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# Health and environmental policies associated with low fatality rate of Covid-19

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**Abstract.** The statistical evidence of the study here shows that countries with a low average COVID-19 fatality rate have high expenditures in health sector and a lower exposure of population to air pollution, regardless a higher percentage of population aged more than 65 years. This study suggest that the negative impact of future pandemics driven by novel viral agents can be reduced with long-run policies directed to support healthcare sector and sustainable environment.

**Keywords.** COVID-19, Fatality rates, Health policy, Air pollution, Sustainability, Crisis management, Policy responses; Preparedness..

**JEL.** F21, F68, O53, K23.

## 1. Introduction

Coronavirus disease 2019 (COVID-19) is an influenza caused by the novel Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which appeared in late 2019 (Coccia, 2020). COVID-19 pandemic is still circulating in 2021 with variants that continue to generate high numbers of COVID-19 related infected individuals and deaths in manifold countries worldwide (Johns Hopkins Center for System Science & Engineering, 2021; CDC, 2021). Seligman *et al.* (2021) show some characteristics of people that are significantly associated with COVID-19 mortality, such as: " mean age 71.6 years, 45.9% female, and 45.1% non-Hispanic white ... disproportionate deaths occurred among individuals with nonwhite race/ethnicity (54.8% of deaths … $p < 0.001$), individuals with income below the median (67.5% . . . $p < 0.001$), individuals with less than a high school level of education (25.6% … $p < 0.001$), and veterans (19.5% … $p < 0.001$)". In this context, the fundamental question is which economic and environmental factors of countries can reduce mortality of COVID-19 and as a consequence reduce the negative impact of COVID-19 pandemic crisis in society (cf., Anser *et al.,* 2020). The study here confronts this question by developing a global analysis based on more than 160 countries to explain, whenever possible, the factors determining a lower rate of COVID-19 mortality between countries worldwide. In particular, the main goal of this study is to clarify health, economic and environmental factors that have reduced fatality rate of the COVID-19 in society. The development of this

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study flows from a recognition that current literature does not clarify the complex economic, social and institutional factors that can mitigate the mortality of COVID-19 between countries. The assumptions of this study are that wealth of nations, healthcare spending and air pollution are factors associated with fatality rate of COVID-19 between countries. Lessons learned from this study can support effective and proactive strategies for reducing fatality rates of infectious diseases in the presence of future epidemics similar to the COVID-19. This study is part of a large research project that investigates factors determining the transmission dynamics of the COVID-19 pandemic and socioeconomic effects of the COVID-19 pandemic crisis in society to cope with future epidemics with appropriate policy responses (cf., Coccia, 2020, 2021).

## 2. Theoretical framework

Manifold studies focus on different aspects of COVID-19 pandemic crisis (cf., Hu *et al.*, 2021; Tian *et al.*, 2021). Asirvatham *et al.* (2020) estimate an adjusted case fatality rate of COVID-19 in India considering some factors of urban environment and population. Results suggest that urban population and population aged more than 60 years were associated with increased adjusted case fatality rate. In this context, healthcare interventions directed to test elderly, people with comorbidities (e.g., having diabetes, cardiovascular diseases, cancer, etc.) and urban population are critical public policies to constrain negative effects of COVID-19 pandemic in society. Siddiqui *et al.* (2020) also analyze the impact of COVID-19 pandemic in India and show that: "low public health expenditure combined with a lack of infrastructure and low fiscal response implies several challenges to scale up the COVID-19 response and management. Therefore, an emergency preparedness and response plan is essential to integrate into the health system of India". Ahmed *et al.* (2020) focus on demographic, socioeconomic, and lifestyle health factors of countries to explain different COVID-19 effects in society. Ahmed *et al.* (2020) suggest that health expenditure per capita has a positive relation with case recovery; in addition, countries with high average age of population and high percentage of urban population have also a high fatality of COVID-19 pandemic in society. In this research field, Kavitha & Madhavaprasad (2020) maintain that preventive health care measures and policies of social distancing applied on a vast portion of population can constraint the spread of COVID-19. Iyanda *et al.* (2020) argue that reinforcing public health sector and epidemiological surveillance programs can both reduce the spread of COVID-19 and prevent unnecessary deaths of this infectious disease. The role of health expenditure is also investigated by Gaffney *et al.* (2020, p. 396) that maintain how: "the United States' underfunded public health infrastructure, fragmented medical care system, and inadequate social protections impose particular impediments to mitigating and managing the outbreak . . . . While the United States has a relatively generous supply of Intensive Care Unit beds and most other health care infrastructure, such medical resources are often unevenly distributed or deployed, leaving some areas ill-prepared for a severe respiratory epidemic". González-Bustamante (2021) shows that in South America the social pressure on healthcare system affects interventions of governments to constrain the diffusion of COVID-19. In China, Jin & Qian (2020) analyze: "the Chinese public-health expenditure at national and provincial levels …, and then compare it with the expenditures of other countries. The results show that: (1) the level of public-health expenditure in China is relatively low and far lower than that in developed countries; (2) Chinese governments have not paid enough attention to the prevention and control of major public-health emergencies, which may be an important reason for the outbreak of COVID-19; (3) Chinese public-health expenditure shows a fluctuating growth trend, but the growth rate is so slow that it is lower than that of GDP and fiscal expenditure; (4) although the Chinese government inclines the public-health expenditure to the poor provinces in central and western regions, the imbalance and inequity of public-health resource allocation are still expanding among provinces; (5) there is a lot of waste of resources in the public-health system, which seriously reduces the efficiency of public-health expenditure in China. Therefore, the Chinese government should improve the quantity and quality of public-health expenditure in the above aspects". Kapitsinis (2020) investigates the diffusion of the novel coronavirus in nine European countries and pinpoints that health investments play a vital role to alleviate mortality rate of the COVID-19. Instead, Barrera-Algarín *et al.* (2020) show that in Europe, a lower level of government health investments per capita is associated with high numbers of COVID-19 deaths per million inhabitants; in general, a high mortality of COVID-19 is also due to low health expenditure associated with high income inequality. Finally, Perone (2021) analyzes Italy and shows that health care efficiency is one of the factors associated with the reduction of fatality rate; moreover, population aged 70 years and above, and concentration of air pollutants are positively associated with fatality rate in society.

Overall, then, current literature shows that economic system and interventions of public policy in specific countries (e.g., India, China, the USA, Italy, etc.) have generated different effects of the evolution of COVID-19 pandemic in society. However, *what is hardly known* is to explain and generalize at global level which economic and environment factors of countries can lower mortality of COVID-19 in society to design effective and proactive strategy to constrain future epidemics similar to COVID-19.

## 3. Materials and methods

This study has the primary objective to explain factors determining a lower fatality rate of the COVID-19 between countries. Results can explain and generalize, whenever possible, vital characteristics of countries for designing an effective and proactive strategy to limit negative impact of future COVID-19 pandemic crisis and similar epidemics.

3.1. Sample and working hypothesis

The study is based on a sample of 161 countries that is categorized in two sub-samples according to the level of Gross Domestic Product (GDP) per capita (wealth of individuals) of nations is higher/lower than arithmetic mean of the sample $N$=161, to compare groups having similar socioeconomic framework.

The main working hypothesis of this study is that high GDP per capita and healthcare spending, and low air pollution are factors associated with reduction of the fatality rate of COVID-19 between countries.

3.2. Measures

The measures for statistical analyses are:

- *Number of COVID-19 infected individuals* (%) is measured with confirmed cases of COVID-19 on 14 December 2020 divided by population of countries under study. Source of data: Johns Hopkins Center for System Science and Engineering (2021).
- *Number of COVID-19 deaths* is measured with fatality rate (%) of COVID-19 given by deaths on 14 December 2020 divided by total infected individuals in countries. Source of data: Johns Hopkins Center for System Science and Engineering (2021).
- *Wealth of population* is measured with Gross Domestic Product (GDP) per capita, Purchasing Power Parity (PPP-current international U.S. dollars $) in 2019 (last year available in dataset). GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Source of data: World Bank (2020).
- The expenditures in health sector are measured by:

a) Level of current health expenditure expressed as a percentage of GDP in 2017 (last year available in dataset). Estimates of current health expenditures include healthcare goods and services consumed during each year. Although this indicator does not include capital health expenditures (e.g., buildings, machinery, IT and stocks of vaccines for emergency or outbreaks), it is a main proxy of investments in health sector; in fact, countries having higher levels of health expenditures as percentage of GDP also tend to have a higher level of Research and Development expenditure (% of GDP)[1]: bivariate correlation, using data of 2017, shows a positive coefficient equal to $r$=.45 ($p$-value 0.01, $N$=115 countries), whereas regression analysis with log-log model reveals that a 1% increase in the Research and Development expenditure (% of GDP), it increases expected current health

[1] Gross domestic expenditures on research and development (R&D), expressed as a percent of GDP, include both capital and current expenditures in the four main sectors: business enterprise, government, higher education and private non-profit. R&D covers basic research, applied research, and experimental development.

expenditure (% of GDP) of .14% (*p*-value .001; coefficient $R^2$ indicates that about 20% of the variation of health expenditure can be attributed linearly to Research and Development expenditure; cf., Coccia, 2012, 2018). Source of data: World Bank (2020a);

b) Domestic general government health expenditure per capita, PPP (current international $) in 2017 (last year available): Public expenditure on health from domestic sources per capita expressed in international dollars at purchasing power parity (PPP time series based on ICP2011 PPP). Source of these data is also World Bank (2020b).

- Elderly are measured with population aged 65 years and above as a percentage of the total population (population here counts all residents regardless of legal status or citizenship in 2019, last year available). Source: World Bank (2020c). Population aged 65 and above is an important factor in infectious diseases because many studies show negative effects of COVID-19 on health of old people (Cohen-Mansfield, 2020; Perone, 2021).
- Air pollution in environment is measured by percent of population exposed to ambient concentrations of $PM_{2.5}$ that exceed the World Health Organization (WHO) guideline value in 2017 (last year available). In particular, it indicates the portion of a country's population living in places where mean annual concentrations of $PM_{2.5}$ are greater than 10 micrograms per cubic meter, the guideline value recommended by the WHO as the lower end of the range of concentrations over which adverse health effects due to $PM_{2.5}$ exposure have been observed. Source: World Bank (2020d). In this context, studies reveal that areas with frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths (Coccia, 2020, 2021, 2021a; Martelletti & Martelletti, 2020). Moreover, high concentrations of particulate air pollutant induce serious damages to the immune system of people, weakening human body to cope with infectious diseases of (new) viral agents and other diseases (Glencross *et al.*, 2020).
- Containment measures against the spread of COVID-19 are assessed with total days of lockdown across countries in the year 2020 (Coccia, 2021b). Tobías (2020, p. 2) states that: "Lockdown, including restricted social contact and keeping open only those businesses essential to the country's supply chains, has had a beneficial effect". Flaxman *et al.* (2020) show that lockdowns seem to have effectively reduced transmission of the COVID-19. Atalan (2020) argues that countries can start lockdown when there is an acceleration of daily confirmed cases beyond a critical threshold and can end it when there is a strong reduction of Intensive Care Unit (ICU) admissions (cf., Chaudhry *et al.*, 2020). Source: COVID-19 pandemic lockdowns (2021).

### 3.3. Data analysis procedure

The sample of *N=161 countries* is divided in two sub-samples (group 1 and 2) having similar socioeconomic conditions for a comparative analysis as follow:

- group 1: *countries with a Gross Domestic Product per capita higher than arithmetic mean of the sample*
- group 2: *countries with a Gross Domestic Product per capita lower and/or equal than arithmetic mean of the sample*

*Firstly*, data are analyzed with descriptive statistics of variables given by arithmetic mean (M) and standard deviation (SD), doing a comparative analysis between two groups of countries just mentioned. In addition, the normality of the distribution of variables, to apply correctly parametric analyses, is analyzed with skewness and kurtosis coefficients; in the presence of not normal distributions, variables are transformed in logarithmic scale to have normality.

*Secondly*, follow-up investigation is the Independent Samples *t*-Test that compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different. The assumption of homogeneity of variance in the Independent Samples *t* Test -- i.e., both groups have the same variance -- is verified with Levene's Test based on following hypotheses:

$H_0$: $\sigma_1^2 - \sigma_2^2 = 0$ (population variances of group 1 and 2 are equal)
$H_1$: $\sigma_1^2 - \sigma_2^2 \neq 0$ (population variances of group 1 and 2 are not equal)

The rejection of the null hypothesis in Levene's Test suggests that variances of the two groups are not equal: i.e., the assumption of homogeneity of variances is violated. If Levene's test indicates that the variances are equal between the two groups (i.e., *p*-value large), equal variances are assumed. If Levene's test indicates that the variances are not equal between the two groups (i.e., *p*-value small), the assumption is that equal variances are not assumed.

After that, null hypothesis ($H'_0$) and alternative hypothesis ($H'_1$) of the Independent Samples *t*-Test are:

$H'_0$: $\mu_1 = \mu_2$, the two population means are equal in countries with a higher and lower level of GDP per capita
$H'_1$: $\mu_1 \neq \mu_2$, the two population means are not equal in countries having a higher and lower level GDP per capita

Statistical analyses are performed with the Statistics Software SPSS® version 26.

## 4. Results

The arithmetic mean (M) of the GDP per capita in 2019 of the sample (*N*=155 valid countries and 6 missing values) is M=$22,794; as consequence the two groups for a comparative analysis are:

- *Countries with a Gross Domestic Product per capita in 2019* > $22,794, *N*= 58 countries
- *Countries with a Gross Domestic Product per capita in 2019* ≤$22,794, *N*=98 countries

**Table 1.** *Descriptive statistics*

| | Countries with *a Gross Domestic Product per capita in 2019 ≤ $22,794* | | Countries with *a Gross Domestic Product per capita in 2019 > $22,794* | |
|---|---|---|---|---|
| Description of variables | M | SD | M | SD |
| – Cases/population, % 2020 | 0.81 | 1.11 | 2.39 | 1.66 |
| – Fatality rate, % 2020 | 2.28 | 1.57 | 1.68 | 0.88 |
| – GDP per capita PPP ($), 2019 | $8,538.85 | $6,035.58$ | 4$46,634.61 | $20,215.07 |
| – Health expenditure (% of GDP), 2017 | 5.97 | 2.12 | 7.59 | 2.77 |
| – General government health expenditure per capita, PPP ($), 2017 | $243.72 | $260.29 | $2,323.90 | $1,373.42 |
| – Population aged 65 years and above as a percentage of population, 2019 | 5.83 | 3.85 | 15.07 | 6.41 |
| – $PM_{2.5}$ air pollution, population exposed to levels exceeding WHO guideline value (% of total), 2017 | 97.70 | 11.95 | 72.34 | 38.23 |
| – COVID-19 pandemic lockdowns (days), 2020 | 55.26 | 51.22 | 96.71 | 85.79 |

**Note:** M= arithmetic mean; SD= Standard Deviation.

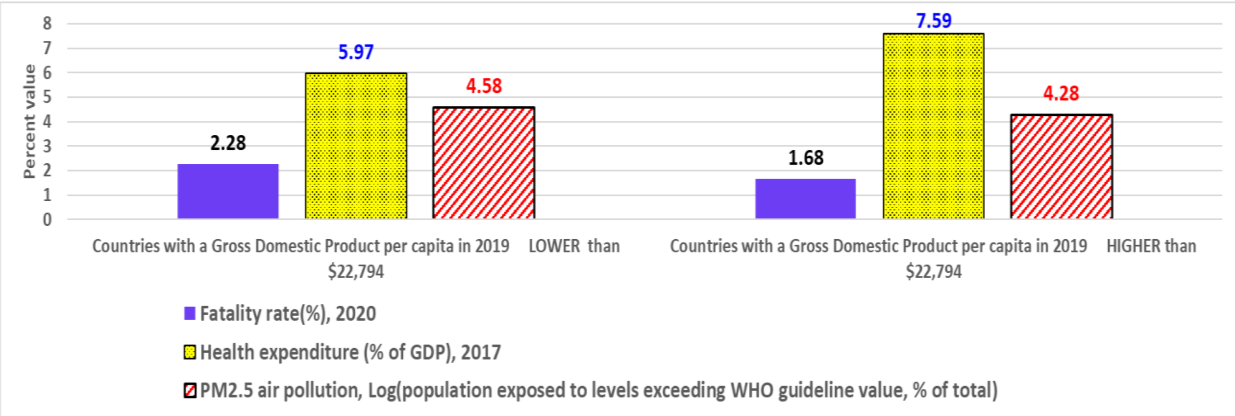


**Figure 1.** *Fatality of COVID-19, health expenditure and population exposed to high levels of air pollution in countries with GDP per capita higher/lower than $22,794. Note: log scale of $PM_{2.5}$ air pollution is to have comparable numbers in the bar graph*

Table 1 shows that fatality rate is lower in richer countries (1.68%) that have an average GDP per capita more than $46,600, a high level of health expenditure of roughly 7.6% of GDP, a high level of government health expenditure of about $2,300 per capita, a lower exposure of population to levels exceeding $PM_{2.5}$ air pollution according to WHO guidelines, and finally a longer period of lockdown, regardless a higher percentage of population aged 65 years and above and a higher incidence of confirmed cases on population in these countries (cf., Figure 1).

Table 2 shows the Independent Samples *t* Test, as follow-up inspection, to assess the significance of the difference of arithmetic mean between groups of countries under study. The *p*-value of Levene's test is significant, and we have to reject the null HP of Levene's test and conclude that the variance in the groups under study is significantly different (i.e., equal variances are not assumed), except lockdown (days) that has *p*-value<.06 and equal variances are assumed. Table 2 reveals a statistically significant difference of arithmetic mean between groups having GDP per capita lower than \$22,794 (group 1) and higher than \$22,794 (group 2) as indicated in table 1.

In particular, table 2 substantiates that:

- There was a significant difference in average cases/population % between groups 1 and 2 ($t_{88.15} = -6.43$, $p < .001$)
- There was a significant difference in average fatality rate % between groups 1 and 2 ($t_{153.67} = 3.06$, $p < .01$)
- There was a significant difference in average GDP per capita between groups 1 and 2 ($t_{63.13} = -13.98$, $p < .001$)
- There was a significant difference in average health expenditure (% of GDP) between groups 1 and 2 ($t_{96.66} = -3.86$, $p < .001$)
- There was a significant difference in average government health expenditure per capita between groups 1 and 2 ($t_{59.48} = -11.41$, $p < .001$)
- There was a significant difference in average population aged 65 years and above as a percentage of total population between groups 1 and 2 ($t_{81.80} = -9.98$, $p < .001$)
- There was a significant difference in average population exposed to levels of $PM_{2.5}$ air pollution exceeding WHO guideline value (% of total) between groups 1 and 2 ($t_{52.34} = 3.19$, $p < .01$)
- There was a significant difference in average days of COVID-19 pandemic lockdowns between groups 1 and 2 ($t_{70.00} = -2.03$, $p < .05$)

**Table 2.** *Independent Samples Test*

| | | Levene's Test for equality of variances | | *t*-test for equality of Means | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *F* | Sig. | *t* | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Cases/population %, 2020 | •Equal variances assumed | 17.462 | 0.001 | -7.079 | 153.000 | 0.001 | -0.016 | 0.002 |
| | •Equal variances not assumed | | | -6.431 | 88.151 | 0.001 | -0.016 | 0.002 |
| Fatality rate %, 2020 | •Equal variances assumed | 7.842 | 0.006 | 2.671 | 154.000 | 0.008 | 0.006 | 0.002 |
| | •Equal variances not assumed | | | 3.057 | 153.670 | 0.003 | 0.006 | 0.002 |
| GDP per capita PPP ($), 2019 | •Equal variances assumed | 46.016 | 0.001 | -17.345 | 153.000 | 0.000 | -38095.761 | 2196.380 |
| | •Equal variances not assumed | | | -13.984 | 63.132 | 0.001 | -38095.761 | 2724.193 |
| Health expenditure (% of GDP), 2017 | •Equal variances assumed | 4.929 | 0.028 | -4.127 | 154.000 | 0.001 | -1.627 | 0.394 |
| | •Equal variances not assumed | | | -3.859 | 96.660 | 0.001 | -1.627 | 0.422 |
| General government health expenditure per capita, PPP ($), 2017 | •Equal variances assumed | 163.442 | 0.001 | -14.446 | 152.000 | 0.001 | -2080.181 | 143.998 |
| | •Equal variances not assumed | | | -11.412 | 59.484 | 0.001 | -2080.181 | 182.286 |
| Population ages 65 years and above as a percentage of population, 2019 | •Equal variances assumed | 21.540 | 0.001 | -11.266 | 154.000 | 0.001 | -9.244 | 0.821 |
| | •Equal variances not assumed | | | -9.975 | 81.803 | 0.001 | -9.244 | 0.927 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Log* $PM_{2.5}$ air pollution, population exposed to levels exceeding WHO guideline value (% of total), 2017 | •Equal variances assumed | 59.944 | 0.001 | 4.311 | 148.000 | 0.001 | 0.518 | 0.120 |
| | •Equal variances not assumed | | | 3.190 | 52.335 | 0.002 | 0.518 | 0.162 |
| *Log* days COVID-19 lockdowns, 2020 | •Equal variances assumed | 3.749 | 0.057 | -2.030 | 70.000 | 0.046 | -0.433 | 0.213 |
| | •Equal variances not assumed | | | -1.999 | 61.106 | 0.050 | -0.433 | 0.217 |

Hence, findings suggest that fatality rate in richer countries (1.7%) is lower than medium-low income per capita countries (2.3%). Factors determining the mitigation of the fatality of COVID-19 in society can be due to a higher level of health expenditure of roughly 7.6% of GDP, higher level of government health expenditure per capita of about $2,300, a lower exposure of population to levels exceeding $PM_{2.5}$ air pollution according to WHO guidelines and a longer duration of lockdown, though countries with lower fatality rates have a higher percentage of population aged 65 years and above (considered as a risk group in population; cf., European Centre for Disease Prevention and Control, 2021)[2] and a higher incidence of confirmed cases in population. These statistical analyses provide important, very important results to explain factors associated with the effects of COVID-19 pandemic in society. In particular, an effective strategy to cope with global pandemic crisis has to be based on three main public policies:

- health policy with higher levels of healthcare expenditure as percentage of GDP directed to specific target of efficiency of overall healthcare sector
- environmental policies based on sustainability for reducing the exposure of population to air pollution
- and finally, a timely policy response based on containment and mitigation measures in a context of advanced economies.

## 5. Discussion and policy implications

Lau *et al.* (2021) argue that in the presence of a continuous global COVID-19 pandemic threat, actual confirmed cases appear vague numbers and suggest the mortality rate as the main indicator to evaluate the real effects of COVID-19 in society (cf., Antony *et al.*, 2020; Liu *et al.*, 2021). In this context, one of the goals of nations to cope with COVID-19 pandemic crisis is to mitigate the mortality rate (cf., Coccia, 2020a). Previous studies suggest that measures of containment, such as full lockdown, can reduce the human-to-human transmission dynamics of infectious diseases and negative effects of COVID-19 pandemic in society (Atalan, 2020; Prem *et al.*, 2020; Tobías, 2020).

2 For instance, in this context, at 9 December 2020, fatality rate in Italy as a percentage of the age group was 3% (between people having 60-69 years), 10.2% (70-79 years), 19% (80-89) and finally about 23% in population aged > 90 years (ISS, 2020; cf., Perone, 2021).

However, these policy responses are necessary but, of course, not sufficient conditions to constraint a negative impact of pandemics in society because many countries with a longer duration of lockdown have also a very high fatality rate, such as Italy; as a consequence an additional inquiry is needed (Coccia, 2021b). *What this study adds to current studies* on the COVID-19 pandemic crisis, performing a global analysis of countries, is to explain, whenever possible, factors determining a lower rate of fatality between countries to support a comprehensive strategy to cope with future epidemics similar to COVID-19. In particular, this study confirms that GDP per capita, healthcare spending and air pollution are factors associated with fatality rate of COVID-19 across countries. Findings here can suggest general guidelines to mitigate fatality rates of future epidemics similar to COVID-19 as schematically summarized in the figure 2.

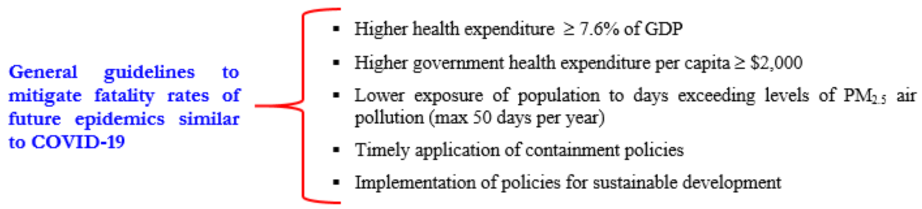


**Figure 2.** *Factors determining a mitigation of fatality rates of COVID-19 between countries to design general guidelines to constrain pandemic crises of novel viral agents similar to Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) that is the strain of the novel influenza that causes coronavirus disease 2019 (COVID-19).*

Hence, follow-up materials to reduce fatality rates of COVID-19 have to be focused on structural public policies and appropriate policy responses to cope with a constant pandemic threat. Especially,

- *Health Policy*

This study reveals that countries with lower fatality rates have a high level of health expenditure given by 7.6% of GDP and government health expenditure per capita of about $2,300, whereas countries with higher fatality rates have a health expenditure of roughly 6% of GDP and very low government health expenditure per capita (a mere average value of about $243 per inhabitants) that indicates a weak healthcare sector to cope with pandemics and also other diseases in society. Scholars, to reduce the risk factors of COVID-19 mortality, also consider socioeconomic, clinical, physical, biophysiological, and biochemical characteristics of people, which can be affected by the type of nutrition system, toxicity, and ecological footprint (Aljerf & Aljurf, 2020). Other scholars, such as Kapitsinis (2020), argue that investments in health sector are a critical public policy to mitigate mortality rate of COVID-19. In this context, countries should also support the expansion of hospital capacity and testing capabilities to reduce diagnostic delays of infectious diseases and foster new technology with the development of effective vaccines, antivirals and other innovative drugs that can counteract future public health threats of new epidemics similar to COVID-19 (Ardito *et al*., 2021; Coccia, 2019, 2020).

- *Environmental policy*

This study finds that sustainable environment plays a vital role for reducing the impact of COVID-19 in terms of COVID-19 related infected individuals and deaths; in particular, a low rate of fatality is associated with a low level of air pollution (cf., Coccia, 2020, 2020b, 2020c). In fact, average population exposed to levels exceeding WHO guideline value (% of total) is 72% in countries with a lower level of fatality rate, whereas in countries with a higher incidence of mortality of the COVID-19 is almost 98%! Coccia (2020, 2021) shows that number of infected people was higher in Italian cities with >100 days per year exceeding limits set for $PM_{10}$ or ozone. Copat *et al.* (2020), considering different studies about the relation between air pollution and the spread of COVID-19, suggest that $PM_{2.5}$ and $NO_2$ can support the spread and lethality of COVID-19, but additional analyses are needed to confirm this relation concerning transmission dynamics of the SARS-CoV-2 (cf., Coccia, 2021). Coccia (2020), using a case study of Italy, explains that: “the max number of days that Italian provincial capitals can exceed per year the limits set for $PM_{10}$ (particulate matter 10 μm or less in diameter) or for ozone, considering the meteorological conditions, is about 48 days. Beyond this critical point, … environmental inconsistencies, because of the combination between air pollution and meteorological conditions, trigger a take-off of viral infectivity (epidemic diffusion) with damages for health of population, economy and society” (cf. also Aljerf & Aljurf, 2020). In fact, days of air pollution, associated with climate change, affect the health of population and environment (Coccia, 2020; 2021). In this field of research, Carugno *et al.* (2018) analyze respiratory syncytial virus (RSV), the primary cause of acute lower respiratory infections in children: bronchiolitis. The study suggests that seasonal weather conditions and concentration of air pollutants seem to influence RSV-related bronchiolitis epidemics in Italian urban areas. In particular, airborne particulate matter (PM) may influence the children's immune system and foster the spread of RSV infection. This study also shows a correlation between short- and medium-term $PM_{10}$ exposures and increased risk of hospitalization because of RSV bronchiolitis among infants. Glencross *et al.* (2020) discuss that air pollution in the long run can cause diseases by perturbing multicellular immune responses, because areas with high air pollution are associated with increased exacerbations of asthma and novel influenza viruses (Coccia, 2020, 2020a, 2021). Moreover, in outdoor environment, studies suggest that the concentration of atmospheric pollutants is associated with the spread of SARS-CoV-2 (Coccia, 2020; Martelletti &Martelletti, 2020), but a high wind speed sustains clean days from air pollution, reducing whenever possible the spread of COVID-19 and other infectious diseases (cf., Coccia, 2020; Rosario *et al*., 2020). To put it differently, a low wind speed in cities prevents the dispersion of air pollutants that can include bacteria and viruses, such as SARS-CoV-2, and can increase the incidence of COVID-19 in society, such as in some European regions (Coccia, 2020, 2021). Instead, in external environment, high wind speed supports the dilution and removal of the droplets, decreasing the concentration of viral agents in the air and the transmission dynamics of viral infectivity among people (cf., Coccia, 2020b, 2020c). In fact, Rosario et al. (2020, p. 4) also show that wind improves the circulation of air and also increases the exposure of the novel coronavirus to the solar radiation effects, a factor having a negative correlation in the diffusion of COVID-19. Guo et al. (2019) argue that haze pollution is a serious environmental problem affecting cities, proposing policies for urban planning that improve respiratory health of population. In addition, scholars argue that: "besides some high negative externalities associated with COVID-19 pandemic in the form of increasing death tolls and rising healthcare costs, the global world should have to know how to direct high mass carbon emissions and population growth through acceptance of preventive measures, which would be helpful to contain coronavirus pandemic at a global scale" (Anser *et al.*, 2020). In fact, Marazziti *et al.* (2021) point out that the activities of human society do not consider the long-term damages of climate change and of high air pollution that may increase in future more and more the diffusion of novel influenza viruses. Reilly *et al.* (2021) maintain that one of the main effects of the COVID-19 pandemic crisis on climate change can be its influence on national commitments to action, such as recovery funds directed to low carbon investments. As a matter of fact, improvements in air quality have been accompanied by demonstrable benefits to human health. In this perspective, countries should introduce organizational, product and process technologies directed to a sustainable development for the improvement of environment, atmosphere, air quality and especially public health of population to cope with future epidemics similar to COVID-19 and other diseases that generate cardiovascular and respiratory disorders in society (Amoatey et al., 2020; Siafakas *et al.*, 2018).

- *Public policy responses*

This study also shows that a lower mortality of COVID-19 is associated with countries having a timely application of lockdowns. The model by Balmford *et al.* (2020) reveals that countries with an immediate application of full lockdown reduced deaths compared to countries that delayed the application of this strong containment measure. Gatto *et al.* (2020) maintain that restriction to mobility and human interactions can reduce transmission dynamics of the COVID-19 by about 45%. In addition, Janssen & van der Voort (2020) show the utility of "smart lockdown" as policy responses based on suggested and not mandated mitigation measures that are focused on responsibility of individuals. In this context, new studies show that specific places have a high risk to be COVID-19 outbreaks (e.g., restaurants, gyms, stadium, discotheques, etc.; cf., Chang *et al.*, 2020); as a consequence, selected measures of containment (e.g., restricting maximum occupancy of specific places, social distancing and wearing of face masks) can be more effective interventions to constrain the spread of COVID-19, without deteriorating economic system, than policies based on uniformly reduction of the mobility of people (Chang *et al*., 2020; cf., Coccia, 2021b; Renardy *et al*., 2020). Studies also report that containment measures for COVID-19 pandemic crisis might affect mental health with: "disturbances ranging from mild negative emotional responses to full-blown psychiatric conditions, specifically, anxiety and depression, stress/trauma-related disorders, and substance abuse. The most vulnerable groups include elderly, children, women, people with pre-existing health problems especially mental illnesses, subjects taking some types of medication including psychotropic drugs, individuals with low socio-economic status, and immigrants" (Marazziti *et al*., 2021). Simon *et al*. (2021) confirm that: "The negative capability well-being, mental health and social support impacts of the Covid-19 lockdown were strongest for people with a history of mental health treatment. Future public health policies concerning lockdowns should pay special attention to improve social support levels in order to increase public resilience".

In general, a continuous pandemic threat highlights fragility, vulnerability and weakness of ecosystem and society, and the difficulties of countries to cope with unforeseen crises. Hence, pandemic threats given by novel infectious diseases, such as the COVID-19, in the long run need timely policy responses of containment based on agility and adaptive governance of nations supported by efficient expenditures in health sector and sustainable policies for reducing air pollution (cf., Coccia, 2020, 2021). In the short run, efficient health systems can support the management of COVID 19 vaccinations to constrain current and future negative effects of pandemics in society (DeRoo et al., 2020; Frederiksen *et al*., 2020; Harrison & Wu, 2020). Evans & Bahrami (2020) pinpoint that super-flexibility can be an appropriate approach to cope with pandemic threats of current COVID-19 in which decision making of policymakers should be oriented to versatility, agility, and resilience. In short, this study, to reiterate, suggests that to constrain the negative impact in society of constant pandemic threats, nations have to apply public policies directed to increase expenditures in health sector and reduce the sources of air pollution for improving healthcare of population in a context of sustainable environment (Coccia, 2020; Sabat *et al*., 2020, p. 917).

## 6. Conclusion observations and limitations

This statistical analysis here suggests that GDP per capita, healthcare spending and air pollution are factors associated with reduction of fatality rate of COVID-19 between countries. In particular, this new study here finds that countries with a low average COVID-19 fatality rates have high expenditures in health sector >7.5 (% of GDP), high health expenditures per capita >$2,300 and a lower exposure of population to days exceeding safe levels of particulate matter ($PM_{2.5}$). Results of the study here also suggest that general guidelines for a global strategy to cope with pandemic threat have to be based on a public policy that supports health system with effective expenditures and investments, and an environmental policy directed to sustainability that reduces the exposure of population to air pollution. These public policies can induce a reduction of fatality rates in the presence of pandemics, regardless a higher incidence of confirmed cases and a higher percentage of elderly on total population.

In addition, results here can also suggest ambidexterity strategies of crisis management for more prosperous or less favored countries:

- Rich countries can focus in the short run on measures of containment of shorter duration because of a stronger healthcare sector based on high health expenditures (as % of GDP), whereas in the long run these countries should support environmental policies for reducing air pollution
- Developing countries have to focus in the short run on measures of containment of a longer duration because of a weak healthcare sector based on low health expenditures (as % of GDP) and in the long run have to support policies for enhancing health system and health of population.

These conclusions are, of course, tentative. A main concern is that there can be differences among countries belonging to the same group of developed and developing countries, having a similar level of GDP, because they can have different healthcare expenditures, institutional contexts and apply different strategies of pandemic management. In fact, despite the study here provides main findings to better design policy responses to pandemic threat, other confounding factors that influence variables under study here (e.g., institutional aspects, culture, religion, political system, structure of pharmaceutical industry, investments in hospital sector, in prevention, in medical personnel, etc.) need to be considered for more comprehensive analysis and policy responses of countries (cf., Stribling *et al*., 2020). The positive side of this study is a global analysis of more than 160 countries to generalize, whenever possible, findings here that are *prima facie* (i.e., accepted as correct until proved otherwise) to support appropriate policy responses at country level. However, future studies have also to focus on follow-up materials and questions investigating the role of different organizational and financing modes of healthcare systems and the allocation of financial resources between healthcare activities (e.g., preventive and curative care) or groups of healthcare providers (for example, hospitals and ambulatory centers) because can affect the health system capability of countries to cope with current and future pandemic crises. In fact, results here have also to be reinforced with much more follow-up investigation concerning detailed research into the relations between negative effects of pandemic threat in society, health systems, public health capacity and pandemic response of countries.

Overall, then, this study suggests that an effective strategy to reduce the negative impact of future pandemic threats, similar to COVID-19, in terms of fatality rates in society, has to be based on high expenditures (and investments) in health system and on policies of sustainable development to improve public health and overall ecosystem. To conclude, this study here could represent a starting point to analyze further socio-economic factors that may shape and support general guidelines for a global strategy to cope with future pandemic threats both in more prosperous and less favored countries.

## Declaration of competing interest.

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this study.

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