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Decrease of mobility, electricity demand, and NO_2 emissions on COVID-19 times and their feedback on prevention measures

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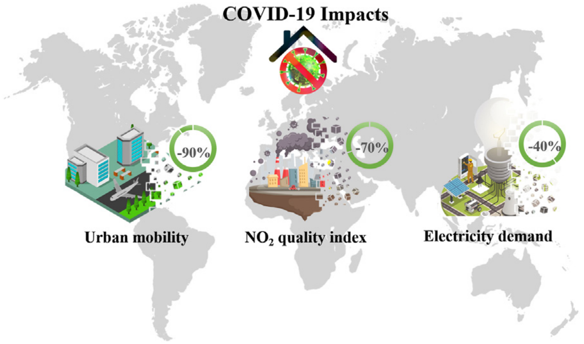
HIGHLIGHTS

- Decrease on mobility, electricity demand, and NO_2 emissions worldwide as a result of the COVID-19 pandemic.
- Characterization of incidence curves to analyse the evolution of the pandemic by country.
- High incidence rate in Latin-American countries despite early prevention measures.

GRAPHICAL ABSTRACT

Modified from original picture on freepik. URL. Vector de Viajes creado por Layerace www.freepik.es. Last time accessed on July 15th, 2020.



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ABSTRACT

The spread of coronavirus disease 2019 (COVID-19) on 2020 has affected human activities in a way never documented in modern history. As a consequence of the prevention measures implemented to contain the virus, cities around the world are experiencing a decrease in urban mobility and electricity demand that have positively affected the air quality. The most extreme cases for cities around the world show a decrease of 90, 40, and 70% in mobility, electricity demand, and NO_2 emissions respectively. At the same time, the inspection of these changes along the evaluation of COVID-19 incidence curves allow to obtain feedback about the timely execution of prevention measures for this and future global events. In this case, we identify and discuss the early effort of Latin-American countries to successfully delay the spread of the virus by implementing prevention measures before the fast growth of COVID-19 cases in comparison to European countries.

1. Introduction

At the end of 2019, Chinese health authorities started the investigation of a new type of viral pneumonia that appeared in the city of Wuhan, China. This disease was later named as severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2) or coronavirus disease 2019

Abbreviations: AQI, Air Quality Index; COVID-19, Coronavirus Disease 2019; D_{100}, Date of 100th COVID-19 Case; I_C, Daily Incidence; I_{CR}, Incidence Rate; I_D, Death Incidence; SARS-Cov-2, Severe Acute Respiratory Syndrome Coronavirus 2; T_D, Threshold Day.

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(COVID-19) due to the crown-like spiked surface of the novel virus causing its spread. Eventually, the World Health Organization (WHO) declared COVID-19 as a global health emergency on January 30th, 2020 (WHO, 2020). Since then, the disease has caused the confirmed infection of more than 25 million people worldwide as well as near a million deaths by early September 2020 (WHO CDD, 2020). The highly contagious rate of this novel virus and the lack of a vaccine has caused most governments to enforce or at least recommend prevention measures such as the use of protective equipment, complete or partial lockdown, quarantine of infected patients, restrictions in transit, curfew hours, closure of borders, cancelation of massive events, and even reduction of activities that require close physical interaction. As a consequence, human lifestyle and therefore, the environment, have changed drastically on 2020.The transport and energy sectors have also been disrupted as a result of the prevention measures with a reduction on jet fuel and gasoline demand down to 50% and 30% in the US (Gillingham et al., 2020) despite a drop of Brent Crude Oil and West Texas Oil prices to $19 and $12 respectively on late April 2020. Consequently, the economy of countries that depend on their exports has been severely affected (ECLAC, 2020). Furthermore, the reduction in transport has caused decreases of 17% in the global CO_2 emissions (Le Quéré et al., 2020), 30% in NO_2 emissions in COVID-19 epicentres such as Wuhan, Italy, and USA (Muhammad et al., 2020; Wang et al., 2020; Gautam, 2020a), as well as 62% in Spanish cities (Baldasano, 2020), 25.5% in $PM_{2.5}$ particles in USA (Berman and Ebisu, 2020), and a 20 years low in the concentration of aerosol particles in India (Gautam, 2020b) compared to pre-pandemic levels. Also, there has been an increase of 24% ozone in southern European cities (Sicard et al., 2020) and 17% in India (Sharma et al., 2020), Hence, keeping track of these and other changes in our environment during the COVID-19 pandemic is a useful practice to obtain feedback of the event itself and the measures applied in order to plan future strategies, especially since there are recent reports that show evidence of the virus RNA in wastewater, (Ahmed et al., 2020) as well as a correlation between the number of COVID-19 deaths to the diurnal temperature range (Ma et al., 2020) and other climate conditions (Coccia, 2020; Chen et al., 2020). Also, some studies conclude that long term exposure to NO_2 and other air pollutants contribute indirectly to COVID-19 fatalities (Ogen, 2020) due to its detrimental effect on the cardio-respiratory and immune systems that manifests as hypertension (Shin et al., 2020), cardiovascular disease (Mann et al., 2002), chronic pulmonary disease (Euler et al., 1988), and a diminished response to viral and bacterial infections (Ciencewicki and Jaspers, 2007). Moreover, it is also proposed that the same pollutants can participate directly in the transmission of COVID-19 as a coronavirus carrier (Bontempi, 2020; Sasidharan et al., 2020; Wu et al., 2020; Zoran et al., 2020). However, this last observation is not yet demonstrated, since high levels of air pollutants are usually evident in cities with high human population and hence, high human interaction (Pisoni and Van Dingenen, 2020).

Therefore, in this article, we conduct a broad evaluation of the impact of the COVID-19 pandemic on the urban mobility, electricity consumption, and NO_2 emissions as a whole for several countries around the world rather than for a single region or sector affected as in previous literature. At the s time, we analyse the evolution of confirmed COVID-19 cases and compare them with the start of prevention measures and changes in sectors affected in different countries to discuss the effectiveness in time in which they are applied. We think that the combination of these two approaches can not only explain how the pandemic affects human activities and the environment, but also how these changes allow us to obtain feedback of the prevention measures applied for this and future events.

2. Materials and methods

Time series of confirmed COVID-19 cases and deaths are downloaded from the COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE, 2020) at Johns Hopkins University starting from January 22nd to June 30th, 2020 for up to 185 countries and regions. Also, population and gross domestic product (GDP) assigned to health services for each country are obtained from the Global Health Expenditure Database (WHO GHED, 2020). These datasets are used to find the date of the 100th COVID-19 case (D_{100}) for each country in order to evaluate their daily incidence (I_C) and death incidence (I_D), which show the quantity of confirmed cases and deaths per 100,000 habitants respectively. Then, it is possible to obtain the incidence rate (I_{CR}) from the slope of I_C versus time curve during the fastest infection period, as well as the threshold day (T_D) from the x-axis intercept of the slope, which estimates the quantity of days after D_{100} in which the infection grows the fastest, as shown in Fig. 1 for Italy. This analysis of the I_C curve is inspired by the evaluation of the turn-on voltage and series resistance of electronic devices such as diodes, and it is a simple approach to assess and compare the evolution of I_C between countries. Here, I_{CR} is useful to evaluate the spread speed of the virus, whereas T_D identifies the moment in time in which fast growth starts. The combination of these parameters allow to estimate and discuss the effectiveness of the actions implemented to stop the spread of the virus, and to plan for future and similar events. However, the disadvantage of this method is its lagging nature, since the fast growth region of the I_C curve is often confirmed at late stages of the pandemic.

Another dataset used is the #COVID19 Government Measures Dataset (ACAPS, 2020), which collects daily country-level data from news, social media, and articles about the prevention measures implemented around the world to fight the pandemic. These measures are classified in 5 categories in the original dataset, however, we reclassify them and discuss them in terms of their effects on health, and economy, but mainly on the environment by analysing changes in mobility, electricity generation, and air quality index (AQI) before and after the pandemic.

Here, the mobility around transit stations such as subway, bus, and train stations is selected as the parameter to study rather than mobility around residential areas, grocery shops and pharmacies, or retail and recreation areas since transit stations usually involve a high concentration of people. This information is obtained from the COVID-19 Community Mobility Reports by Google (2020) and presents the percentage change in the number of people visiting transit stations compared to a baseline level, which is the median value for each day of the week during January 3rd and February 6th, 2020.

Also, hourly and daily electrical power consumption is obtained for 26 countries from their respective Transmission System Operator

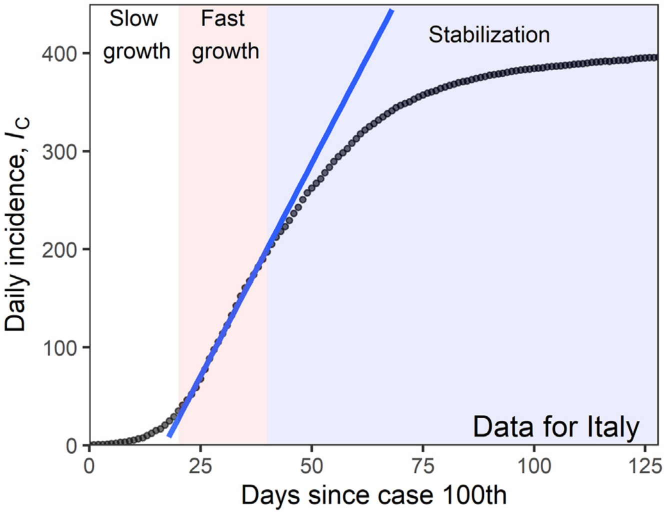

Fig. 1. Evolution of incidence curve for Italy. I_{CR} and T_D are evaluated from the slope and x-axis intercept of the fast growth region, respectively.

(TSO) in order to evaluate their daily percentage change in electrical energy consumption between March 1st and June 30th for 2019 and 2020. Here, the daily data is adjusted to compare days of the week rather than dates. This adjustment is applied because power consumption during the weekends is usually different than during the weekdays. Data for most European countries are available at the European Network of Transmission System Operators for Electricity (ENTSOE, 2020), whereas other sources are used for Italy (Terna, 2020), Spain (Red Eléctrica de España, 2020), Russia (SOUES, 2020), UK (Elexon, 2020), India (Andrew, 2020; POSOCO, 2020), Japan (TEPCO, 2020), Singapore (EMA, 2020), Turkey (Exist, 2020), Bolivia (CNDC, 2020), Brazil (ONS, 2020), Chile (CEN, 2020), Colombia (XM, 2020), Mexico (CENACE, 2020), Peru (COES, 2020), Uruguay (ADME, 2020), and USA (EIA, 2020).

Finally, daily AQI index for NO_2 measured by monitoring stations is analysed for 36 capital cities around the world to compare the percentage change between the first half of 2019 and 2020. Here, we select capital cities assuming that they represent a significant amount of population and human activities affected by the pandemic. Also, NO_2 is chosen as the air pollutant to study instead of other pollutants such as CO, CO_2, SO_2, $PM_{2.5}$, or PM_{10}, since most of the NO_2 in cities is produced by combustion vehicles while driving, a common activity worldwide. These and other environmental data are available at the World Air Quality Index Project (WAQIP, 2020).

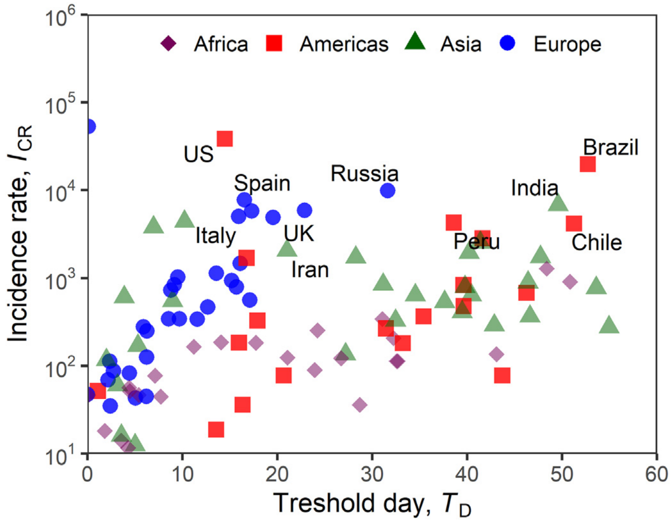

Fig. 3. High T_D values reveal that prevention measures managed to delay the fast COVID-19 contagion period. Response by European countries was late compared to other regions of the world.

3. Results and discussion

Fig. 2a shows the number of confirmed COVID-19 cases through time for different countries around the world since their case 100th. Figures like this circulate since the beginning of the pandemic to identify the countries with more confirmed cases as the most critical. However, the number of cases can be misleading if other factors such as the population, area of the country, evolution of the pandemic through time, and number of tests per habitant are not considered. Therefore, we use I_C as a better parameter to compare the infection between countries, as shown in Fig. 2b. Also, D_{100} is chosen as a reference rather than a date or the day of the first case because the infection starts at different times for each country and because the initial cases are often irregular in time. Additionally, Fig. 2c shows that I_D behaves linearly against I_C

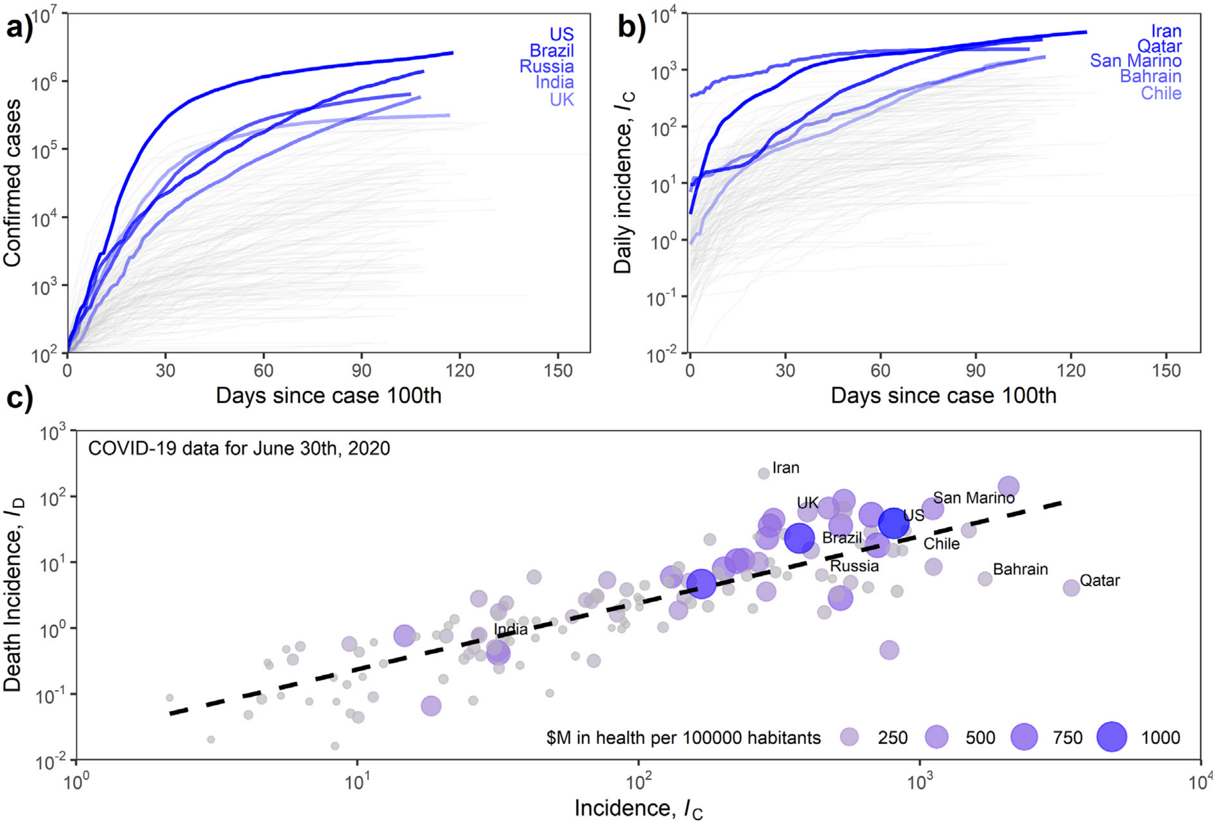

Fig. 2. a) Increase of confirmed COVID-19 cases, and b) incidence curves for countries around the world since case 100th. Top 5 countries by June 30th, 2020 are colored in blue. c) Log plot of I_D vs I_C. Investment in health (2018 data) does not correlate to deaths by COVID-19.

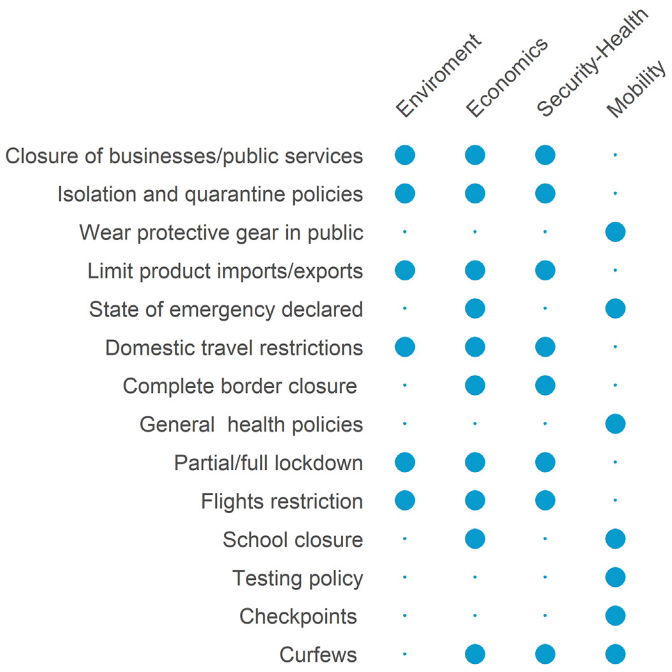

Fig. 4. Examples of prevention measures and the area they affect.

when both parameters are plotted in a logarithmic scale, and that I_D is not clearly dependent on the investment in health services per habitant in each country. Therefore, I_D at this time of the pandemic is barely attributed to the medical attention received, but rather on the individual and social measures oriented to prevent the infection. However, with so many unknowns about the virus and with so little documented history about pandemics in modern times, it is natural to expect a varying degree of success to contain the contagion across the world. This is estimated by plotting I_{CR} versus T_D for the different countries in Fig. 3. It is observed that European countries share lower T_D values compared to those of other continents. This means that the fast growth region of the I_D curve occurred soon after the initial contagion because of the unanticipated event, with Spain, Italy, UK, and Russia in the top 10 countries with more confirmed COVID-19 cases by June 30th, 2020, and with a high I_{CR} value. On the other hand, countries in the Americas are separated by their T_D, where US and Canada (not labelled) show lower T_D values than Brazil, Peru, Chile, and other Latin-American countries. This shows that the prevention measures applied in Latin-American countries managed to delay the spread of the virus, however, the fast growth region of the I_D curve eventually arrived with a high I_{CR} for the mentioned countries as well as Mexico and Colombia (not labelled). This demonstrates the importance of implementing prevention measures before the fast growth region in order to delay the spread of the virus. Recent studies in India show similar conclusions (Bherwani et al., 2020). On the other hand, countries in Asia vary in T_D and I_{CR} due to the way the pandemic evolved in that continent, since it showed first in China, South Korea, and Japan, and much later in the southern region. Finally, African countries show the lowest I_{CR} values by June 30th, 2020, which is probably attributed to the early stage of the pandemic in that continent.

Another point to consider besides the development of the pandemic around the world is the impact that it has in modern life, since the execution of prevention measures implies an adjustment on the usual human activities, and therefore, the environment. Some of the measures applied until now are classified as shown in Fig. 4, with many of them affecting more than one category. Particularly, the mobility of people around transit stations is clearly lower in terms of percentage for all countries compared to their baseline levels at the beginning of the year, as shown in Fig. 5. Also, the average mobility curves by continent reveal that the drop in mobility starts in the middle of March for Europe, Asia, and the Americas, reaching levels of approximately −60% compared to the baseline, whereas the change in Africa is lesser and later. However, there is a significant difference in the average D_{100} by continents, since the average mobility curve in Europe is still close to the baseline before its average D_{100}. This means that the pandemic in that region had already started by the time mobility measures were applied, whereas some Asian countries and most of the Americas and Africa had already restricted their mobility before D_{100}. This explains the high T_D values observed for Latin-American countries, which are attributed to an early decrease of mobility in order to delay the spread of COVID-19 and to prepare hospitals to apply therapy measures. Nevertheless, some Latin-American countries such as Brazil, Peru, Chile, and Mexico show high values of I_{CR} since early June, which are probably associated to an early relaxation of the prevention measures, economic pressure, or civil disobedience. This makes us wonder whether there

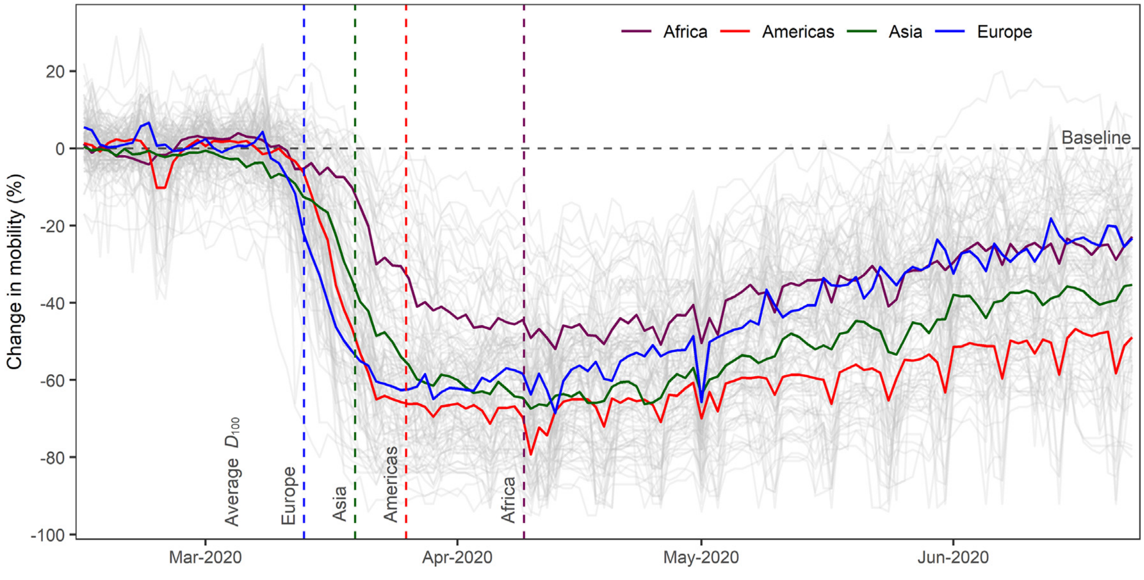

Fig. 5. Change in average mobility of people in transit stations by continent. Average D_{100} in Europe occurred soon after the beginning of prevention measures, whereas countries in the Americas and Africa implemented early measures before the average D_{100}. The most extreme change in mobility percentage for a single country at any point in time is −90% approximately. Details by country in Supplementary Material (Fig. S1a and b).

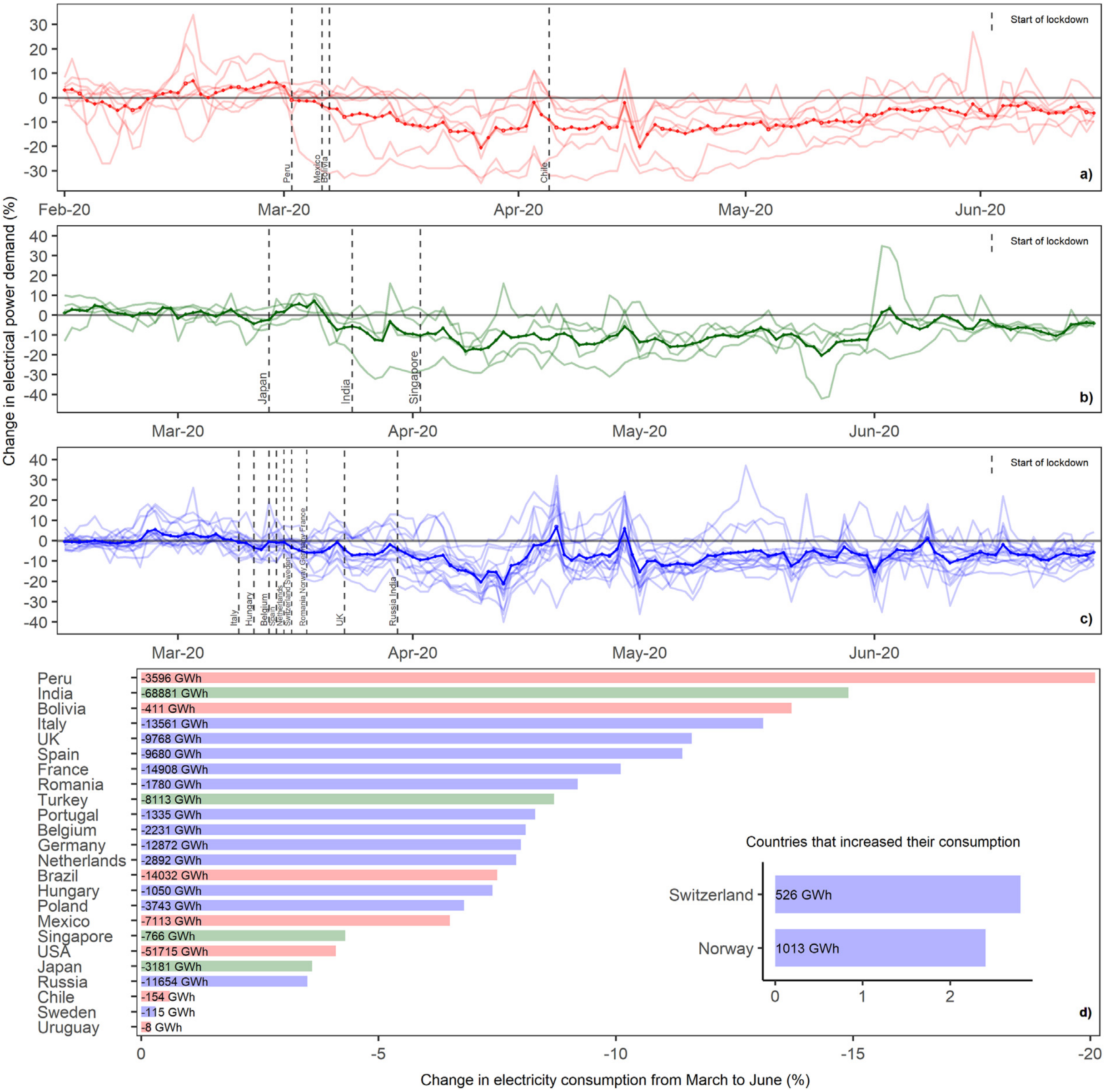

Fig. 6. a) – c) Change in average electricity demand by continent. The most extreme change in electrical power demand percentage for a single country at any point in time is −40% approximately. d) Monthly average percentage change by country (March–June 2020 vs March–June 2019) in bars and absolute change in GWh. Details by country in Supplementary Material (Fig. S2).

is an optimum time to apply prevention measures during a pandemic in modern times and what factors influence it. Finally, the steep mobility increase in Europe in early April can explain why the decrease of confirmed COVID-19 cases has taken more time in that continent compared to countries already in the stabilization phase, such as, China, South Korea, Japan, and New Zealand.

Similarly to mobility, the electrical energy consumption around the world is also affected by the pandemic, as shown in Fig. 6, which reveals a decrease of the average electricity consumption curve by continents since the middle of March 2020 compared to the values of 2019 despite people spending more time at their homes. Therefore, we attribute this change to a decrease of industrial activity, closure or partial operation of transit stations and retail sector, as well as flexible times to work from home. Fig. 6 also shows the dates in which some countries recommended or enforced their citizens to stay at home. These dates do not differ significantly between the nations analysed, which once again demonstrates an early action by most of Latin-America. Finally, the percentage change and absolute change in terms of GWh is shown in Fig. 6d, where it is observed that electricity consumption decreased in most countries analysed except Norway, and Switzerland. The last one in particular is a country focused on tertiary sector activities which are probably not heavily affected by the pandemic, which could explain the difference in electrical consumption compared to the other countries.

Finally, Fig. 7 shows the percentage decrease in the AQI for NO_2, which is a measure of the air pollution by NO_2, where higher values represent a higher risk to health. Particularly, the AQI for NO_2 in cities depend mainly on the combustion of fossil fuels and therefore, driving. Also, the AQI for this and other air pollutants is affected by the weather seasons, with winter slowing the dilution and dispersion of pollutants (Yang et al., 2019). This explains the decrease in the AQI from January 2019 to July 2019 in Rome, Italy (shown in the inset) as winter in the northern hemisphere transitions to spring and eventually summer. On the contrary, AQI increases on the second half of the year as summer

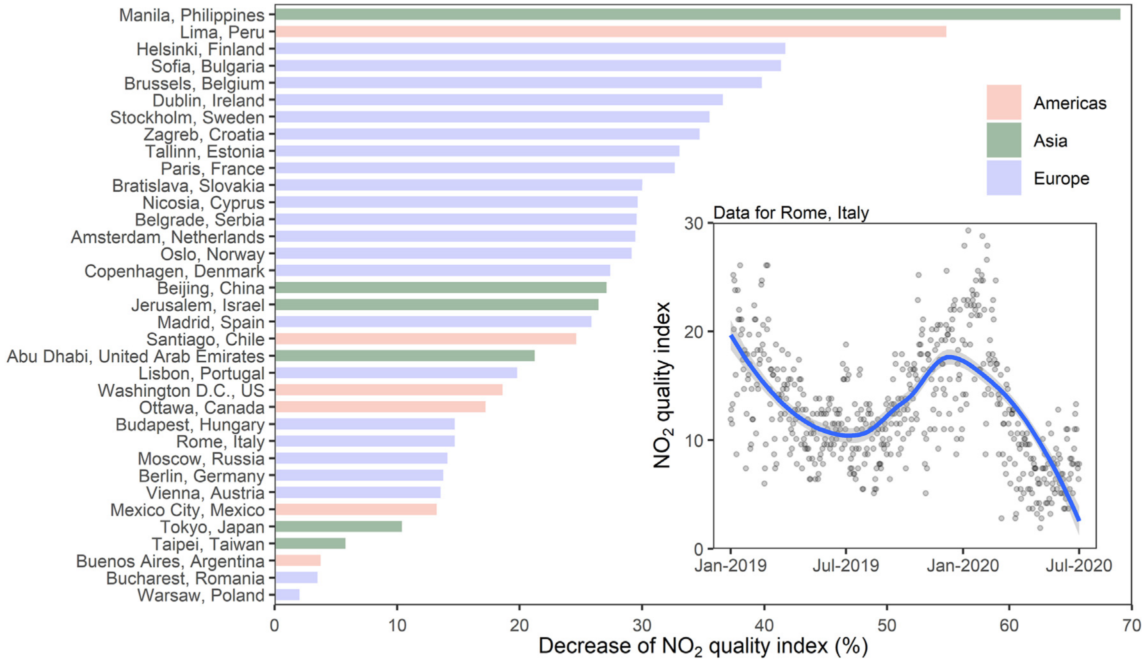

Fig. 7. Percentage decrease of mean NO$_2$ quality index by country (January – June 2020 vs January – June 2019). Detailed data for Rome, Italy in the inset. Philippines had an approximate 70% decrease of mean NO$_2$ quality index for the period evaluated. Details by country in Supplementary Material (Fig. S3a and b).

changes into autumn and then winter. However, the decrease observed in Rome on the first half of 2020 is steeper than on 2019 due to a drastic drop of NO$_2$ emissions as a consequence of the decrease in driving activity during the lockdown on early March. Furthermore, the index values observed there at the end of the first half of 2020 are lower compared to the same period on 2019. This situation must be similar in other cities around the world, since all the other capital cities with data available in this study show a percentage decrease in the mean AQI for NO$_2$ from January 1st to June 30th, 2020 in comparison to 2019, as summarised by bars in Fig. 7.

It is now observed that the prevention measures applied limited human activities and caused the decrease of urban mobility as well as electricity consumption, which led to a decrease of NO$_2$ emissions. Therefore, the appearance of the virus paradoxically had a positive effect on the air quality to the point that many authors consider the decrease of NO$_2$ has saved more human lives than COVID-19 has claimed (Dutheil et al., 2020). Some studies now indicate that 24,000 to 36,000 premature deaths per month have been avoided in China due to an improved air quality (He et al., 2020), whereas the total COVID-19 deaths in the same country are less than 5000. However, the reopening of human activities after the lockdown demonstrate that the improvement in air quality is unsustainable (Zambrano-Monserrate et al., 2020), since pollution levels are back to the normal trend compared to previous years (Liu et al., 2021). These observations should serve as the basis to design and implement actions oriented towards the improvement of human health and air quality, for example, traffic control, investment in public transportation, replacement of face-to-face work with online work, renewable energy projects, electric vehicles infrastructure, and more.

4. Conclusions

In summary, the adoption of prevention measures to mitigate the impact of COVID-19 on human health has caused a decrease of mobility in transit stations as well as a decline in electricity demand around the world. As a consequence, the air quality has been positively affected as observed by the decrease of NO$_2$ in multiple capital cities. Therefore, these observations can be used to implement traffic control programs, investment in public transportation, replacement of face-to-face work with online work, electric vehicles infrastructure, and other green energy projects oriented towards the improvement of air quality and, therefore, human health. At the same time, the analysis of changes in mobility and electricity demand along the evaluation of T_D and I_{CR} from the I_C curves allow to discuss the timely execution of the prevention measures, which works as a feedback to consider and plan actions for the current pandemic or future global events. Here, it is observed that European countries experienced low T_D values attributed to the lack of time to prepare against the spread of the virus, whereas Latin-American countries implemented early prevention measures which managed to delay the contagion, as demonstrated by an early decrease in mobility compared to the baseline level. However, the high I_{CR} values eventually observed in Latin-America cast doubts about the optimum time and factors to consider in order to implement prevention measures such as restrictions in mobility. Finally, we expect that the experience of this historic event along this and other reports can draw some useful insights in order to create new solutions for current environmental problems and to prepare for similar events in the future.

CRediT authorship contribution statement

Asiel N. Corpus-Mendoza: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Hector S. Ruiz-Segoviano:** Data curation, Formal analysis, Investigation, Visualization, Writing - review & editing. **Sergio F. Rodríguez-Contreras:** Data curation, Formal analysis, Investigation, Visualization, Writing - review & editing. **David Yañez-Dávila:** Data curation, Formal analysis, Investigation, Writing - review & editing. **Araceli Hernández-Granados:** Data curation, Formal analysis, Investigation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.143382.

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