Scientometric analysis of COVID-19 studies: how the velocity of science leads to discoveries and new technology

Mario Coccia (mario.coccia@cnr.it)
National Research Council of Italy

Research Article

Keywords: COVID-19, Coronavirus, Dynamics of Science, Scientific Development, mRNA Vaccine, Scientific Discovery, Paradigm shift, Technological process, Public health

Posted Date: January 18th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-148447/v1

Scientometric analysis of COVID-19 studies: how the velocity of science leads to discoveries and new technology

MARIO COCCIA

CNR -- NATIONAL RESEARCH COUNCIL OF ITALY
Via Real Collegio, n. 30
(Collegio Carlo Alberto)
10024 - Moncalieri (TO), Italy

Contact E-mail: mario.coccia@cnr.it

Abstract

Scholars argue that the ''science of science'' studies have to investigate the critical role of exogenous events in the emergence of new research fields. The goal of this study is to analyze and explain the birth and growth of new research fields driven by exogenous event to science, such as COVID-19 (Coronavirus disease 2019) global pandemic crisis. This study here analyzes how the novel research field of COVID-19 emerges, in a comparative analysis with other scientific fields concerning respiratory illnesses (e.g., Chronic Obstructive Pulmonary Disease, COPD and Lung Cancer), to explain factors determining the unique dynamics of science that is generating scientific breakthroughs in a short period of time. The origin and evolution of the research field of COVID-19 reveal that has an acceleration of scientific production equal to a growth of 1.71% daily in 2020, laying the foundations for science advances and a likely paradigm shift in the treatment of infectious diseases with novel mRNA vaccines. Main results are generalized in properties that clarify the dynamics of science and explain the characteristics that generate the origin and evolution of new research fields driven by unforeseen crises with critical implications for technological and social change directed scientific progress of human societies.

Keywords: COVID-19, Coronavirus, Dynamics of Science, Scientific Development, mRNA Vaccine, Scientific Discovery, Paradigm shift, Technological process, Public health.

INTRODUCTION

The evolution of scientific fields can explain the dynamics of science and technology associated with development of human society (Coccia, 2020, 2018; Coccia and Watts, 2020; Gibbons et al., 1994; Haskins, 1965, Xu et al., 2021)[1]. This study focuses on research field of Coronavirus Disease 2019 (COVID-19) that is a new viral infection with a severe acute respiratory syndrome having clinical symptoms given by fever, dry cough, dyspnea, and pneumonia and may result in progressive respiratory failure and death (Coccia, 2020a, 2020c, 2020d, 2020e, 2020f, 2020o; Coccia, 2021, 2021a). The COVID-19 crisis has raised challenges for economic, social and political order within and between states and a main question is how this scientific field of COVID-19 is evolving to generate new knowledge and innovative drugs to solve this global issue that threats nations and global economy (Guerrieri et al., 2020; del Rio-Chanona et al., 2020).

The *first goal* of this study is to analyze the evolution of the research field of COVID-19 compared to other vital scientific fields concerning respiratory disorders to explain the dynamics of science that is generating scientific breakthroughs in a short period of time. The *second goal* is to clarify the driving factors underlying the evolution of scientific field of COVID-19 and systematize findings in general properties that explain the evolution of science directed to scientific advances that support the development of human societies (cf., Coccia, 2019d, 2019e). This study is part of a large body of research on the evolution of science that endeavors to explain how scientific disciplines emerge, evolve and decline in human society to clarify and forecast the structure and evolution in applied and basic sciences and design appropriate science and research policies (Coccia 2018, 2020; Coccia and Bozeman 2016, Coccia and Wang 2016). The vast literature on the dynamics of science has generated many contributions from different disciplines (Börner and Scharnhorst, 2009; Börner et al., 2011, 2012; Scharnhorst et al., 2012; Kuhn, 1996; Price, 1986). However, the evolution of the research field of COVID-19 is hardly known, though it is showing unique characteristics in the history of science that deserve in-depth investigations. This is the first studies, to our knowledge, that endeavors to explain the characteristics of this new

[1] cf., Coccia, 2005, 2006, 2011, 2014, 2014a, 2015, 2015a, 2015b, 2016b, 2017c, 2018a, 2018b, 2018d, 2019, 2019d, 2019e, 2020b, 2020l, 2020m; Coccia and Wang, 2016; Coccia and Bozeman, 2016; Coccia et al., 2015).

research field that is generating an unparalleled volume of contributions to detect, whenever possible, regularities that can clarify the origin and evolution of research fields that are problem-driven by on-going crisis and how they can lead to scientific and technological paradigm shifts in human society.

THEORETICAL BACKGROUND

The investigation of the research field of COVID-19 is crucial for explaining possible relationships underlying the scientific development in the presence of environmental threats in society. The philosophy, history, sociology, scientometrics and economics of science have produced valuable insights into the nature and dynamics of science and technology (Börner et al., 2011, 2012; cf., Bush, 1945; Johnson, 1972; Coccia, 2019b, 2019f, Coccia and Watts, 2020; Lai, 1989; Stephan, 1996, Stephan and Levin, 1992). This topic here of "The science of science" can offer a deeper understanding of the driving factors of successful discovery leading to economic, social and technological change (Fortunato et al., 2018; Hanson, 1969). Social studies of science argue that knowledge, science and technology advance with new ideas and discoveries (Fanelli and Glänzel, 2013; Coccia, 2015, 2017). Factors determining ideas and discoveries in science can be due to scientific processes for solving main and consequential problems in society (De Roeck, 2016; Coccia, 2017c). Coccia (2015b, p. 215) argues that countries perform strategic investments to cope with consequential environmental threats and to solve overriding and relevant problems in society starting from its accumulated technical knowledge and by a process of learning and adaptation. In fact, science is an accumulation of knowledge driven by discoveries, new concepts, new theories, new methods from basic and applied fields of research (Coccia, 2018, 2018a, 2018b, 2020, 2020b; Godin, 2001). Börner et al. (2012, p. 3) claim that: "Science is in a constant state of flux. Indeed, one of the purposes of science is to continually generate new knowledge, to search for or create the next breakthrough that will open new doors of understanding". Kot (1987) argues that science is a dynamic system governed by flows of scientific information and discoveries that are fueled by scientific research, which is continued search for advancing scientific knowledge by scientific methods (cf., Coccia, 2018a; Coccia and Benati, 2018; Evans and

Foster, 2011; Polanyi, 1958). Popper (1959) suggests that for making discoveries is important to pay attention to problems. Usher (1954), using Gestalt psychology, argues that new knowledge can be due to:

1. Perception of the problem: an incomplete pattern in need of resolution is recognized
2. Setting stage: assimilation of data related to the problem
3. Act of insight: a mental act finds a solution to the problem
4. Critical revision: overall exploration and revision of the problem and improvements by means of new acts of insight

According to some scholars, discoveries can be due to a collection of garbage cans in which problems and solutions are mixed randomly (cf., Newell and Simon, 1972, p.51; the garbage-can model by March and Simon in Cohen et al., 1972). In this context, discoveries are driven by scientists, institutions, nations, and other forces "knit, weave and knot" together (Latour,1987, p. 94) into an overarching scientific fabric (Latour, 1987; Latour and Woolgar, 1979; Callon, 1986). In particular, discoveries are driven by an activity of accumulation in science (Haskins, 1965; Whitley, 1984), application-driven, curiosity-driven and problem driven approaches (Coccia, 2012, 2012a, 2014a, 2016, 2016a, 2017, 2017a, 2017b, 2018a; Coccia and Wang, 2015). The application-driven discovery is to find a solution to a problem in society, such as a new vaccine against epidemics that generate a high number of deaths (cf., Coccia, 2018b). Application-driven research is based on extrapolating the current established knowledge into new scientific and technological regimes, assessing pathways and risks. Kroeber (1917) considers two factors in the making of inventions: mental ability and cultural elements that must be brought together (cf., Coccia, 2019c, 2019g). In fact, in the presence of a problem, its solution has to be socially desired to lead to discovery (cf., Bernal, 1939; Russel, 1952). In short, the need of an invention as problem solving activity has an association with factors of mental ability, cultural elements, and previous accumulation of knowledge (Coccia, 2014, 2014a, 2014b, 2015, 2015a). To put it differently, mental ability and cultural preparation are determinants in the origin of discovery in specific socioeconomic contexts to cope with consequential environmental threats or to take advantage of main opportunities (cf., Ogburn and Thomas, 1922; Coccia, 2015a, 2017). Hence, the discovery may occur if there is a problem and a cultural need for solving it

(Coccia, 2015a, 2017). De Roeck (2016) argues that scientific discovery is possible thanks to funding of governments and funding agencies (cf., Coccia 2011, 2019, 2019a). Coccia (2018), investigating the evolution of scientific fields, suggests some empirical properties to explain dynamics of science and scientific advances: the first property states that the evolution of a research field is driven by few disciplines (3–5) that generate more than 80% of documents (concentration of scientific production); the second property states that the evolution of research fields is path-dependent of critical disciplines (they can be parent disciplines that have originated the research field or new disciplines emerged during the evolution of science); the third property states that the evolution of research fields can be also due to a new discipline originated from a process of specialization within applied or basic sciences and/or convergence between disciplines. Finally, the fourth property states that the evolution of specific research fields can be due to both applied and basic sciences. Other properties of the dynamics of science associated to scientific progress are (Coccia, 2020): (a) scientific fission, the evolution of scientific disciplines generates a process of division into two or more research fields that evolve as autonomous entities, creating new disciplines of scientific specialization; (b) ambidextrous drivers of science, the evolution of scientific disciplines by scientific fission is due to scientific discoveries or new technologies; (c) higher growth rates of the scientific production are in new research fields of a scientific discipline rather than old ones; (d) average duration of the growth phase of scientific production in research fields is about 80 years, almost the period of one generation of scholars.

In this research field, one of the problems is to clarify the endogenous processes driving the evolution of specific research field to cope with a crisis in society (Coccia, 2020g, h, i). This study confronts the problem just mentioned by developing an inductive analysis, which explains as far as possible dynamics, driving factors and underlying relationships of the evolution of COVID-19 studies to solve the global issue of COVID-19 pandemic and understand general properties that predict determinants of scientific discoveries to support scientific, technological, economic and social change in human development (Coccia, 2017c, 2017d, 2017e, 2018c, 2019, 2019a; Coccia and Bellitto, 2018). Next section describes the methodology of this study.

STUDY DESIGN

1.1 Source and research setting

The study uses data of Scopus (2020), which is a multidisciplinary database that covers journal articles, conference proceedings, and books and allows citation analysis. Scopus database is used to detect scientific documents having in title, abstract or keyword the terms connected with lung diseases, such as: "COVID", "COPD", and "LUNG CANCER". Scientific products (articles, conference papers, conference reviews, book chapters, short surveys, letters, etc.) are a unit of analysis that allows to explain the structure and evolution of science leading to scientific discoveries.

A brief background of vital concepts under study is useful to clarify the methods of inquiry here.

- First of all, COVID-19, as said, is coronavirus disease 2019 a novel viral infection that generates a severe acute respiratory syndrome with clinical symptoms given by fever, dry cough, dyspnea, and pneumonia and may result in progressive respiratory failure and death (Coccia, 2020a).
- Chronic Obstructive Pulmonary Disease (COPD) is defined as a disease state characterized by the presence of airflow obstruction due to chronic bronchitis and emphysema. COPD is a highly prevalent disease affecting >10% of the population worldwide. The first manifestations occur at the cellular level with biochemical processes that lead to inflammation. Typically, the disease presents in the fourth or fifth decade with subtle symptoms, such as morning cough productive of mucoid sputum or simply an insidious progression of exertional dyspnea (Decramer and Cooper, 2010). COPD is thought to result from an accelerated decline in forced expiratory volume in 1 second (FEV1) over time (Lange et al., 2015). It is well known that COPD is a very common disease with great morbidity and mortality (Halbert et al., 2006; Siafakas et al., 2018).
- Finally, lung cancer is a: "Cancer that forms in tissues of the lung, usually in the cells lining air passages" [as defined by the National Cancer Institute (2012)]. Lung cancer is one of the main diseases in several developed countries and a leading cause of cancer death worldwide (Coccia, 2012, 2012a, 2014b).

Period under study: From 1st April to 31 December 2020, using daily data of document results from Scopus (2020).

1.2 Measures

- Accumulation and development of knowledge in research fields under study here (COVID-19, COPD and Lung Cancer) are measured with total document results given by: article, letter, review, note, editorial, conference paper, short survey, book chapter and conference review. In particular, data are gathered from Scopus (2020) in 2020 and 2021 (January) from April 2020 onwards, day per day for 260 days.
- Documents of research fields under study per Subject area (e.g., Medicine, Biochemistry, Genetics and molecular biology, etc.)
- Document type of research fields under study (i.e., Article, letter, conference paper, book chapter, etc.)
- Documents of research fields under study per source title, which is given mainly by journals.
- Documents of research fields under study per affiliation, which is given mainly by universities, public and private research labs, hospitals, etc.
- Documents of research fields under study per funding sponsor, such as National Science Foundation, National Institutes, etc.
- Documents of research fields under study per countries.

1.3 Data analysis and procedure

Data of documents (in short, Docs) per research fields (*i* = COVID-19, COPD and Lung Cancer) are gathered daily from 1st April 2020 to 31 December 2020.

In addition, it is calculated the daily growth (%) of documents (Docs) per research field (*i*) given by:

$$\Delta Docs\ (\%)\ of\ reserach\ field\ i = \left[\frac{(Docs_{day\ t} - Docs_{day\ t-1})}{Docs_{day\ t-1}}\right] \cdot 100 \qquad [1]$$

The data of documents and derived variables can be transformed in logarithmic scale to have a normal distribution for appropriate parametric statistical analyses or to design graphs and trends with comparable values.

Firstly, preliminary analyses of variables are descriptive statistics based on mean, std. deviation, skewness and kurtosis to assess the normality of distributions and, if necessary, to fix distributions of variables with a *log*-transformation.

Secondly, the study analyzes the evolution of documents as a function of time.

The specification of the relationship is based on a linear model that fits scatter data:

Linear model: $Y_i = b_0 + (b_1 t) + \varepsilon$ [2]

Y= scientific documents in the research field *i* (COVID-19, COPD, Lung Cancer)

t = *time*= progressive series (N) indicating the time from 1 (1^{st} day), 2 (2^{nd} day), …, to 260 (260^{th} day)

b_0= constant

b_1=coefficient of regression

ε= error term

Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of models [2] in regression analysis.

Thirdly, the study analyzes whether the difference of arithmetic mean of $\Delta Docs\ (\%)$ [1] between research fields considered as independent groups (e.g., COVID-19=group 1 vs. COPD=group 2, etc.) is significant, using the Independent Samples *t*-Test. In particular, the Independent Samples *t*-Test 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 Independent Samples *t*-Test requires the assumption of homogeneity of variance -- i.e., both groups have the same variance and as a consequence Levene's Test is performed. The hypotheses for Levene's test are:

H_0: $\sigma_1^2 - \sigma_2^2 = 0$ (the population variances of group 1 and 2 are equal)

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

If we reject the null hypothesis of Levene's Test, it suggests that the variances of the two groups are not equal; i.e., that the homogeneity of variances assumption is violated. If Levene's test indicates that the variances are equal across two groups (i.e., *p*-value large), Equal variances assumed. If Levene's test indicates that the variances are not equal across two groups (i.e., *p*-value small), the assumption is: Equal variances not assumed.

In particular, 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 groups

H_1: $\mu_1 \neq \mu_2$, the two population means are not equal in groups.

The arithmetic mean of groups is compared considering pair of research fields as follows:

COVID-19 (group 1) –COPD (group 2),

COVID-19 (group 1)-Lung Cancer (group 3),

and COPD (group 2)-Lung Cancer (group 3).

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

EMPIRICAL ANALYSES

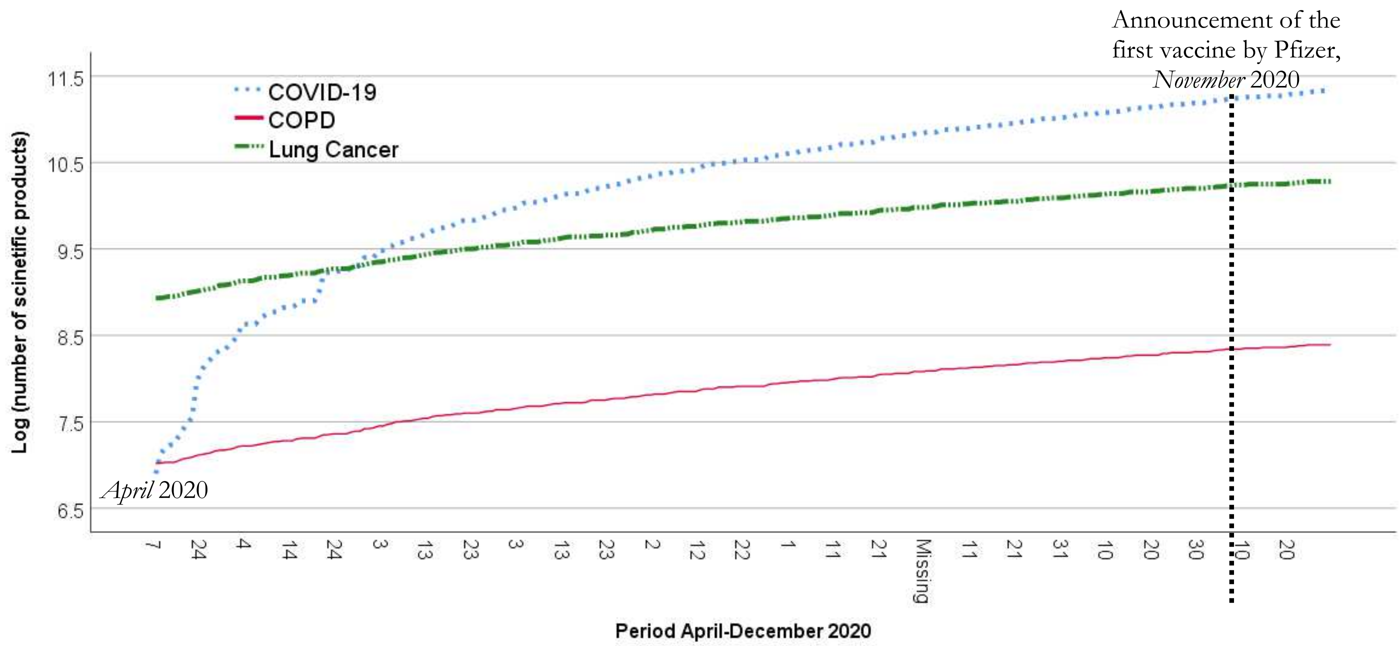

Figure 1. Evolution of COVID-19 compared to COPD and Lung Cancer (*t*=260 days from April to December 2020). *Note*: COVID-19 = Coronavirus Disease 2019; COPD = Chronic Obstructive Pulmonary Disease

Table 1. Descriptive statistics of scientific documents in the research fields of COVID-19, COPD and Lung Cancer based on 260 days from April to December 2020.

Variables of scientific documents	Arithmetic Mean	Std. Error	Std. Deviation
COVID-19, documents (Docs)	38795.770	1514.468	24420.059
COPD, documents	2747.580	60.011	967.653
Lung Cancer, documents	18343.450	395.938	6384.302
$\Delta Docs$ (%) of COVID-197	1.711	0.249	3.995
$\Delta Docs$ (%) of COPD	0.534	0.035	0.556
$\Delta Docs$ (%) of Lung Cancer	0.526	0.031	0.506

Note: COVID-19= Coronavirus Disease 2019; COPD= Chronic Obstructive Pulmonary Disease

Table 1 and figure 1 reveal the unparalleled evolution of the research field of COVID-19 compared to lung cancer and COPD. In April 2020, the research field of COVID-19 was at embryonal stage and had the lowest number of publication, whereas in December 2020 it has outclassed over other research fields (COPD and Lung

Cancer) that have had a stable evolution over 2020 period. In fact, the average daily growth of the research field of COVID-19 is 1.7%, whereas other research fields have had a normal evolution with a growth equal to about .53% of daily publications (Figure 2).

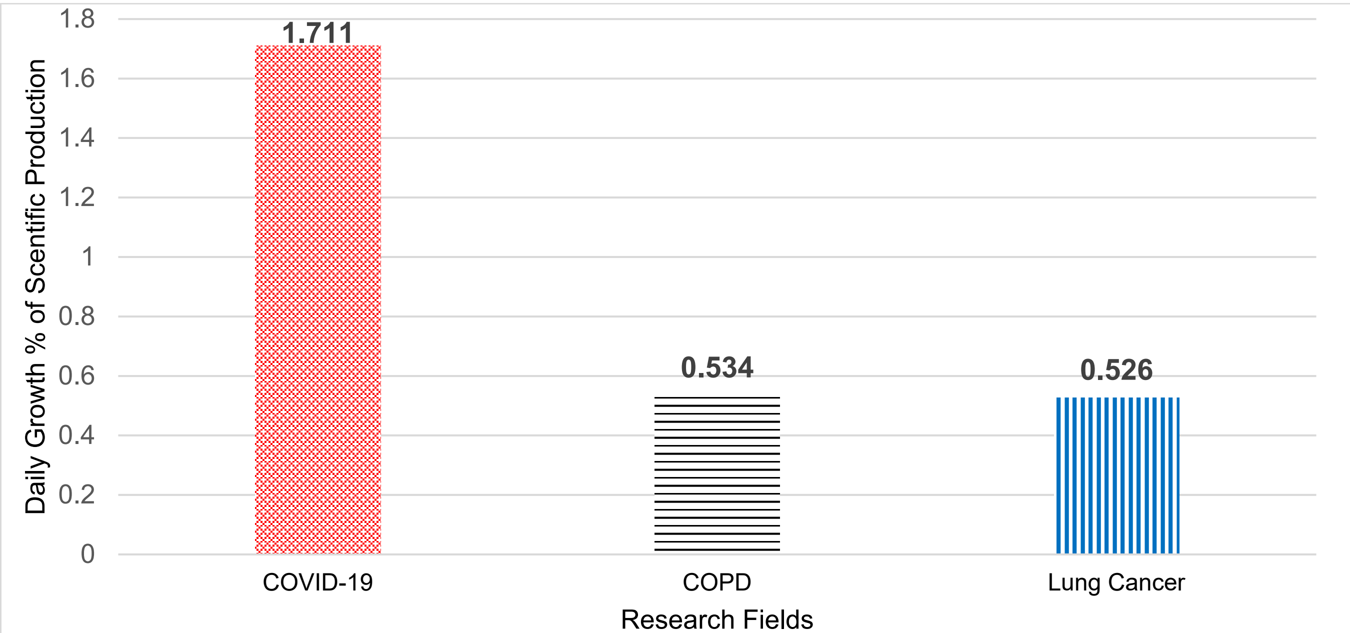

Figure 2. Daily growth (%) of scientific production of research field from April to December 2020
Note: COVID-19= Coronavirus Disease 2019; COPD= Chronic Obstructive Pulmonary Disease

Table 2. Parametric estimates of the relationship of scientific production in research fields as function of time (T=260 days)

	Model Linear COPD	Model Linear Lung cancer	Model Linear COVID-19
Constant α (St. Err.)	1068.99*** (3.37)	7267.76*** (19.98)	−3499.76*** (189.84)
Coefficient β *(time)* (St. Err.)	12.86*** a (.000)	84.87*** a (.13)	324.10*** a (1.26)
Standardized Coefficient Beta	1.00	1.00	.998
F	330573.41***	408990.93***	66058.54***
R^2	0.99	.99	.996

Note: *** *p*-value<0.001
a= predictor is a progressive series (N) indicating the time from 1 (1st day), 2 (2nd day) … to 260 (260th day) from April to December 2020.

Table 2 suggests that in the research field of COVID-19, an increase of 1 day, it increases the expected number of publications by about 324 units (*p*-value<.001), whereas in research field of COPD by about 13 units (*p*-value<.001), finally in research field of Lung Cancer, the expected number of publications increases by about 85 units (*p*-value<.001) over 2020 period. This result confirms the unparalleled growth of scientific production of the research field of COVID-19.

Finally, the Independent Samples *t*-Test compares the means of two independent groups in order to determine whether there is statistical evidence that the associated population means of *ΔDocs* are significantly different.

Table 3. Group statistics

Equation [1] in method	Groups	Mean	Std. Deviation
$\Delta Docs$ (%)	COVID-19	1.711	4.00
	COPD	0.538	.56
$\Delta Docs$ (%)	COVID-19	1.711	4.00
	Lung Cancer (LC)	.5304	.51
$\Delta Docs$ (%)	COPD	0.538	.56
	Lung Cancer (LC)	.5304	.51

Note: N=256 days over April-December 2020 period.

Table 4. 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
$\Delta Docs$ (%), COVID-19/COPD	Equal variances assumed	35.53	0.001	4.690	510	0.001	1.186	.2528
	Equal variances not assumed			4.690	264.809	0.001	1.186	.2528
$\Delta Docs$ (%), COVID-19/LC	Equal variances assumed	37.28	0.001	4.727	510	0.001	1.194	.2524
	Equal variances not assumed			4.727	263.118	0.001	1.194	.2524
$\Delta Docs$ (%), COPD/LC	Equal variances assumed	1.204	0.273	.161	510	.872	.00758	.0470
	Equal variances not assumed			.161	505.496	.872	.00758	.0470

In order to assess the significance of the difference of arithmetic mean of *ΔDocs* between groups under study (table 3), the Independent Samples *t*-Test is performed. The *p*-value of Levene's test is significant, and we have to reject the null of Levene's test and conclude that the variance in the groups under study is significantly different (i.e., Equal variances not assumed), except $\Delta Docs$ (%) between COPD and LC that has p-value<.27 and Equal variances assumed.

Table 4 shows main results about a statistically significant difference of arithmetic mean of $\Delta Docs$ between groups. In particular, table 4 substantiates that:

- There was a significant difference in mean $\Delta Docs$ (%) between research fields of COVID-19 and COPD ($t_{264.809} = 4.69$, $p < .001$).
- There was a significant difference in mean $\Delta Docs$ (%) between research fields of COVID-19 and Lung cancer ($t_{263.118} = 4.727$ $p < .001$).
- Whereas, arithmetic mean of $\Delta Docs$ (%) between research fields of COPD and Lung cancer is not different but is rather similar ($t_{505.496} = .161$ $p < .872$).

The conclusion of these statistical analyses are that the rate of evolutionary growth of the research field of COVID-19 is definitely statistically different from other normal research fields, such as COPD and Lung cancer, having an accelerated and disproportionate growth with the potential to lead to scientific breakthroughs in a short period of time (cf. figure 1).

DISCUSSION

The accelerated growth of the research field of COVID-19 is due to some driving forces that are described as follows.

□ *Driving areas of research in COVID-19 studies*

The most productive research areas in the study of COVID-19 are mainly related to life science (Figure 3). Of the top 10 research areas about 58% of documents published on COVID-19 is in Medicine, 9.3% in Social science and 8.5% in Biochemistry, genetics and molecular biology. In the top ten areas, there is also environmental science (3.5%) because manifold studies analyze possible relations between air pollution and the spread of COVID-19 (Coccia, 2020)[2]. This research field of COVID-19 confirms the properties by Coccia (2018)

[2] Cf., Coccia, 2014c.

that the evolution of a research field is driven by few disciplines (3–5) that generate more than 80% of documents (*concentration of scientific production)*.

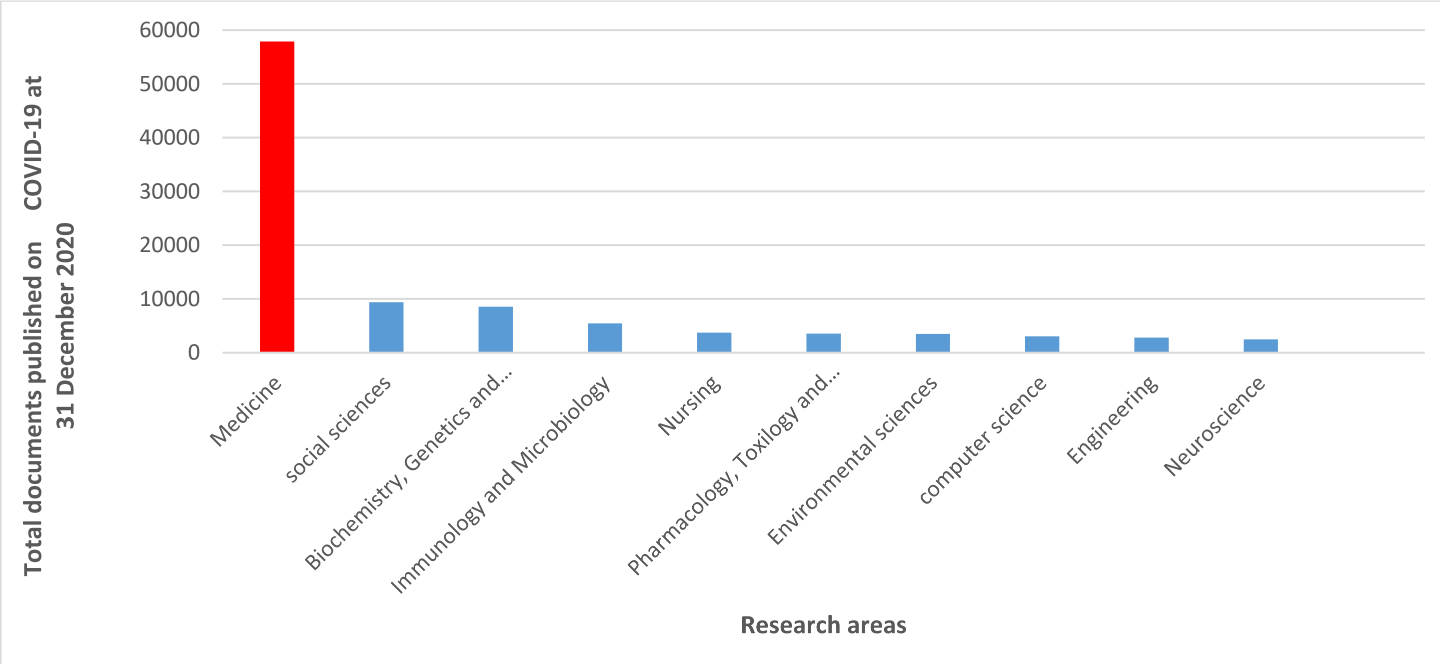

Figure 3. Top ten areas having documents published on COVID-19 at 31 December 2020.

□ *Leading scientific journals in the scientific production of COVID-19*

Table 5 shows the top ten journals that have published more contributions on COVID-19 at 31 December 2020. Five of the top ten journals are related to medicine, virology, public health and one is interdisciplinary with a percentage higher than 10% each on a total of the top ten. In the top ten, there are also journals related to environmental and sustainability science for the reasons associated with relations between air pollution and the spread of COVID-19. In the top ten, it is also important to note the presence of the journal "Medical Hypothesis" because in the presence of a new and little explored problem in society, alike COVID-19, a lot of scholars have suggested at beginning multiple working hypotheses to explain likely determinants of transmission dynamics and treatments to reduce the impact of COVID-19 pandemic in society.

Table 5. Top ten journal having articles published on COVID-19 at 31 December 2020.

Journals	Documents published in	%
International Journal of environmental research and public health	737	14.87
Journal of medical virology	648	13.07
BMJ Clinical research from British Medical Association	615	12.41
BMJ from British Medical Association	576	11.62
Plos ONE	562	11.34
Lancet	413	8.33
International Journal of Infectious diseases	399	8.05
Medical Hypotheses	354	7.14
Science of the total environment	327	6.60
Sustainability	326	6.58
Total	4957	100.00

□ *Driving research institutions*

The most prolific institution in published documents on COVID-19 is Harvard Medical School and two Chinese institutions, Huazhong University of Science and Technology and Tongji Medical College. The top 10 active institutions in producing studies on COVID-19 are localized in specific countries: 2 in USA, 2 in China, 2 in England, 2 in Italy, 1 in France and 1 in Canada (Table 6).

Table 6. The top ten prolific institutions in the production of COVID-19 studies at 31 December 2020.

Research institutions	Documents published by	%
Harvard Medical School, USA	1422	15.56
Huazhong University of Science and Technology, China	1111	12.16
Tongji Medical College, China	1056	11.56
The Institut national de la santé et de la recherche médicale, the French National Institute of Health and Medical Research	983	10.76
University of Toronto, Canada	908	9.94
Università degli Studi di Milano, Italy	776	8.49
University of Oxford, England	761	8.33
Università di Roma la Sapienza, Italy	755	8.26
University College London, England	704	7.71
Massachusetts General Hospital, USA	660	7.22
Total	9136	100.00

□ *Driving funding sponsor*

The top ten funding organizations that have supported the publication of documents on COVID-19 are in USA (4 funding sponsors), China (2), UK (2) and Brazil (2). In particular, institutions in the USA have funded about 43% of published documents of top ten institutions, in China about 35%, in UK roughly 12.5% of documents and finally in Brazil about 9%. Table 7 shows the driving role of funding organizations in two large countries given by the USA and China that have funded more than 78% of documents on COVID studies among top ten instructions. De Roeck (2016) argues that scientific discovery is due to main role of funding of governments and funding agencies.

Table 7. Top ten institution that have funded studies on COVID-19 at 31 December 2020.

Funding institutions	Documents funded by	%
National Natural Science Foundation of China	1901	30.84
National Institutes of Health, USA	1641	26.62
National institute for health research, UK	422	6.85
National Science Foundation, USA	411	6.67
Wellcome Trust, UK	346	5.61
National Institute of allergy and infectious disease, USA	344	5.58
Conselho nacional desenvolvimento Cient, Brazil	326	5.29
Fundamental Research Funds for the Central Universities, China	277	4.49
National heart, Lung and Blood institute, USA	256	4.15
Coordenecao de aperfeicoamento de pessoal de Nivel Superior, Brazil	240	3.89
Total	6164	100.00

□ *Driving countries*

The highest production of COVID-19 studies is concentrated in 4 countries that have published about 68% of documents of the top ten countries (Table 8). This result further confirms the concentration of scientific production in specific geoeconomic contexts (Coccia, 2018). These results can be also due to main socioeconomic factors as explained by Coccia (2020):

- Science advances and new technology are a source of socioeconomic power for countries to take advantage of important opportunities or to cope with consequential environmental threats.
- Science advances and new technology are drivers of economic and productivity growth for nations and of a higher wellbeing of citizens.
- Science advances and new technology increase reputation and recognition of nations worldwide to support an endogenous power in international system based on scientific and technological superiority that endorses their leadership and affects other geoeconomic regions to take advantage of commercial and political opportunities.

Table 8. Top ten countries with the highest number of documents published on COVID-19 at 31 December 2020.

Countries	Documents published	%
United States	21285	30.37
China	9293	13.26
United Kingdom	9004	12.85
Italy	7765	11.08
India	5885	8.40
Spain	3585	5.11
Canada	3542	5.05
Germany	3274	4.67
France	3253	4.64
Australia	3209	4.58
Total	70095	100.00

PROPOSED PROPERTIES OF THE EVOLUTION OF RESEARCH FIELDS, CRISIS-DRIVEN

The inductive analysis here, based on case study of the research field of COVID-19, has main theoretical implications to explain the evolution of research fields that generates scientific discoveries that can be systematized with following empirical properties of the dynamics of science.

1. The first property states that the evolution of a research field is driven by average daily growth of

scientific production over one year of about 0.50% that generates scientific breakthroughs in the long run.

2. The second property states that the evolution of research field with high rate of average daily growth over one year of more than 1.5% generates scientific breakthroughs and scientific and technological paradigms shifts in a short run.
3. The third property suggests that a high rate of average daily growth over one year of more than 1.5% are driven by consequential environmental threats for human societies, such as COVID-19 pandemic crisis.
4. The fourth properties states that the emergence of a new research field can be due to consequential environmental threats and relevant problem in human society, such as COVID-19 pandemic caused by a novel coronavirus called SARS-CoV-2, a problem that has not been seen before.

The main findings of this study suggest that in general research fields evolve with accumulation of "normal science" that have discontinuous transformation in the long run by new theoretical and empirical approaches that support the transition from an existing scientific paradigm to an emerging one (Kuhn, 1996). In the study of the social dynamics of science, Sun et al. (2013) argue that new scientific fields emerge from splitting based on branching mechanisms, such as specialization and merging of social communities that can capture the synthesis of new fields from old ones. However, what this study adds is that in the presence of consequential environmental threats and relevant problems for human society (such as novel coronavirus called SARS-CoV-2 that has generated COVID-19 and a lot of deaths in society), new research fields can emerge as specialties[3] and evolve with accelerated rates of growth that generate radical transformation and discoveries in a very short period of time to solve and/or reduce the emergency. In fact, the COVID-19 pandemic crisis has generated in medicine the specialty of COVID-19 with an accelerated rate of growth that has supported a scientific paradigm shift

[3] Scientific specialty (e.g., COVID-19 studies), within a discipline (e.g., medicine), includes a set of scientists that perform research along similar lines (cf., Mullins, 1973).

towards a novel type of vaccine based on messenger RNA, known as mRNA for high levels of protection by preventing COVID-19 among people that are vaccinated. This new approach is different from the classical approach to vaccination that is based on two categories of vaccines, live-attenuated and killed, such as vaccines for polio and measles, mumps and rubella (MMR), etc. The scientific breakthrough of mRNA vaccines is based on accumulated knowledge that the infective process itself is effective in raising an immune response and genetic engineering can be utilized to construct virus-like particles from the capsid and envelope proteins of viruses (Smoot, 2020). In fact, immunogenic proteins of a pathogen can be engineered into a non-pathogenic or attenuated vector (e.g., adenovirus, Salmonella) that can stimulate the immune system similarly to a real infection. Currently, antigens have been shown to be deliverable as nucleic acid (either RNA or DNA) for the host to translate the encoded protein(s) for processing by the immune system (Smoot, 2020). COVID-19 has accelerated the transition towards these types of vaccines based on new approaches and leading companies in pharmaceutical sector, such as AstraZeneca, Pfizer, etc. are now focusing human and economic resources on vectored, subunit, RNA, and DNA platforms, respectively. The messenger RNA (mRNA) vaccines can leapfrog the barriers of developing traditional vaccines, such as producing noninfectious viruses, or producing viral proteins at medically demanding levels of purity. Moreover, mRNA vaccines eliminate a lot of the manufacturing process because rather than having viral proteins injected, the human body uses the instructions to manufacture viral proteins itself. Also, mRNA molecules are simpler than proteins. In short, for vaccines, mRNA is manufactured by chemical rather than biological synthesis, so it is much faster than conventional vaccines to be redesigned, scaled up and mass-produced. mRNA vaccines are being tested for other viral agents, such as Ebola, Zika virus, and influenza (Komaroff, 2020). mRNA vaccine tools can become viable and quickly tailored for other future epidemics similar to COVID-19 (Sanjay Mishra, 2020). In addition, previous vaccines have been developed in about four years, now mRNA vaccine is created in about 11 months after the discovery of the SARS-CoV-2 virus, and public regulators in the United Kingdom and the US confirmed that mRNA vaccine for COVID-19 can be effective and safely tolerated, paving the path to widespread immunization of population and a technological paradigm shift in the treatments of novel infectious diseases.

Overall, then, the scientific background of mRNA has been accelerated in the presence of unpredictable COVID-19 pandemic crisis (Abbasi, 2020; Heaton, 2020; Jeyanathan et al., 2020; Komaroff, 2020). In fact, in the presence of COVID-19 pandemic that threats public health of nations from 2020, the paradigm shift of mRNA vaccine is driven by manifold factors, such as: accumulation of knowledge in understanding the structure of DNA and mRNA, process to produce a protein, the invention of a new technology to determine the genetic sequence of a virus, process to construct an mRNA that would make a particular protein, solution of problems associated with mRNA to be injected into the muscle of a person's arm from finding its way to immune system cells deep within the body, and coaxing those cells to make the critical protein, and finally the support of governments and cultural need to apply this new technology in the presence of a environmental threat given by COVID-19 global pandemic crisis (Coccia, 2015a, 2017e).

CONCLUDING REMARKS

Price (1986) suggests that the main factor that leads to the creation of a new specialty is the demand to make effective research possible. The success in solving relevant problems can generate discoveries that support the scientific development to deal with consequential problems for further research (cf., Mulkay, 1975). In addition, socio-economic-political and cultural needs can drive the development of new technology and support the search for new approaches (Coccia, 2014, 2014a, 2015a, 2017e; Good 2000, p. 271). The evolution of science is a natural process that is due to a cumulative change driven by ideas during the exploration and solution of new and consequential problems in nature and society that fuel scientific discoveries (cf., Coccia, 2016, 2016a; 2017; Scharnhorst et al., 2012; Popper, 1959). In general, discoveries and new ideas can be explained with the necessity of solving a problem that is a main driving force that induces a series of scientific advances (cf., Iacopini et al., 2018; Ogburn and Thomas, 1922; Tria et al., 2014). In this context, literature shows that factors determining the emergence and evolution of research fields are due to *splitting* and *merging* of social communities: splitting can account for branching mechanisms, such as specialization and fragmentation, while merging can capture the synthesis of new fields from old ones. The birth and evolution of disciplines is thus guided mainly by the social interactions among scientists (Sun et al., 2020).

This study revels interesting results of the emergence and evolution of research fields, investigating the new specialties of COVID-19. In particular, relevant problems and environmental threat generated by unpredictable crisis to prevent can support scientific advances with accelerated production of new studies directed to explain and solve unknown problems generating discoveries and also scientific paradigm shifts in the presence of social and cultural conditions given by willingness of institution and society to invest in new scientific research to solve problems in human society (cf., Becsei-Kilborn, 2010).

However, a limitation is that sources of this study may be incomplete, or only capture certain aspects of the on-going dynamics of science in this new field of research; hence, conclusions here are of course tentative because we know that other things are not equal in the dynamics of science over time and space. There is need for much more research into the relations underlying the evolution of scientific fields in the presence of crisis and environmental threats. Overall, then, the study here cannot be enough to explain the comprehensive characteristics of the evolution of science within and between research fields in the presence of unforeseen shock and crisis in society, because scientific fields and society change rapidly within very short periods of time under a general social stress. Therefore, to conclude, the identification of general patterns of science in the presence of social, economic and health crisis is a non-trivial exercise. The future development of this study has to reinforce proposed results here with additional empirical research considering other new emerging research fields both in the presence of stable and unstable evolution of society.

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.

REFERENCES

Abbasi J. 2020. COVID-19 and mRNA Vaccines-First Large Test for a New Approach. JAMA, 324(12), 1125–1127. https://doi.org/10.1001/jama.2020.16866

Becsei-Kilborn E. 2010. Scientific discovery and reputation: the reception of Peyton Rous' discovery of the chicken sarcoma virus. Journal of the history of biology, vol. 43, pp. 111-157, DOI: 10.1007/s10739-008-9171-y

Bernal J.D. 1939. The Social Function of Science, MIT Press: Cambridge.

Börner K., Boyack K.W, Milojević S., Morris S. 2012. An Introduction to Modeling Science: Basic Model Types, Key Definitions, and a General Framework for the Comparison of Process Models. In Scharnhorst A., Börner K., Besselaar P. 2012. Models of Science Dynamics: Encounters Between Complexity Theory and Information Sciences. Springer Verlag. Chapter 1, pp. 3-22

Börner K., Glänzel W., Scharnhorst A., den Besselaar P. V. 2011. Modeling science: studying the structure and dynamics of science. Scientometrics vol. 89, pp. 347–348.

Börner K., Scharnhorst, A. 2009. Visual conceptualizations and models of science. J. Informetrics 3, 161–172.

Bush V. 1945. Science: The Endless Frontier, Ayer Co, North Stratford.

Callon M. 1994. Is Science a Public Good? Fifth Mullins Lecture, Science, Technology, and Human Values, vol. 19, n. 4, Autumn, pp. 395-424.

Coccia M. 2005. A taxonomy of public research bodies: a systemic approach, Prometheus –The journal of issues in technological change. Innovation. Information economics, communications and science policy, vol. 23, n. 1, pp. 63-82. https://doi.org/10.1080/0810902042000331322

Coccia M. 2006. Analysis and classification of public research institutes, World Review of Science, Technology and Sustainable Development, vol. 3, n. 1, pp.1-16. https://doi.org/10.1504/WRSTSD.2006.008759

Coccia M. 2011. The interaction between public and private R&D expenditure and national productivity, Prometheus-Critical Studies in Innovation, vol.29, n. 2, pp.121-130.

Coccia M. 2012. Evolutionary growth of knowledge in path-breaking targeted therapies for lung cancer: radical innovations and structure of the new technological paradigm. International Journal of Behavioural and Healthcare Research, vol. 3, nos. 3-4, pp. 273-290. https://doi.org/10.1504/IJBHR.2012.051406

Coccia M. 2012a. Driving forces of technological change in medicine: Radical innovations induced by side effects and their impact on society and healthcare, Technology in Society, vol. 34, n. 4, pp. 271-283, https://doi.org/10.1016/j.techsoc.2012.06.002

Coccia M. 2014. Socio-cultural origins of the patterns of technological innovation: What is the likely interaction among religious culture, religious plurality and innovation? Towards a theory of socio-cultural drivers of the patterns of technological innovation, Technology in Society, vol. 36, n. 1, pp. 13-25. https://doi.org/10.1016/j.techsoc.2013.11.002

Coccia M. 2014a. Religious culture, democratisation and patterns of technological innovation. International Journal of sustainable society, vol. 6, n.4, pp. 397-418, DOI: http://dx.doi.org/10.1504/IJSSOC.2014.066771.

Coccia M. 2014b. Path-breaking target therapies for lung cancer and a far-sighted health policy to support clinical and cost effectiveness, Health Policy and Technology, vol. 1, n. 3, pp. 74-82. https://doi.org/10.1016/j.hlpt.2013.09.007

Coccia M. 2014c. Steel market and global trends of leading geo-economic players. International Journal of trade and global markets, vol. 7, n.1, pp. 36-52, http://dx.doi.org/10.1504/IJTGM.2014.058714

Coccia M. 2015. Technological paradigms and trajectories as determinants of the R&D corporate change in drug discovery industry. Int. J. Knowledge and Learning, vol. 10, n. 1, pp. 29–43. DOI: http://dx.doi.org/10.1504/IJKL.2015.071052

Coccia M. 2015a. General sources of general purpose technologies in complex societies: Theory of global leadership-driven innovation, warfare and human development, Technology in Society, vol. 42, August, pp. 199-226, http://doi.org/10.1016/j.techsoc.2015.05.008

Coccia M. 2015b. Spatial relation between geo-climate zones and technological outputs to explain the evolution of technology. Int. J. Transitions and Innovation Systems, vol. 4, nos. 1-2, pp. 5-21, http://dx.doi.org/10.1504/IJTIS.2015.074642

Coccia M. 2016. Radical innovations as drivers of breakthroughs: characteristics and properties of the management of technology leading to superior organisational performance in the discovery process of R&D labs. Technology Analysis & Strategic Management, vol. 28, n.4, pp. 381-395, DOI: 10.1080/09537325.2015.1095287

Coccia M. 2016a. Problem-driven innovations in drug discovery: co-evolution of the patterns of radical innovation with the evolution of problems, Health Policy and Technology, vol. 5, n. 2, pp. 143-155. https://doi.org/10.1016/j.hlpt.2016.02.003

Coccia M. 2016b. The relation between price setting in markets and asymmetries of systems of measurement of goods, The Journal of Economic Asymmetries, vol. 14, part B, November, pp. 168-178, https://doi.org/10.1016/j.jeca.2016.06.001

Coccia M. 2017. Sources of technological innovation: Radical and incremental innovation problem-driven to support competitive advantage of firms. Technology Analysis & Strategic Management, vol. 29, n. 9, pp. 1048-1061, https://doi.org/10.1080/09537325.2016.1268682

Coccia M. 2017a. Sources of disruptive technologies for industrial change. L'industria –Rivista di economia e politica industriale, vol. 38, n. 1, pp. 97-120, DOI: 10.1430/87140

Coccia M. 2017b. The source and nature of general purpose technologies for supporting next K-waves: Global leadership and the case study of the U.S. Navy's Mobile User Objective System, Technological Forecasting & Social Change, vol. 116 (March), pp. 331-339. https://doi.org/10.1016/j.techfore.2016.05.019

Coccia M. 2017c. Varieties of capitalism's theory of innovation and a conceptual integration with leadership-oriented executives: the relation between typologies of executive, technological and socioeconomic performances. Int. J. Public Sector Performance Management, Vol. 3, No. 2, pp. 148–168. https://doi.org/10.1504/IJPSPM.2017.084672

Coccia M. 2017d. New directions in measurement of economic growth, development and under development, Journal of Economics and Political Economy, vol. 4, n. 4, pp. 382-395, http://dx.doi.org/10.1453/jepe.v4i4.1533

Coccia M. 2017e. The source and nature of general purpose technologies for supporting next K-waves: Global leadership and the case study of the U.S. Navy's Mobile User Objective System, Technological Forecasting & Social Change, vol. 116 (March), pp. 331-339. https://doi.org/10.1016/j.techfore.2016.05.019

Coccia M. 2018. General properties of the evolution of research fields: a scientometric study of human microbiome, evolutionary robotics and astrobiology, Scientometrics, vol. 117, n. 2, pp. 1265-1283, https://doi.org/10.1007/s11192-018-2902-8

Coccia M. 2018a. Evolution of the economics of science in the Twenty Century. Journal of Economics, Library, 5(1), 65–84. https://doi.org/10.1453/jel.v5i1.1577.

Coccia M. 2018b. The origins of the economics of Innovation, Journal of Economic and Social Thought, vol. 5, n. 1, pp. 9-28, http://dx.doi.org/10.1453/jest.v5i1.1574

Coccia M. 2018c. An introduction to the theories of institutional change, Journal of Economics Library, vol. 5, n. 4, pp. 337-344, http://dx.doi.org/10.1453/jel.v5i4.1788

Coccia M. 2018d. Disruptive firms and technological change, Quaderni IRCrES-CNR, vol., 3, n. 1, pp. 3-18, http://dx.doi.org/10.23760/2499-6661.2018.001

Coccia M. 2019. Why do nations produce science advances and new technology? Technology in society, vol. 59, November, 101124, pp. 1-9, https://doi.org/10.1016/j.techsoc.2019.03.007

Coccia M. 2019a. The Role of Superpowers in Conflict Development and Resolutions. A. Farazmand (ed.), Global Encyclopedia of Public Administration, Public Policy, and Governance, Springer Nature Switzerland AG, Print ISBN: 978-3-319-20927-2, https://doi.org/10.1007/978-3-319-31816-5_3709-1

Coccia M. 2019b. A Theory of classification and evolution of technologies within a Generalized Darwinism, Technology Analysis & Strategic Management, vol. 31, n. 5, pp. 517-531, http://dx.doi.org/10.1080/09537325.2018.1523385

Coccia M. 2019c. Comparative Incentive Systems. A. Farazmand (ed.), Global Encyclopedia of Public Administration, Public Policy, and Governance, Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-319-31816-5_3706-1

Coccia M. 2019d. Revolution: Characteristics, taxonomies and situational causes, Journal of Economic and Social Thought, vol. 6, no. 1, pp. 48-56, http://dx.doi.org/10.1453/jest.v6i1.1790

Coccia M. 2019e. Revolutions and Evolutions. A. Farazmand (ed.), Global Encyclopedia of Public Administration, Public Policy, and Governance, Springer Nature Switzerland AG, ISBN: 978-3-319-20927-2, https://doi.org/10.1007/978-3-319-31816-5_3708-1

Coccia M. 2019f. The theory of technological parasitism for the measurement of the evolution of technology and technological forecasting, Technological Forecasting and Social Change, vol. 141, pp. 289-304, https://doi.org/10.1016/j.techfore.2018.12.012

Coccia M. 2019g. Theories of Self-determination. A. Farazmand (ed.), Global Encyclopedia of Public Administration, Public Policy, and Governance, Springer Nature Switzerland AG, Print ISBN: 978-3-319-20927-2, https://doi.org/10.1007/978-3-319-31816-5_3710-1.

Coccia M. 2020. The evolution of scientific disciplines in applied sciences: dynamics and empirical properties of experimental physics, Scientometrics, 124, 451–487 (2020). https://doi.org/10.1007/s11192-020-03464-y

Coccia M. 2020a. Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID, Science of the Total Environment, volume, 729, Article Number: 138474, https://doi.org/10.1016/j.scitotenv.2020.138474

Coccia M. 2020b. Deep learning technology for improving cancer care in society: New directions in cancer imaging driven by artificial intelligence. Technology in Society, vol. 60, February, pp. 1-11, https://doi.org/10.1016/j.techsoc.2019.101198

Coccia M. 2020c. An index to quantify environmental risk of exposure to future epidemics of the COVID-19 and similar viral agents: Theory and Practice. Environmental Research, volume 191, December, Article number 110155, https://doi.org/10.1016/j.envres.2020.110155

Coccia M. 2020d. How do low wind speeds and high levels of air pollution support the spread of COVID-19? Atmospheric Pollution Research, https://doi.org/10.1016/j.apr.2020.10.002.

Coccia M. 2020e. How do environmental, demographic, and geographical factors influence the spread of Covid-19. Journal of Social and Administrative Sciences, vol. 7, n. 3, pp. 169-209. ISSN: 2149-0406. www.kspjournals.org, Istanbul - Turkey. http://dx.doi.org/10.1453/jsas.v7i3.2018

Coccia M. 2020f. How (Un)sustainable Environments are Related to the Diffusion of COVID-19: The Relation between Coronavirus Disease 2019, Air Pollution, Wind Resource and Energy. Sustainability 2020, 12, 9709; doi:10.3390/su12229709

Coccia M. 2020g. Critical decision in crisis management: Rational strategies of decision making. Journal of Economics Library, vol. 7., n. 2, pp. 81-96. http://dx.doi.org/10.1453/jel.v7i2.2049

Coccia M. 2020h. Comparative Critical Decisions in Management. In: Farazmand A. (eds), Global Encyclopedia of Public Administration, Public Policy, and Governance. Springer Nature Switzerland AG 2020, Springer, Cham. https://doi.org/10.1007/978-3-319-31816-5_3969-1

Coccia M. 2020i. Comparative Concepts of Technology for Strategic Management. In: Farazmand A. (eds), Global Encyclopedia of Public Administration, Public Policy, and Governance. Springer Nature Switzerland AG 2020, Springer, Cham. ISBN: 978-3-319-20927-2, online ISBN 978-3-319-31816-5. https://doi.org/10.1007/978-3-319-31816-5_3970-1

Coccia M. 2020l. Fishbone diagram for technological analysis and foresight. Int. J. Foresight and Innovation Policy, Vol. 14, Nos. 2/3/4, pp. 225-247. DOI: 10.1504/IJFIP.2020.111221

Coccia M. 2020m. Asymmetry of the technological cycle of disruptive innovations. Technology Analysis & Strategic Management, vol. 32, n. 12, p. 1462-1477. https://doi.org/10.1080/09537325.2020.1785415

Coccia M. 2020o. Effects of Air Pollution on COVID-19 and Public Health, Research Article-Environmental Economics-Environmental Policy, ResearchSquare, DOI:10.21203/rs.3.rs-41354/v1.

Coccia M. 2021. Effects of the spread of COVID-19 on public health of polluted cities: results of the first wave for explaining the dejà vu in the second wave of COVID-19 pandemic and epidemics of future vital agents. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-020-11662-7

Coccia M. 2021a. The effects of atmospheric stability with low wind speed and of air pollution on the accelerated transmission dynamics of COVID-19. Journal: International Journal of Environmental Studies, vol. 78, n. 1, pp. 1-27, https://doi.org/10.1080/00207233.2020.1802937

Coccia M., Bellitto M. 2018. Human progress and its socioeconomic effects in society, Journal of Economic and Social Thought, vol. 5, n. 2, pp. 160-178, http://dx.doi.org/10.1453/jest.v5i2.1649

Coccia M., Benati I. 2018. Comparative Models of Inquiry, A. Farazmand (ed.), Global Encyclopedia of Public Administration, Public Policy, and Governance, Springer International Publishing AG, part of Springer Nature, https://doi.org/10.1007/978-3-319-31816-5_1199-1

Coccia M., Bozeman B. 2016. Allometric models to measure and analyze the evolution of international research collaboration. Scientometrics, vol. 108, n. 3, pp. 1065-1084.

Coccia M., Falavigna G., Manello A. 2015. The impact of hybrid public and market-oriented financing mechanisms on scientific portfolio and performances of public research labs: a scientometric analysis, Scientometrics, vol. 102, n. 1, pp. 151-168, https://doi.org/10.1007/s11192-014-1427-z

Coccia M., Wang L. 2015. Path-breaking directions of nanotechnology-based chemotherapy and molecular cancer therapy, Technological Forecasting & Social Change, 94(May):155–169. https://doi.org/10.1016/j.techfore.2014.09.007

Coccia M., Wang L. 2016. Evolution and convergence of the patterns of international scientific collaboration. Proceedings of the National Academy of Sciences of the United States of America, vol. 113, n. 8, pp. 2057-2061, www.pnas.org/cgi/doi/10.1073/pnas.1510820113

Coccia M., Watts J. 2020. A theory of the evolution of technology: technological parasitism and the implications for innovation management, Journal of Engineering and Technology Management, vol. 55, 101552, https://doi.org/10.1016/j.jengtecman.2019.11.003

Cohen M.D., March J.G., Olsen J.P. 1972. A garbage can model of organizational choice. Adm. Sci. Q. 17 (1), 1–25.

De Roeck A. 2016, The probability of discovery, Technol. Forecast. Soc. Change 112, pp. 13-19, DOI: 10.1016/j.techfore.2016.04.020

Decramer M., Cooper C. B. 2010. Treatment of COPD: the sooner the better? Thorax; 65:837e841. doi:10.1136/thx.2009.133355

del Rio-Chanona RM, Mealy P, Pichler A, Lafond F, Farmer D. 2020. Supply and demand shocks in the COVID-19 pandemic: An industry and occupation perspective; 2020. Available from: http://arxiv.org/abs/2004.06759.

Evans J.A., Foster J.G., 2011. Metaknowledge. Science 331 (6018), 721–725.

Fanelli D., Glänzel W. 2013. Bibliometric evidence for a hierarchy of the sciences. PLoSONE, vol. 8, n. 6, e66938. doi: 10.1371/journal.pone.0066938

Fortunato S., Bergstrom C. T., Börner K., Evans J. A., Helbing D., Milojević, S., Petersen A. M., Radicchi F., Sinatra R., Uzzi B., Vespignani A., Waltman L., Wang D., Barabási A.-L. 2018. Science of science. Science, vol. 359, n. 6379, DOI: 10.1126/science.aao0185

Gibbons M., Limoges C., Nowotny H., Schwatzman S., Scott P., Trow M. 1994. The New Production of Knowledge: the dynamics of science and research in contemporary society. Sage Publications, London.

Godin B. 2001. Defining Research: Is Research Always Systematic? Project on the History and Sociology of S&T Statistics, No.5, OST: Montreal.

Good G. A. 2000. The assembly of geophysics: Scientific disciplines as frameworks of consensus. Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics., 31(3), 259–292

Guerrieri V, Lorenzoni G, Straub L, Werning I. 2020. Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages? National Bureau of Economic Research Working Paper Series. 2020;53(9):1689{1699.doi:10.3386/w26918.

Halbert R.J., J.L. Natoli, A. Gano, E. Badamgarav, A.S. Buist, D.M. Mannino, 2006. Global burden of COPD: systematic review and meta-analysis, Eur. Respir. J. 28 (2006)523–532.

Hanson N. R. 1969. Patterns of Discovery, Cambridge University

Haskins C. P. 1965. Report of the President. Carnegie Institution of Washington Yearbook 63, 1963-64, Washington, D.C.

Heaton P. M. 2020. The Covid-19 Vaccine-Development Multiverse. The New England journal of medicine, 383(20), 1986–1988. https://doi.org/10.1056/NEJMe2025111

Iacopini I., Milojević S., Latora V. 2018. Network Dynamics of Innovation Processes, Phys. Rev. Lett., vol. 120, n. 048301, pp. 1-6, https://doi.org/10.1103/PhysRevLett.120.048301

Jeyanathan M, Afkhami S, Smaill F, Miller MS, Lichty BD, Xing Z. Immunological considerations for COVID-19 vaccine strategies. Nat Rev Immunol. 2020 Oct;20(10):615-632. doi: 10.1038/s41577-020-00434-6.

Johnson H.G. 1972. Some economic aspects of science, Minerva, 10(1), 10-18.

Komaroff A. 2020. Why are mRNA vaccines so exciting? Harvard Health Blog, https://www.health.harvard.edu/blog/why-are-mrna-vaccines-so-exciting-2020121021599 (Posted December 10, 2020, 2:30 pm, Updated December 18, 2020, 7:52 pm).

Kot S.M. 1987. The stochastic model of evolution of scientific disciplines. Scientometrics 12, 197–205 doi:10.1007/BF02016292

Kroeber A. L. 1917. The Superorganic. American Anthropoloogist, New Series, vol. 19, n. 2, April-June, I917, pp. I63-214.

Kuhn T. S. 1996. The structure of scientific revolutions. University of Chicago Press.

Lai T. 1989. How We Make Discoveries. Synthese, 79(3), 361-392. Retrieved March 3, 2020, from www.jstor.org/stable/20116652

Lange P., Cell, B., Agustí A., Boje Jensen G., Divo M., Faner R., Guerra S., Marott J. L., Martinez F. D., Martinez-Camblor P., Meek P., Owen C. A., Petersen H., Pinto-Plata V., Schnohr P., Sood A., Soriano J. B., Tesfaigzi Y., Vestbo J. 2015. Lung-Function Trajectories Leading to Chronic Obstructive Pulmonary Disease. The New England journal of medicine, 373(2), 111–122. https://doi.org/10.1056/NEJMoa1411532

Latour B., 1987. Science in Action: How to Follow Scientists and Engineers Through Society. Harvard University Press

Latour B., Woolgar S. 1979. Laboratory Life: the Social Construction of Scientific Facts. Sage, London and Beverly Hills.

Mulkay M. J. 1975. Three models of scientific development. The Sociological Review vol. 23, pp. 509–526.

Mullins N. C. 1973. The Development of Specialties in social Sciences: The Case of Ethnomethodology', Science Studies, vol. 3, pp. 245-273

National Cancer Institute 2012 [online] http://www.cancer.gov/cancertopics/ (accessed 6th–29th February 2011).

Newell A., Simon H.A., 1972. Human Problem Solving. Prentice-Hall.

Ogburn W.F., Thomas D. 1922. Are Inventions Inevitable? A Note on Social Evolution Source: Political Science Quarterly, Vol. 37, No. 1, pp. 83-98, Stable URL: https://www.jstor.org/stable/2142320

Polanyi M. 1958. Personal Knowledge, Routledge and Kegan Paul, London.

Popper K. 1959. The Logic of Scientific Discovery. Hutchinson, London.

Price De Solla D. J. 1986. Little science, big science... and beyond. Columbia University Press, New York, Ch. 3.

Russell B. 1952. The Impact of Science on Society, Allen & Unwin, London.

Sanjay Mishra 2020. How mRNA vaccines from Pfizer and Moderna work, why they're a breakthrough and why they need to be kept so cold. Vanderbilt University Medical Center, Vanderbilt University. November 18, 2020 1.19pm GMT. https://theconversation.com/how-mrna-vaccines-from-pfizer-and-moderna-work-why-theyre-a-breakthrough-and-why-they-need-to-be-kept-so-cold-150238

Scharnhorst A., Börner K., Besselaar P. 2012. Models of Science Dynamics: Encounters Between Complexity Theory and Information Sciences. Springer Verlag.

Scopus 2020. Document Search, Document (Article title, Abstract, Keywords). https://www.scopus.com/search/form.uri?display=basic (Accessed from 1st April to 31 December 2020) March)

Siafakas N., Bizymi N., Mathioudakis A., Corlateanu A. 2018. EARLY versus MILD Chronic Obstructive Pulmonary Disease (COPD). Respiratory medicine, 140, 127–131. https://doi.org/10.1016/j.rmed.2018.06.007

Smoot J. 2020. Classic and new technologies vying to be the first COVID-19 vaccine. Posted June 11, 2020. https://www.cas.org/blog/covid-19-vaccine

Stephan P.E. 1996. The economics of science. Journal of Economic Literature, vol. 34, n. 3, pp. 1199-1235.

Stephan P.E., Levin S.G. 1992. How science is done; Why science is done, in Striking the Mother Lode in Science: The Importance of Age, Place and Time, Chapter 2. Oxford University Press, New York, pp. 11-24.

Sun X., Kaur, J., Milojevic´ S., Flammini A., Menczer F. 2013. Social Dynamics of Science. Scientific Reports, vol. 3, n. 1069, pp. 1-6, doi:10.1038/srep01069.

Tria F., Loreto V., Servedio V. D. P., Strogatz S. H. 2014. The dynamics of correlated novelties, Scientific Reports volume 4, number: 5890, pp. 1-8, | DOI: 10.1038/srep05890

Usher A.P.1954. A history of mechanical inventions. Cambridge: Harvard University Press; 1954.

Whitley R. 1984. The intellectual and social organization of the sciences. Oxford University Press, Oxford.

Xu H., Winnink J., Yue Z., Zhang H., Pang H. 2021. Multidimensional Scientometric indicators for the detection of emerging research topics, Technological Forecasting and Social ChangeVolume 163, February 2021, https://doi.org/10.1016/j.techfore.2020.120490

Figures

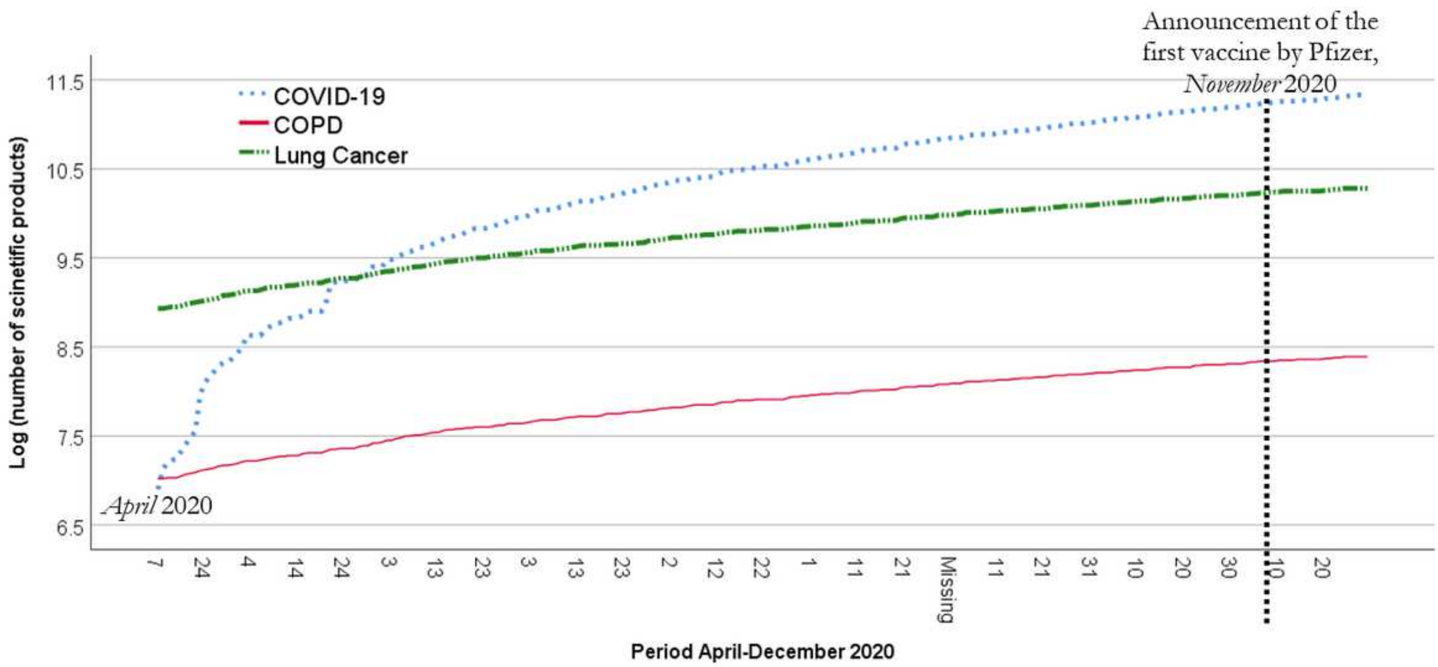

Figure 1

Evolution of COVID-19 compared to COPD and Lung Cancer (t=260 days from April to December 2020). Note: COVID-19 = Coronavirus Disease 2019; COPD = Chronic Obstructive Pulmonary Disease

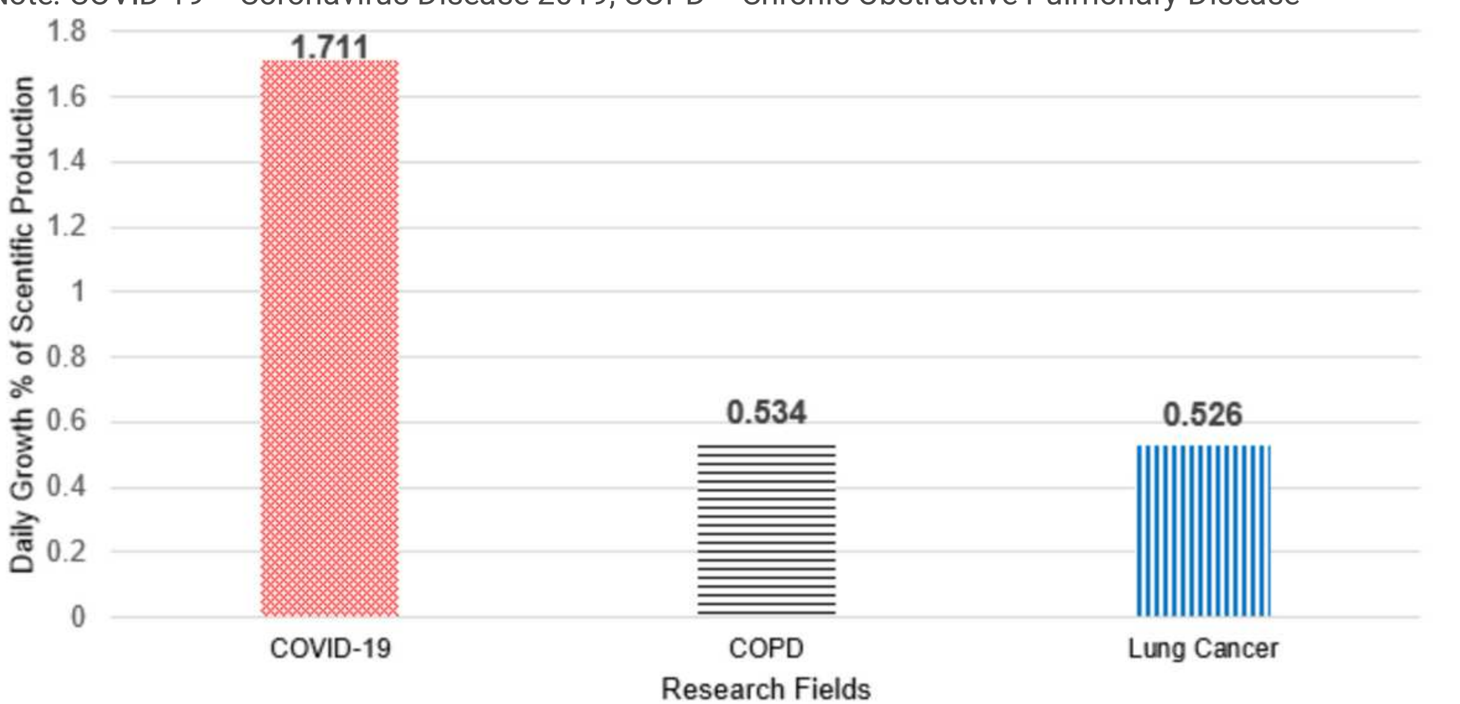

Figure 2

Daily growth (%) of scientific production of research field from April to December 2020 Note: COVID-19= Coronavirus Disease 2019; COPD= Chronic Obstructive Pulmonary Disease

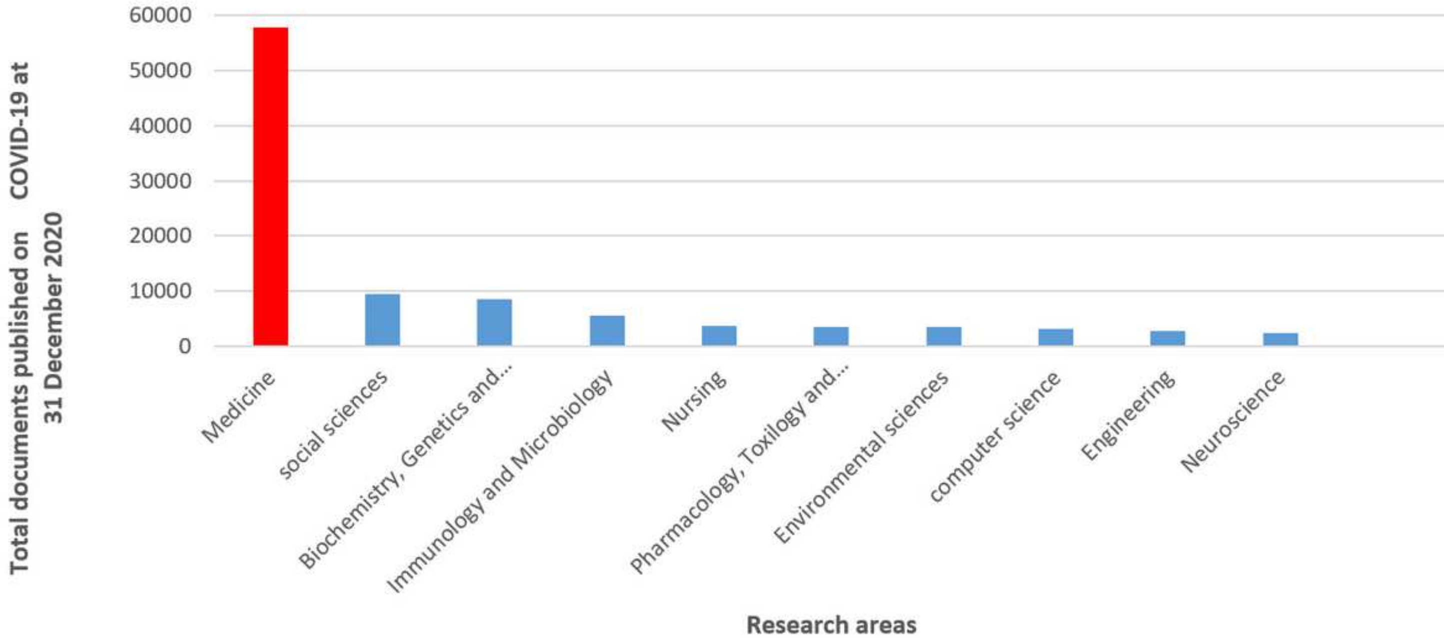

Figure 3

Top ten areas having documents published on COVID-19 at 31 December 2020.