Research performance of the GCC countries: A comparative analysis of quantity and quality

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ABSTRACT

Given the increased focus on scientific research in the Gulf Cooperation Council (GCC) countries, it is important to have a thorough bibliometric study about their research productivity and its progress over a long period of time. Using the world's largest bibliometric database (Scival/Scopus), we analyzed the research output of the GCC countries, from 1996 to 2020, in various disciplines. We considered raw metrics of quantity (number of articles) and quality (citations, citations/article, and Field-Weighted Citation Impact - FWCI), and then normalized them to population size, Gross Domestic Product (GDP), Gross Expenditure on Research and Development (GERD), and number of researchers. Over the past 25 years, the GCC countries have witnessed an increase in research productivity, with Saudi Arabia having the highest research output (ca. 38,000 articles for 2020) and Qatar having the highest fold growth (77.6-fold increase). The GCC countries had diverse research portfolios with varying growth over the years across almost all disciplines. When normalized to population size or GDP, growth rates were dampened for all GCC countries. The increased research output in the GCC was coupled with a high percentage of international collaborations and a reasonable increase in the quality of publications. While the research performance in the GCC countries has promisingly enhanced, it remains low compared to that of international countries (Switzerland, Singapore, and Canada) which have remarkable research productivity. Considering the GCCs economic standings and the potential for further growth, the GCC countries would need increased investment in scientific research and in human capital to be able to catch up with the highest international standards in research.

1. Introduction

The Gulf Cooperation Council (GCC) was established in 1981. It includes six countries: Bahrain, Kuwait, Oman, Qatar, Kingdom of Saudi Arabia, and the United Arab Emirates (UAE), with a total area of 2,673,108 km². In the most recent report (2020) from the United Nations on the Human Development Index, which measures progress in life expectancy, access to education, the standards of living including income per capita, and much more, the GCC countries rank reasonably high in the world. They range from 31st (for the UAE, which is the highest in the Arab world) to 64th (for Kuwait) [2]. The most recent estimated combined population of the GCC countries in 2020 is 58.6 million, with a cumulative economy of over 1.6 trillion dollars in 2019 [1]. The majority of the GDP of the GCC countries are from natural resources such as oil and gas. However, many of them have shown a desire to diversify their economies away from relying exclusively on oil and gas revenues. The ultimate aim is to foster economic diversification and to grow a foundation for a knowledge-based economy, thus creating more opportunities for their citizens. Towards this, the GCC countries are trying to promote high quality education and advance their national capabilities in research and innovation. In the last two decades, some of the GCC countries have invested heavily in establishing new universities and actively recruiting top researchers as part of their effort for future economic diversification and expansion. They have increased their attention to sciences and research by developing national strategies to mark a leap forward in research activities and to sustain this expansion in research in the coming years. While a well-functioning research ecosystem is challenging to build, the GCC has been able to make some strides towards this goal, in the last few years, in many areas. For example, according to the 2019 records, the GCC countries’ share of the world population and GDP is 0.8% and 1.9%, respectively [1], which are proportional to their share of the world research output, 1.7%. The research productivity of the GCC

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countries relative to their population or GDP is, thus, very reasonable compared to that of the Organisation for Economic Co-operation and Development (OECD) countries. The OECD countries contribute 57.5% of the world share of research output, with a population share of 17.8% and a GDP share of 61.4%. In other words, the GCC’s number of articles per GDP as a percent share of the world (1.7%/1.9% = 0.9), is identical to that of the OECD countries (57.5%/61.4% = 0.9). Similarly, the number of articles per population, as percent share of the GCC with respect to the world (1.7%/0.8% = 2.3) is comparable to that of the OECD countries (57.5%/17.8% = 3.2).

Above is a general comparison of the research performance of the GCC countries vs. the OECD, with respect to the world. However, little is published about the current state or the accumulative changes over time in research productivity for each of the GCC countries. Published reports about research output are limited in scope and timeframe. In most cases, it is either focused on Arab countries in general or only on specific countries or disciplines [3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. These reports provide a rather incomplete picture of the GCC research productivity, quality, and impact. One more recent study highlighted the research output of the UAE with respect to the average output in the GCC or Arab Leagues. It showed that, while the UAE witnessed remarkable growth over the years, this growth was less significant when normalized to the country’s GDP or population, or when quality of the publications are measured [13].

In this study, we provide an up-to-date and systematic comparative analysis of the development and the current state of research productivity in the GCC countries. This is important as it would provide the necessary to make informed decisions, guide strategies, update corresponding policies, and develop the progress agenda for shaping the future of research within the GCC countries. In addition, a bibliometric analysis of the research productivity in the GCC countries highlights the evolutionary progress of research in this part of the world. It presents a comparative insight about the performance of each country with respect to the others in this cooperation council, and it provides clear evidence- and statistical-based insights for decision makers to focus on certain aspects more than others. Towards this, we used the world’s largest bibliometric database (Scopus) to gather metrics related to the quantity and quality of research in various disciplines in the GCC countries over the last quarter of a century. In addition, we compared the research productivity of the GCC countries when normalized to population, GDP, GERD, and the number of researchers (when available) within each country. Finally, we compared the research output of the GCC countries to other international countries that have had, over the same period, remarkable research output considering their GDP and population size. Finally, we provide recommendations on enhancing the chances of research success in the GCC countries.

2. Data sources and methodology

2.1. Data sources and quantity of research output

Data on research publications presented in this study was collected on June 23, 2021 from SciVal, an electronic bibliometric repository based on Scopus, which covers over 40,000 English-language journals in various disciplines of Health and Life Sciences, Physical Sciences, and Social Sciences. The search was carried out in Scival by selecting each of the countries covered in this study from the “Country, Regions and Groups” search and by choosing “All subject areas”. For more details about how the documents are collected in Scopus itself or how other metrics are considered, please refer to the Research Metrics Guidebook [14] and the Scopus Content Coverage Guide [15] published by Elsevier. The collected metrics include the number of articles and citations, citations per publication, publications in different percentile journals (1%, 5%, 10%, Q1, Q2, Q3, and Q4), Field-Weighted Citation Impact (FWCI), and publications in various disciplines. The data on the number of articles was obtained for the last 25 years, from 1996 to 2020. As depicted in Figure 1, the substantial increase in publications for the GCC countries was not observed until 2010. Therefore, for the rest of the data collected in this study, we consider the later period, from 2011 to 2020. The 2021 data is not complete to be used at the time of this analysis. The terms “Articles”, “Publications”, or “Research Output” are used in this study to refer to the total number of documents including articles, reviews, and conference proceedings covered by Scopus. Publications in the Arabic language have been estimated not to exceed 0.01% of the total number of collected documents in Scopus [16]. Therefore, data in the GCC from certain disciplines such as Social Sciences and Humanities that publish frequently in Arabic are likely to be underrepresented. Many of the collected SciVal/Scopus metrics were normalized to human capital (population and number of researchers) and to the economy size (GDP and GERD). These data are retrieved from UNESCO [17] or the Word Bank [1] which, themselves, collect data from a large number of primary sources. The total populations were reported (in million) based on the Demographic and Socio-Economic (full dataset) from UNESCO for the years 1996–2019, and the GDP (current US$, except for Figures 6 where GDP is in PPP-current international $) data was reported (in billion) from UNESCO for the years 1996–2019 [17]. The GDP data for 2020 was not available, thus the latest metrics normalized to GDP or GDP per capita refer to year 2019. The number of researchers and GERD (PPP, current international $) were collected (in thousand) from UNESCO [17]. However, because of the scarcity in the GERD and number of researchers for the GCC countries, we completed the normalization with respect to these measures for only one year, 2018, as this is the most recent year for which maximum data is available, i.e. data for four of the GCC countries (Kuwait, Oman, Qatar, and the UAE) [1].

Figure 1. To the left is the number of research articles published between 1996 and 2020 for all GCC countries. To the right is the percent share per country of research articles published between 1996 and 2020 among the GCC countries.
All percent shares reported in this study are given by the value of interest over the total times a hundred. For example, the UAE's percent share of the total publications in the GCC is given by:

\[
\text{UAE's } \% \text{ share of publications in the GCC} = \frac{\text{Publication in the UAE}}{\sum \text{publications in the GCC countries}} \times 100.
\]

### 2.1.1. Compound Annual Growth Rate and fold change over time

For reporting changes over time, we evaluated the Compound Annual Growth Rate (CAGR), which is defined as the year-on-year constant growth rate over a specified period of time. The formula for percentage CAGR is given by:

\[
\text{CAGR } \% = \left( \frac{\text{Final Value}}{\text{Initial Value}} \right)^{\frac{1}{n}} - 1 \times 100,
\]

where \( n \) is the total number of years, and \( \text{Final Value} \) and \( \text{Initial Value} \) is the fold change over the specified period.

### 2.1.2. Quality of research output

As measures for research impact or quality of publications, we collected, from Scopus, publications in different journal percentiles (1%, 5%, 10%, Q1, Q2, Q3, and Q4), citations, citations per publication (also referred to as citations/article), and FWCI. Publications in top journal percentiles is the number of publications (from a particular country) in the top journals indexed by Scopus. Citations and citations per publication refer to the total number of citations in a particular country or the average number of citations per publication in that country, respectively. FWCI adjusts countries for differences in citation frequencies by dividing the number of citations received for a publication by the average number of citations received by publications in the same field, of the same type, and published in the same year. An FWCI of 1.0 indicates that the publications have been cited at world average of publications in the same field.

### 2.1.3. International collaborations and academic-corporate collaborations

Since collaboration can positively affect research productivity and the quality of research [18, 19], we compared international collaborations and academic-corporate collaborations of the GCC countries. This data was also retrieved from Scopus (2011–2020), and the details of collecting this data in Scopus is available in references [15, 20], by Elsevier.

### 2.1.4. Research disciplines

We examined research productivity across 27 subject areas classified according to All Science Journal Classification (ASJC) from Scopus. The numbers of articles as well as percent growth within each of these subject areas were analyzed for the GCC countries. In addition, these 27 subject areas were further aggregated into six main research disciplines according to the OECD classification: Engineering and Technology, Natural Sciences, Medical and Health Sciences, Social Sciences, Agricultural Sciences, and Humanities. Analysis was completed for the 27 subject areas as well and the six aggregated disciplines. It is worth noting that some publications may belong to more than one subject area.

### 2.1.5. Comparative context

To provide context for the research productivity in the GCC countries, we compared their data over time to those of Switzerland, Singapore, and Canada. These are three countries from Europe, Asia, and North America with (i) similar population size or GDP to different GCC countries, and (ii) distinguished scholarly output over the past years, especially when normalized to GDP or population size [21]. These comparisons would provide the necessary guidance for the GCC countries to enhance their research productivity and impact. Note: the total population of Singapore was not available from UNESCO, it was retrieved from the World Bank [1].

### 3. Results

#### 3.1. Quantity of research output

In this section, we compared the research output in the GCC countries in terms of quantity, i.e. number of published articles, over the period of 1996–2020. Figure 1 highlights the growth of the scholarly output in the GCC countries. It shows that there is a growing trend for the GCC countries in scientific research and scholar activity over the last 25 years. The data shows that, up to 2008, none of the GCC countries had a significant number of articles published per year. However, the GCCs research productivity has been increasing more prominently since then. Among the GCC countries, Saudi Arabia, the UAE, and Qatar have the majority of publication output, with the highest values belonging to Saudi Arabia. The total number of publications in Bahrain, Kuwait, and Oman did not increase to the same extent over the years. For the 25-year period from 1996 to 2020, Qatar witnessed the highest increase in the number of annual research publications (77.6 folds), and the lowest was from Kuwait with only 4.0-fold increase (Figure 1, left). Similarly, the CAGR of scholarly output over the same 25-year period for the GCC countries are between 5.7% and 19.0%, with the highest growth rate also for Qatar, followed by the UAE, Saudi Arabia, Oman, Bahrain and the lowest for Kuwait. We noted that CAGR is the highest in the last 5 years for all GCC countries, except Qatar which has a CAGR that is ca. 10% lower in the second half than the first half of the last decade. Figure 1 (right) shows the share, per GCC country, of the total publication output over the past 25 years. The data shows that while Saudi Arabia's share of articles had fluctuated over the years, it remained the largest in the GCC, with a current share of ca. 60%. The UAE's share of research publications within the GCC is the second highest at ca. 18% in 2020. Moreover, the data clearly shows that the share of publications from Qatar has steadily increased from 2.0% in 1996 to 9.0% in 2020, while Kuwait's contribution has steadily decreased from 18.1% in 1996 to 4.1% in 2020. The increase in Qatar's share of research article and decrease in Kuwait's share within the GCC countries is more pronounced over the last 10 years. Bahrain's share of research articles within the GCC is the lowest.

The research output of the GCC countries was then normalized to their population (Figure 2A), GDP (Figure 2B) and GDP/capita (Figure 2C). While the absolute values are captured in the graphs to the left, the corresponding shares per country are displayed to the right. We observed a reasonable increase in the research productivity for most of the GCC countries when the data was normalized to population size (Figure 2A, left). Over the past 25 years, the highest increase in the number of research publications normalized to population size is observed for Qatar (a 14.1-fold increase, with a CAGR of 11.2%) (Figure 2A), followed by Saudi Arabia (10.2-fold increase) and then the UAE and Oman (6.8-fold increase each). While the population-normalized research output in Kuwait was the highest amongst the GCC countries, until 2010, it has remained almost constant since then, while those of other countries (especially, Qatar, Saudi Arabia, and the UAE) have consistently progressed, especially after 2010 (Figure 2A, left). Currently, Bahrain, Kuwait, and Oman have similar numbers of
research articles per million capita (667, 583 and 541, respectively), and they are the lowest among the GCC countries. In addition to having the highest number of articles per capita in the earlier years (1996–2010) (Figure 2A, left), Kuwait had the dominant share of the articles per capita among the GCC countries (Figure 2A, right). However, amongst the GCC countries, Qatar currently has the leading contribution (32.2%) in the number of articles per capita, followed by Saudi Arabia and the UAE (18.7% each).

The number of articles normalized to GDP have not sharply increased in the recent years as did the articles per capita (Figure 2B, left vs. Figure 2A, left). In fact, when normalized to GDP, the fold increase (0.9 fold for Kuwait to 3.9 folds for the UAE) and the growth rate CAGR (-0.6% for Kuwait to 5.8% for the UAE) in the research productivity, from 1996 to 2019, were much more modest (Figure 2B). When normalized to GDP, the UAE’s progress in research output was the highest, followed by Qatar, Saudi Arabia and Oman, while Kuwait’s progress was the lowest. This observation is also clear from the GCC countries’ percent share of articles per GDP (Figure 2B, right). Kuwait had a major contribution in the earlier years, but it dropped to the smallest share in 2019. On the contrary, the UAE and Qatar had the smallest contributions in the early years and their share increased over time. Although they have not increased significantly over the years, Bahrain, Oman and Saudi Arabia’s shares of the articles per GDP are the most dominant over the years (Figure 2B, right).

Although Saudi Arabia consistently outperforms the other GCC countries in the number of articles, when normalized to GDP/capita, the highest fold increase of the number of articles per GDP/capita from 1996 to 2019 is for Qatar (17.3 folds) followed by the UAE (15.0 folds), and the lowest is for Kuwait at 2.3-fold increase (Figure 2C, left). The corresponding CAGR values are also the highest for Qatar (12.6%), the UAE (11.9%), and the lowest for Kuwait (3.5%) (Figure 2C, left), a trend similar to the one observed for the research output per capita (Figure 2A, left). The GCC countries with the highest research output per GDP/capita are Saudi Arabia, followed by the UAE and Oman. The data (in absolute value and in percent share) for Saudi Arabia and the UAE are the highest (Figure 2C). Kuwait’s percent share, which dropped over the years for the articles per GDP and per population, separately (Figures 2A and 2B, right), also dropped significantly per GDP/capita (Figure 2C, right), although Kuwait’s absolute values of the articles per GDP/capita are relatively flat over the years (Figure 2C, left). In recent years, Bahrain’s values and percent share of the articles per GDP/capita are the lowest among all GCC countries. In summary, all GCC countries have had an increased research output over the last 25 years, although to different extents in absolute values and in percent shares. The increase in research
outputs normalized to population, GDP, or GDP/capita was more modest than the unnormalized data. This higher growth rate of scholarly output of the GCC countries reflects the increased attention many of the GCC universities and institutions have given to scholarly activity and scientific research in recent years.

3.2. Quality of research output

We used publication ranking in different journal percentiles (1%, 5%, 10%, Q1, Q2, Q3, and Q4), citations, citations per publication, and FWCI as measures for research impact or quality. Figure 3A shows the stacked percent share of articles by journal percentile for each of the GCC countries. In other words, the 5% share (shown in red in Figure 3A) is the share of articles in top 1%-5% (not including the top 1% share). Similarly, the top 10% share (shown in green in Figure 3A) is the share of articles in top 5%-10% (not including articles published in top 5% and top 1%), and so on. This figure shows that the publications in Q1, Q2, and Q3 are roughly equal for all countries except Qatar where its smaller share of Q3 publications is compensated for with roughly equal shares of Q1 and Q2 publications; and Bahrain where its share of Q1 and Q3 publications are slightly lower at the cost of having more Q4 publications. Thus, Qatar slightly outperforms other GCC countries with the quality of publications, while Bahrain needs to improve the quality of its publications. This figure also shows that over the last 10 years, all GCC countries have increased their publication share in higher-ranking journals such as top 10% (noticeable increase) and Q1 (milder increase) while their shares of publications have decreased in lower-ranking journals such as Q4 (noticeable decrease) and Q3 (milder decrease). While this is promising for the quality of publications in the GCC countries, their share of publications in top 5% and top 1% journals are still

Figure 3. Metrics for publication quality within the GCC countries. (A) Stacked percent share of the published articles by journal percentiles (1%, 5%, 10%, Q1, Q2, Q3, and Q4) for all GCC countries for each of the years between 2011 and 2020. (B) Citations (left), citations per publication (middle), and FWCI (right) between 2011 and 2020 for all GCC countries. C) Percent share by country of the values (articles, citations, citations/article, and FWCI) and the values normalized to GDP, population, and GDP/capita, for 2019.
minimal, to a lesser extend for Qatar though, and therefore there is room for growth. Overall, the data clearly shows that Qatar has performed the best among the GCC countries in this measure of quality, especially in the recent years where almost a third of its publications are in top 10% journals (including publications in top 5% and top 1% journals).

Vis-à-vis the number of citations, the data shows that Saudi Arabia has the highest number of citations over the last 10 years, followed by Qatar and the UAE, then Oman and Kuwait, while Bahrain has the lowest citations (Figure 3B, left). This is not unexpected as Saudi Arabia has the highest number of publications among the GCC countries. In fact, as the number of articles increase, the citations are likely to increase as well, although this is not always necessarily the case as the citations are better correlated with the quality of publications than their quantity. The highest number of citations for Saudi Arabia was in 2015, with a gradual decrease for later years, likely since citations lag the publications by a few years. This latter trend is also observed for the rest of the GCC countries. Citations per publication is a better way to measure quality of publications as it normalizes for the differences in the number of articles published among the countries. Bahrain performs the best with respect to this measure, followed by Qatar and Saudi Arabia, and then by the UAE, Oman and Kuwait (Figure 3B, middle). The lower values of citations per publication in Saudi Arabia (Figure 3B, middle) suggest that the high citations (Figure 3B, left) is a result of quantity (proportional to higher numbers of publications, Figure 1, left), and not quality. Bahrain shows the highest citations per publication values in 2015, which could be a result of combined factors: (i) more publications in top 5% journals in previous years (Figure 3A) leading to higher number of citations starting in 2015, (ii) fewer publications in 2015 itself (Figure 1, left), and (iii) possibly the increase in international collaborations in 2015 (Figure 4).

FWCI, which adjusts countries for field-specific differences in citation frequencies, shows a similar pattern, i.e. Bahrain has the highest FWCI over the years, followed by Qatar, then Saudi Arabia and the UAE, and then Kuwait and Oman (Figure 3B, right). Notably, in most of the years, many of the GCC countries have an FWCI higher than the world's average (an FWCI of 1.0) for publications in the same field. These quality metrics (citations, citations/article, and FWCI) were then normalized to population, GDP and GDP/capita, for 2019 (Figure 3C). Note that Bahrain's percent share of the FWCI corresponds to an absolute value of FWCI of 1.0, i.e. the same as the world's average. Figure 3C depicts the inverse proportionality between the shares of GDP (or population) and the shares of the values (i.e. citations, citations/article, and FWCI) when normalized to GDP (or population size). For example, Saudi Arabia has high shares of GDP and population within the GCC, and therefore, low shares of Value/GDP and Value/Capita. On the contrary, Bahrain has low shares of GDP and population, but high shares of Value/GDP and Value/Capita. This figure also depicts that the trends of Value per GDP/Capita is the same as that of Value, meaning that the raw values of articles, citations, citations/article, and FWCI are directly indicative of how well each person is doing given a certain amount of money in that particular country. Figure 3C illustrates that, in 2019, Saudi Arabia performed the best in raw values, but when normalized to population and GDP, Qatar and Bahrain were the best performers, respectively. Saudi Arabia also had the highest Value per GDP/capita. When normalized to population, the shares of FWCI and citations/article were the highest for Bahrain and Qatar, while the shares of citations (and articles, Figure 2A, right) were the highest for Qatar. When normalized to GDP, the shares of FWCI and citations/article were the highest for Bahrain and Oman. When normalized to GDP and population, the shares of value (proportional to publications in top percentiles, Figures 2A and 3B, right) were the highest for Saudi Arabia and the lowest for Kuwait. Saudi Arabia and the UAE's share of citations/article or FWCI was minimal when the data was normalized to population or GDP. When citations were normalized to population, Qatar had the highest share, but when normalized to GDP, Saudi Arabia had the highest share, followed by Qatar. When normalized to GDP/capita, the UAE's share for all values (i.e. citations, citations/article, and FWCI) were roughly even. In summary, while there was a remarkable growth in the number of publications in the GCC countries over the last 25 years (Figure 1, left), there is a modest increase in the quality of publications by the GCC countries in the last 10 years, even when these measures were normalized to population, GDP, or GDP/capita, with the best performers being Qatar, Bahrain, and Saudi Arabia, respectively. Therefore, there is a still potential for growth in the GCC countries and we will provide, in the Discussion and Recommendations section, details on how to improve publication quality within the GCC countries.

3.2.1. International and academic-corporate collaborations

Publications resulting from international or academic-corporate collaborations have a higher impact than those from a single country or from solely academic authorship [18, 19]. Most of the GCC universities established international collaborations to promote the research culture [22]. Over the last 10 years (2011–2020), international collaborations have increased for all GCC countries (Figure 4A). Qatar has the highest levels of collaborations, which could be linked to the higher share of its publications in top percentile journals (Figure 3A). In terms of percent changes in international collaborations, Oman and the UAE have had more consistent growth than the other GCC countries over these years, while Qatar's collaborations have recently declined the most (Figure 4A). Qatar's average published papers (over the past decade) with international co-authors was the highest at approximately 75% (Figure 4B). Saudi Arabia, the UAE, and Oman had slightly lower collaboration levels ranging between ca. 60% and 70% (Figure 4B). While these international collaborations are relatively high, academic-corporate collaborations are still relatively limited, they do not exceed 5% (Figure 4B). Given their larger standard deviations, the academic-corporate collaborations span a wider range of values than the international collaborations. In summary, the percent publications with international collaborations are quite high in the GCC countries, while that of academic-corporate collaborations are fairly low. Therefore, more efforts could be spent to encourage academic-corporate collaborations.

3.3. Research in various subject areas

To examine research productivity of the GCC countries across different fields, the number of articles published between 2011 and 2020 in the 27 ASJC subject areas were assessed. Figure 5A shows the accumulated number of articles from all GCC countries for each of the 27 ASJC subject areas. This figure reveals that the GCC's highest cumulative numbers of articles are in Engineering, Medicine, and Computer Science. These three fields are also the most popular in each of the GCC countries individually, except for Saudi Arabia where the top three areas, according to the number of articles, are Engineering, Medicine, and Chemistry, followed by Computer Science and Material Sciences. The top 4 and 5 areas vary significantly among the GCC countries: Bahrain (Social Sciences; Business, Management and Accounting), Kuwait (Energy; Earth and Planetary Sciences), Oman (Agricultural and Biological Sciences; Social Sciences), Qatar (Physics and Astronomy; Material Sciences), and the UAE (Social Sciences; Energy). The lowest overall research outputs in the GCC are in Veterinary, Psychology, and Nursing. The overall total number of articles in Health Professions, Neuroscience, Dentistry and Arts and Humanities are also quite low. The publications in Arts and Humanities are low likely because of the language discrepancy as Scopus does not report publications in Arabic which is the mother language in the GCC countries. Figure 5A also shows that Saudi Arabia has the highest while Bahrain has the lowest contributions in almost all subject areas.

We also considered the share, by discipline, of the publications in each of the GCC countries over the last decade (from 2011 to 2020) when we aggregated the 27 ASJC subject areas from Scopus into six main research disciplines according to the OECD classification (see Figure 5B). The data shows that the GCC countries have the greatest publication output share in the disciplines of Natural Sciences, Engineering and Technology, and Medical and Health Sciences, with very little focus on Humanities, Agricultural Sciences, and Social Sciences disciplines. In Saudi Arabia, 45.5% of their total research output is in Natural Sciences,
followed by 27.4% in Engineering and Technology, and 18.0% in Medical and Health Sciences. In the UAE, 39.7% of their total research output is in Natural Sciences, 29.6% in Engineering and Technology, followed by 13.5% and 13.3% in Medical and Health Sciences, and Social Science, respectively. The data for Kuwait, Oman and Qatar looks very similar with ca. 39% of the share of their publications in Natural Sciences, followed by ca. 25% in Engineering and Technology, and ca. 20% in Medical and Health Sciences. In Bahrain, the shares of publications among the four disciplines of Natural Sciences, Medical and Health Sciences, Engineering and Technology, and Social Science are spread more evenly with 33.6%, 25.9%, 20.7%, and 16.6%, respectively (Figure 5B).

Finally, Figure 5C shows that, over the last decade (from 2011 to 2020), the percent growth across the different subject areas in the GCC countries varies from one country to another. Compared to other GCC countries, Qatar’s growth is more diverse with a higher percent growth across more subject areas, specifically in Dentistry, Multidisciplinary, and Neurosciences. Kuwait’s growth rate in the different subject areas is the least overall, with particular focus on Veterinary. Dentistry witnessed a decrease in the percent growth over the last decade in Kuwait and Oman. The largest percent growth in Bahrain is in Decision Sciences, Management and Accounting, and Multidisciplinary research. In the past decade, the interests in Bahrain, Oman, Saudi Arabia, and the UAE have obviously grown in the area of Decision Sciences. In summary, the data shows that the focus of most of the GCC countries is primarily on the disciplines of Natural Sciences, Engineering and Technology, and Medical and Health Sciences.

Figure 4. International and academic-corporate collaborations, between 2011 and 2020, for all GCC countries. A) Percent publications with international collaborations. B) Average collaborations (international in blue, and academic-corporate in red) over the past decade with standard deviations.
Figure 5. Research output in various subject areas or research disciplines within the GCC countries from 2011 to 2020. (A) The number of articles, stacked by country, published in the 27 ASJC subject areas in the GCC countries. (B) Percent share, by subject area with six of them according to the OECD classification, of the publications from each of the GCC countries. (C) Percent growth in the number of articles published in the 27 subject areas in the GCC countries.
3.4. Normalization of the research output to GERD and number of researchers

Normalization of research output (quantity and quality) to population, GDP, or GDP/capita (Figures 2 and 3) may not be sufficient measures to capture research productivity at the national level. A more focused representation of research output would require normalization to more specific metrics such as GERD, GERD/GDP (where both GERD and GDP are in PPP-current international $; GERD is in thousand, and GDP is in billion), number of researchers, researchers/capita (population is in million), and GERD/researcher. The values normalized to GERD/GDP show the performance given the amount of research expenditure with respect to the country’s GDP. The values normalized to researcher/capita show the performance given certain number of researchers with respect to the country’s population. Among all the considered metrics, the ones related to GERD and researchers are not available for Saudi Arabia and Bahrain. Thus, the normalized values were calculated only for four countries (Kuwait, Oman, Qatar, and the UAE) and only for one year (2018), that is the year for which the latest data was available (Figure 6). The ratios of researchers to total population and of GERD to total GDP are relatively low in these four countries (see the Discussion and Recommendations section).

In 2018, the UAE had the highest percent share of GERD, GDP, GERD/GDP, number of researchers, population, and researchers/capita, GERD/researcher, GDP/capita. This made all of the UAE’s measures per GERD (or GDP) or per researcher (or capita) low despite the highest share in the number of articles and citations.
(Figure 6B). The values shown in Figure 6B include measures of quantity (number of articles) and quality (citations, citation/article, and FWCI). Of the four countries, Kuwait had relatively low share of values (specifically the number of articles and citations), however its share of values/GERD, per GERD/GDP, and per GERD/researcher were the highest since its share of GERD was the lowest. This implies that Kuwait did very well in research productivity quantitatively, and even more so qualitatively, given its lowest share of GERD ($133.4 million), and its low GERD/GDP (0.06%). Therefore, there is a good potential for Kuwait to increase its research productivity provided that its GERD/GDP (which is currently very low relative to other GCC countries and world average of 2.28%) is increased. Similarly, of the four countries, Qatar had the highest share of values/researcher and values/capita since it had the lowest share of the number of researchers and population. In 2018, the UAE invested the most in research compared to its GDP, and had the highest number of researchers per capita (Figure 6A). This suggests that the UAE made the highest effort in supporting research relative to the other countries considered, and this was positively reflected in its higher share of articles and citations. Kuwait, Oman, and Qatar had roughly equal shares to values per GDP and per researcher/capita. In summary, Kuwait had the highest share of values per GERD, per GERD/GDP, and per GERD/researcher. Kuwait, Oman, and Qatar had roughly equal shares to values per GDP and per researcher/capita. Qatar had the highest share of values/research and values/capita. In addition, the percentage of GERD with respect to GDP, and the number of researchers with respect to population are low compared to international countries. Thus, increasing these percentages can enhance research productivity (see the Discussion and Recommendations below).

3.5. The global context

To place the research performance (quantity and quality) of the GCC countries in a global perspective, we compared them to three countries that have similar population size or GDP, yet high research outputs: Switzerland, Singapore, and Canada. These countries have given considerable attention to research and development and, thus, have made significant contributions in research output and impact in the recent years. Despite the significant increase in the volume of publications over the years in the GCC countries (Figure 1, left), they are still relatively low compared to international high standards. The three international countries have a higher annual number of published articles, over the last 25 years (1996–2020), than the GCC countries, with the exception of Saudi Arabia as it has surpassed Singapore’s publication output in the past couple of years [21]. However, the CAGR values over the past 25 years for all of the GCC countries (except Kuwait) were higher, e.g. 19.0% for Qatar and 14.0% for the UAE compared to 8.8% for Singapore and 4.9% for Switzerland, and so were the fold increase values (77.6 folds and 26.3-folds vs. 8.2-folds and 3.3-folds, respectively). Similarly, when we assessed the publication output for the year 2019, the three comparative countries still had a significantly higher number of articles compared to all GCC countries, with the exception of Saudi Arabia (Figure 7A). The total number of articles for Canada was the highest amongst all these countries. GDP/capita of the countries were also compared and ranked from the highest (left) to lowest (right) (Figure 7A, red line). Relative to the GDP/capita, Canada and Saudi Arabia demonstrated the highest research output among the countries considered in this study (Figure 7A). When the number of articles published from these countries was normalized to the population size for the year 2019 (Figure 7B), Switzerland, Singapore, and Canada led the way, while Qatar performed the best amongst the GCC countries. The red line in Figure 7B represents the population of the countries ranked from the highest (left) to the lowest (right). Relative to their population sizes, Switzerland, Singapore, and Qatar have distinguished research performance. When normalized to GDP, Singapore, Canada, and Switzerland again led the way, they had the highest number of published articles (Figure 7C). Amongst the GCC countries, Saudi Arabia and Oman had a higher number of publications relative to their GDP (Figure 7C). The red line in Figure 7C is the GDP of the countries ranked from the highest (left) to lowest (right). Relative to their GDP (red line), Switzerland, Singapore, Oman, and Bahrain had exceptional performances compared to the other countries.

We also analyzed, for year 2019, the GDP/capita, citations/article, and normalized research articles (to GDP, population, and GDP/capita) for the GCC and the three chosen international countries (Figure 7D). When normalized to population, the research performance of the GCC countries compared to Switzerland, Singapore, and Canada were again notably lower. In fact, in 2019, the articles per capita for Switzerland (5.8 publications for every thousand inhabitants) was up to 3.6 folds higher than Qatar’s (1.6 publications for every thousand inhabitants), which in turn, was higher than other GCC countries’, with 0.9 and 0.8 publications for every thousand inhabitants in the UAE and Saudi Arabia, respectively. Similarly, when normalized to GDP, the research productivity of the GCC countries compared to Switzerland, Singapore, or Canada were markedly lower, with Switzerland having twice as many publications per GDP in billion (71.2) compared to Saudi Arabia (35.2), the highest amongst the GCC countries. It is worth noting that all countries considered in this study had a relatively similar GDP/capita ranging from $16.5K (Oman) to $46.4K (Canada), with the exception of that of Switzerland ($81.8K), and to a lesser extent those of Qatar and Singapore ($65.9K, $65.2K, respectively). When normalized to GDP/capita, Canada led the way by far with 100 articles per GDP/capita, followed by Saudi Arabia at half value (48 articles per GDP/capita), then Switzerland at quarter value (25 articles per GDP/capita), and the rest of the countries had values less than 10 articles per GDP/capita except for Singapore (15 articles per GDP/capita). Finally, while Singapore and Switzerland had the highest quality measures, i.e. 99 and 90 citations/article, respectively, other GCC countries like Qatar and Saudi Arabia had very comparable citations/article (82 and 78, respectively), noting that the lowest citations/article were roughly half of Switzerland’s, i.e. 53 and 44 citations/article for Oman and Bahrain, respectively. Figure 7D shows that the citations/article was not exclusively distinct for any of the countries, unlike other measures, especially the articles per GDP/capita, the articles/capita, and the articles/GDP. Overall, in 2019, the three international countries performed the best with Saudi Arabia and Qatar catching up in some of the measures. However, the rest of the GCC countries need extra efforts before they can mark their fingerprint in research internationally.

4. Discussion and Recommendations

The GCC countries witnessed an increase in their research productivity over the last 25 years. There are several plausible reasons for this remarkable growth, especially over the past 10 years. The GCC countries have (i) established an increasing number of universities and research institutes over the last few decades [23], (ii) enhanced their focus on research productivity (Figure 1) in an effort to strengthen international recognition and ranking, and (iii) increased funding opportunities for scientific research as demonstrated by increased GERD/GDP over the years, e.g. 0.5% in 2011, 0.7% in 2014, and 1.3% in 2018 for the UAE. The development of graduate programs, especially PhD programs in some of these universities have also helped with this growth in research output, e.g. the United Arab Emirates University launched its PhD program in 2010 [24]. In addition, the UAE Higher Education Strategy 2030 [25] set clear objectives for increasing funding support for graduate programs and increasing the number of PhD students. Overall, the driving force for the exceptional growth in the research productivity, especially in Saudi Arabi, the United Arab Emirates, and Qatar, is likely due to the development of national strategies towards higher education and scientific research, the increased number of universities and institutions, and the enhanced support given to scholarly activity in the recent years. The scientific production of the large scientific systems, such as Saudi Arabia in the GCC, could have a positive impact on other systems as the former could be an exemplary model for the latter to
believe that better research productivity can be achieved within neighboring areas. In addition, smaller systems can benefit from the strategies used by the exemplary countries and follow the same path to improve their own records in research productivity.

Governmental strategies on research, among the GCC counties, have been rather different. This has led to emphasis across different scientific areas in these countries and a diverse national research portfolio. For example, the top ranked disciplines in Saudi Arabia, according to the number of publications, are Engineering, Medicine, and Chemistry, whereas the focus in the UAE has been on Engineering, followed by Computer Sciences and Medicine. However, the research outputs in some fields such as Veterinary, Psychology, and Nursing, Health Professions, Neuroscience, Dentistry and Arts and Humanities are low in the GCC countries.

The number of publications in the GCC countries have increased over the years with a reasonably high growth rate. However, when normalized to GDP, an unrealized potential for these countries was noted, especially when compared to other countries, outside the GCC, with similar GDP or population size, yet remarkable research output over the years, e.g. Switzerland, Singapore, and Canada. In 2019, the GCC’s world share of research publications accounted for 1.7%, which is similar to the Switzerland’s share (1.5%). However, the GCC’s share of the global GDP was 1.9% vs. only 0.8% for Switzerland [1]. The GCC’s share of publication output is close to their share of global GDP, making their ratio of article share with respect to GDP share (1.7%/1.9% = 0.9) almost half compared to that of Switzerland (1.5%/0.8% = 1.9). The unrealized potential of the GCC countries can be also attributed to two main factors: (i) the GERD as a percent of the GDP in the GCC countries (with the highest at 1.3% in the UAE, and the lowest at 0.06% in Kuwait, in 2018) is significantly lower compared to that of the world average (2.3%) in 2018, OEDC average (2.6%) in 2018, or research-focused countries such as Switzerland (3.4%) in 2017 [1], and (ii) the number of researchers as a percent of population in the GCC countries (averaging to less than a 1,000 researchers per million inhabitants) are also much lower compared to the three comparative countries (e.g. Switzerland’s which is more than five times higher). For example, there are 2379 researchers per million population in the UAE (highest amongst the GCC countries) and only 281 researchers per million population in Oman in 2018. This is significantly lower than the number of researchers per million capita, in 2017, in Switzerland (5450), Singapore (6803) or Canada (4326). Therefore, since the three comparative countries (Switzerland, Singapore, and Canada) have higher researchers/capita and GERD/GDP values, it is no surprise that they outperform the GCC countries in research productivity. Government investment in research and development (GERD as a percent of GDP and number of researchers per capita) is clearly important in increasing publication output and publication quality. It is, thus, recommended that the GCC countries increase the values of researchers/capita and GERD/GDP as such strategies seem to have boosted the research output of the three

Figure 7. A) Number of research articles in 2019 for all GCC countries and the three comparative countries (Switzerland, Singapore, and Canada). GDP/capita of the countries are also compared and ranked from the highest (left) to lowest (right) (red line). (B) Number of research articles per capita in 2019 for all GCC countries and the three comparative countries. Population of the countries are also compared and ranked from the highest (left) to lowest (right) (red line). (C) Number of research articles per GDP in 2019 for all GCC countries and the three comparative countries. GDP of the countries are also compared and ranked from the highest (left) to lowest (right) (red line). (D) Relative number of research articles normalized to GDP, population, GDP/capita, as well as citations per publication and GDP/capita for all GCC countries and the three comparative countries.
international countries. We realize that data availability, e.g. on the number of researchers as well as GERD in the GCC countries, is limited. Therefore, it is necessary to regularly collect data that can help inform national authorities to advance the science agenda and increase research productivity in an effort to build a knowledge-based economy. Furthermore, comparisons to other countries that are distinguished in research may provide additional insights about the GCC's research performance.

Finally, to further develop their research infrastructure and achieve sustainable improvement in quality and quantity of research, the GCC countries would need to develop clear national research strategies, increase public and private investment in scientific research, attract and retain top researchers and scientists, increase the number of researchers, support graduate programs and students (especially PhD), provide research-active faculty sufficient time to conduct research, support flexible and conducive research environment, and incentivize researchers to establish collaborations. However, it is worth noting that although collaborations boost the impact of publications, increase chances of fund, improve the quality of research, and promote the exchange of expertise, they may have disadvantages such as conflicts, ambiguity in leadership, and dependence of the smaller teams on the more established international teams. Therefore, it is important to have, at the early stages of the collaborations, agreements with clear terms and conditions to maximize the benefits while minimizing the disadvantages for both parties, in the short and the long runs. Furthermore, as a country is setting its research infrastructure and growth, it may be more beneficial to have high levels of collaborations at the early stages. However, it is not a healthy sign to maintain this high level of collaborations (e.g. up to 75% in the GCC), but rather to show more autonomy and independence by reducing these levels of collaborations to e.g. ~35–40% which is the range of percentages reported for the EU and the USA.

In addition, it is important that the strategies at the national or institutional levels encourage publications in high-quality journals rather than higher volume of publications in lower-quality journals. This is because high-quality research has a greater impact on the economic growth in the long term [26, 27]. If these components are implemented, then the GCC countries will have greater chances of success in building a thriving and sustainable academic research ecosystem, which is an important step towards building a knowledge-based economy.

This study has some limitations such as the exclusion of documents in the Arabic language and the scarcity in the GERD and number of researchers for the GCC countries. Another limitation is the analysis of some metrics extracted only form the past decade as opposed to the full period of 25 years. However, this limitation is not as serious given that minimal changes in trends (if any) are observed in the earlier years. In the future, this study can be extended to including institutes in each of the seven GCC countries. Another future direction is to consider, in the GCC countries, each field of research separately. At an international scale, this study can be repeated across a larger number of countries around the world. At the technological level, machine learning tools can be used to predict the future of research performance in various countries.

5. Conclusions

A bibliometric analysis of research productivity in the GCC countries was performed. The research performance metrics used include quantity, quality, and diversity of subject areas. These metrics (raw and normalized to economy and human capita) were compared to those of three international countries (Switzerland, Singapore, and Canada) that have remarkable research performance, especially per capita or per GDP. The GCC countries have increased their research output to various degrees over time, e.g. Saudi Arabia has the highest number of research articles across the last 25 years, with ca. 38,000 articles published in 2020. Qatar has the highest increase in research productivity (77.6 folds) over the same period of time. However, when normalized to population or GDP, Qatar's performance was less notable: the fold increase for the number of articles per capita, per GDP, or per GDP/capita was only 14.1 folds, 3.2 folds, and 17.3 folds, respectively. Similarly, the fold change as well as the GAGR in publications of all the GCC countries were dampened with the normalization of the number of articles to population size, GDP, or GDP/capita. The growth in research quantity was coupled with only a slight increase in the quality of publications, where the number of publications in top journals increased and that in Q3 and Q4 decreased. In addition, quality was reflected with the increased FWCI over the last decade for most of the GCC countries. When normalized to population or GDP, the metrics of quality (FWCI and citations/article) increased for Bahrain, Kuwait, and Oman, but decreased for Qatar, Saudi Arabia, and the UAE.

The international collaborations have increased for all GCC countries over time (up to ca. 75% for Qatar). The academic-corporate collaborations level was low, it did not exceed 5%. The focus of the GCC countries is mostly on Natural Sciences, Engineering and Technology, and Medical and Health Sciences. The percent growth in research output varied substantially across the different subject areas and the different GCC countries, with Qatar's growth being the most noticeable in many of the fields. The GERD and number of researchers in the GCC countries were found to be low relative to their respective GDP and population. Overall, while Saudi Arabia and Qatar are catching up, in quantitative and qualitative measures of research output, compared to the three international countries that have excellent research output, there is an unrealized potential for the GCC countries to improve their research performance. This can be achieved through increasing research funds and the number of researchers. Countries with low citations per publication need to encourage and support researchers to publish in journals with open access or highly-ranked journals to increase the levels of citations. For low records of scholarly output per unit currency, the orientation shall be directed towards the quality control on the efficiency of using research fund. The results of this study can be used to benchmark and inform strategic decision-making for the GCC countries as they race towards knowledge-based economies.

Declarations

Author contribution statement

Ahmed H. Al-Marzouqi, PhD; Alya A. Arabi, PhD: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data will be made available on request.

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