20	Mar-20	Feb-20	Jan-20
				28.1	19.4	19.5	9.5	13.4	6.5	12.3	56.9	16.6
Difference (%)				37%	10%	81%	30%	52%	-17%	-9%	594%	100%

Extending the period of analysis to the entire decade of 2010-20, the report “Effects of the SARS-COV-19 crisis on urban air quality in Spain” carried out by Ecologistas en Acción (2020) shows a variation of around 60% that for NO<sub>2</sub> (see Table 10).

**Table 10.** Variation in NO<sub>2</sub> levels in Santa Cruz de Tenerife (2010 - 2020)

NO <sub>2</sub>			
	14/3-30/4: 2010-19	14/3-30/4: 2020	Variation 2010-2020
	19	7	-61%

The levels of NO<sub>2</sub> are particularly significant in urban areas. As mentioned above, they are influenced by socioeconomic characteristics, and also by the climate and the mountains. The images recorded by satellite sensors such as the European Space Agency's Sentinel-5 Precursor (Sentinel-5P), in orbit since 2017, confirm this fact; specifically, in the area close to the Canary Islands, southern Europe and North Africa they show that the highest levels of NO<sub>2</sub> are concentrated in urban areas and that these levels were drastically reduced as a direct effect of the lockdown. The levels in the Canary Islands are lower than at the other sites, though still significant, and they also fell dramatically as a consequence of the confinement.

## 6. Health risks due to the intake of pollutants

In order to estimate the effects of air pollution on population health, we need first to quantify the population exposed to pollutants. To do so, we need to determine the total population and also how it is broken down by age and sex. This will help us to define the populations at risk, which we will then analyse by means of dose-response functions.

**Table 11.** Dose-Response Functions

	CRF	µg/m <sup>3</sup>
PM2.5	6.20%	0.0062
NO <sub>2</sub>	5.50%	0.0055
O <sub>3</sub>	1.40%	0.0014
PM10	4.00%	0.0004

This study uses the concentration-response functions defined by [12], which are based on relative risks (RR). Relative risks capture the increase in mortality that can be attributed to a given increase in the concentration of air pollutants. They are defined at the population level (as statistical averages) and cannot be assigned to specific individuals. In the case of mortality, therefore, it is not possible to identify the individual cases caused by air pollution [15, 26]. Relative risks are defined as the interaction between the



concentration of the pollutant (Table 12) and the dose-response function itself (Table 11), as shown in this equation:

$$\text{Relative Risk (RR)} = \exp(\Omega \times \text{concentration})$$

In the case of PM<sub>2.5</sub>, the concentration-response function used for total mortality in people older than 30 years implies a relative risk of 1,062 per 10 µg/m<sup>3</sup>. This means that, assuming linearity, an increase in PM<sub>2.5</sub> of 10 µg/m<sup>3</sup> is associated with a 6.2% increase in total mortality in the total population considered.

**Table 12.** Average levels of concentration of pollutants in the three study areas (year 2019)

	Metropolitan		Southern		Northern
	Max value	Min value	Max value	Min value	Value
PM <sub>2.5</sub> average annual value	16	6	12	7	n.d.
NO <sub>2</sub> average annual value	25	10	14	8	5
PM <sub>10</sub> average annual value	40	10	35	19	14

After determining the RR, in order to estimate the number of deaths attributable to the pollutant analysed (PD), the attributable fraction (AF) is calculated. The AF is the mortality rate (in the case of Tenerife, 0.7% of the population according to ISTAC population statistics) multiplied by the population affected.

$$PD = AF \times \text{mortality} \times \text{population, with } AF = (RR-1)/RR$$

The estimates of the impacts on the health RR (in our study, mortality) are presented in Table 9 for our three study areas. Bearing in mind the uncertainties inherent in this type of analysis, the PD is calculated for each pollutant and area, using the maximum and minimum annual values of concentrations recorded at the monitoring stations (with the exception of the Northern area where there is only one station).

The estimates obtained suggest that in 2019 the risk of population mortality derived from the depositions of the pollutants studied<sup>4</sup> ranges between 9 and 38 deaths<sup>5</sup> in the case of the Metropolitan area, between four and 13 deaths in the Southern area, and between two and four in the Northern area (table 13).

**Table 13.** Estimation of population mortality risks derived from the depositions of pollutants studied (year 2019)

Capital								
	Concentration		RR		AF		PD	
	Max value	Min value	Max value	Min value	Max value	Min value	Max value	Min value
PM <sub>2.5</sub>	16	6	1.1042871	1.0379005	0.0944384	0.0365165	24	9
NO <sub>2</sub>	25	10	1.1474017	1.0565406	0.12846565	0.0535148	33	14
PM <sub>10</sub>	40	10	1.1735108	1.0408107	0.14785621	0.0392105	38	10
Southern								
	Concentration		RR		AF		PD	
	Max value	Min value	Max value	Min value	Max value	Min value	Max value	Min value

<sup>4</sup> O<sub>3</sub> and SO<sub>2</sub> have been omitted: in the case of O<sub>3</sub> due to a lack of reliable data, and in the case of SO<sub>2</sub> due to the lack of dose-response functions that are widely accepted by the scientific community

<sup>5</sup> Due to the uncertainties of studies of this kind, and at the current stage of the research, it is not advisable to attempt to quantify the number of deaths more precisely – or the deaths attributable to each pollutant, given their complexity and the interactions between them.

PM2.5	12	7	1.0772376	1.0443555	0.0716997	0.0424717	7	4
NO2	14	8	1.0800420	1.0449823	0.0741101	0.0430460	7	4
PM10	35	19	1.1502738	1.0789625	0.1306417	0.0731837	13	7
Northern								
	Concentration	RR	AF	PD				
PM2.5	n/a	n/a	n/a	n/a				
NO2	5	1.02788162	0.02712532	2				
PM10	14	1.05759768	0.05446086	4				

The falls in deposition values caused by the restrictions on mobility, and especially during the lockdown, suggest a change in lifestyle that reduces levels of pollutants has a notable effect on the risk of human mortality. And if we consider a more conservative scenario, with a reduction of 10%, the risk of death caused by the intake of pollutants may have fallen by between one and five people in each of the areas studied, using the most conservative reduction and health risk scenarios.<sup>6</sup> In the context of the archipelago as a whole, these figures may represent a significant factor in the planning of public policies and regulations.

## 7. Conclusions and final comments

The health emergency caused by SARS-CoV-2, raised to the level of international pandemic by the WHO on March 11, has caused a crisis without precedent in recent Spanish and European history, with wide repercussions for mobility and economic activity. In the Canary Islands, the loss of tourism and the maintenance of restrictions on mobility and social distancing have had a devastating effect on the island's economy – far greater than the effect on Spain as a whole. The state of emergency declared by Royal Decree on March 14 and its later extensions was followed by a de-escalation process that was partially interrupted by the arrival of a second wave of infections in August 2020. Over this time, the authorities have imposed measures to limit the freedom of movement of people. After the declaration of the state of emergency, interurban traffic and access to the main cities fell by around 70%, while the outflows of petroleum products from the CLH Group to the Spanish market fell dramatically: by 75% in the case of gasoline, by 55% in the case of diesel A and by 93% in the case of aviation fuels. Electricity demand fell by 20% compared with pre-restriction times.

These measures led to a drastic, generalized reduction in transport and, to a lesser extent, in industrial activity and the generation of electricity (the main sources of the emission of pollutants into the atmosphere). In the large cities, the reduction in traffic reached an average of 77% in Barcelona, Madrid, Malaga, Seville and Valladolid, attaining levels of up to 90% during weekends. Steep falls were also observed in the use of urban public transport, surpassing 90% in buses and suburban trains. Given that motor traffic affects urban air quality more than any other factor, such a marked decrease in circulation and its emissions into the atmosphere significantly improves the quality of the air we breathe. Obviously, this improvement is due to a highly exceptional set of circumstances.

On a global scale, the Sustainable Development are directly or indirectly related to the mitigation of atmospheric emissions and changes in atmospheric composition. Air pollution is currently the most important environmental risk to human health and is perceived as the second biggest environmental concern by Europeans, after climate change [3].

Effective action to reduce air pollution and its impacts requires a better understanding of its causes: how pollutants are transported and transformed in the atmosphere, how

<sup>6</sup> The impacts on morbidity would also be reduced, with the resulting improvement in population well-being.

the chemical composition of the atmosphere changes over time, and how they affect humans, ecosystems, the climate, society and the economy.

In this context, the effect of the SARS-CoV-2 crisis on air quality in the main cities of Spain has shown that reducing motor traffic and introducing changes in mobility patterns are the best way to combat pollution, even taking into account the exceptional nature of the extreme situation we are currently experiencing. This is demonstrated by the satellite images and measurements from air quality monitoring stations recorded by institutions and research centres, even though the data series used are sometimes limited or heterogeneous. Data from EEA member countries show that concentrations of NO<sub>2</sub>, a pollutant emitted mainly by road transport, have decreased in many European cities that implemented lockdown measures. Although a decrease in concentrations of fine particles (PM<sub>2.5</sub>) can also be expected, no consistent reduction has yet been seen in European cities. This is probably because of the wide variety of sources of this pollutant: for example, the combustion of fuel for heating residential, commercial and institutional buildings, industrial activity, and road traffic. A significant fraction of particulate matter is also formed in the atmosphere from reactions with other air pollutants – among them ammonia, a pollutant caused by the application of agricultural fertilizers at this time of year. The implementation of integrated policies would also mitigate the negative impacts of measures introduced to regulate air quality. One example is the subsidy on diesel cars (which typically emit less CO<sub>2</sub> per kilometre but more PM and NO<sub>x</sub> than the equivalent gasoline vehicle). Similarly, the burning of wood for residential heating may potentially increase emissions of PM and other carcinogenic air pollutants [8].

In the case of the Canary Islands, the impact of the reduced mobility, and specifically, the strict lockdown imposed in Tenerife until May 2020, was highly significant in terms of the levels of depositions registered in the areas in our study. The implications of this reduction for the health of the population are difficult to quantify, but significant falls in morbidity and mortality were recorded. The data presented here should serve to initiate a debate on the design and implementation of measures, on global economic policies, and on ways to achieve attitudinal changes on the part of the general public, institutions, and businesses. The emphasis should be placed on the benefits of reducing pollution not just to enhance efficiency but also to improve public health. This is a factor that, in general, has not been given sufficient consideration in the global analyses of environmental sustainability. The paradigm shift that seems to be emerging as a consequence of the effects of the pandemic, and the reappraisal of the interaction between the environment, society, and economic activity, also point in this direction.

**Author Contributions:** Conceptualisation and methodology S. Corral; formal analysis, J. Hernández; and validation J. L. Rivero. All authors participated in writing the original manuscript. All authors have read and agreed to the published version of the manuscript."

**Conflicts of Interest:** The authors declare no conflict of interest.

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