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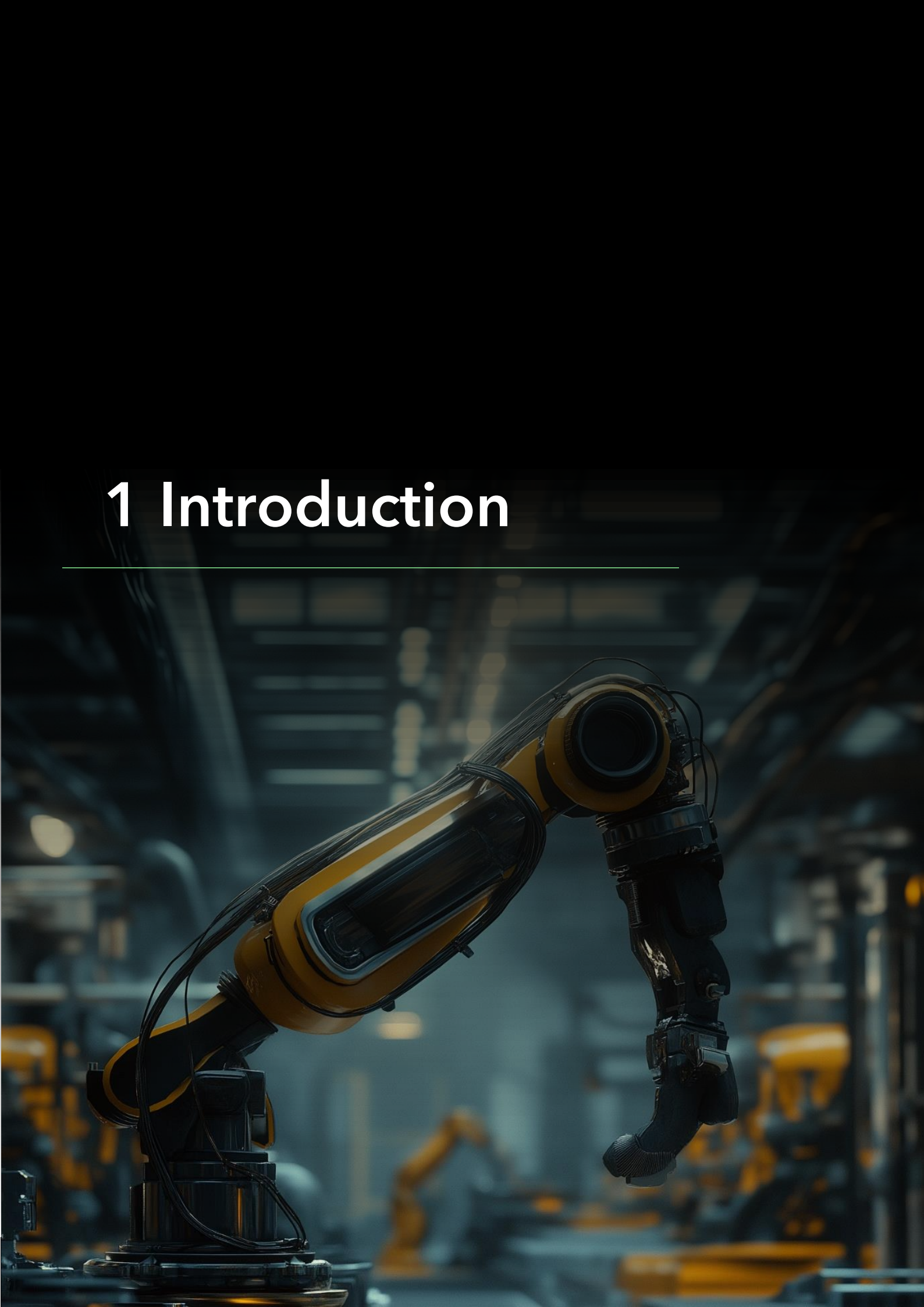
Energy and Industrial Leadership RDI National Priority in Saudi Arabia: Analytical Study

Full Study

Innovation Ecosystem in Focus

Contents

1 Introduction



The Kingdom of Saudi Arabia is undergoing a transformative journey emphasizing the importance of a knowledge-based economy as a driving force behind Saudi Vision 2030. This essential transformation is set to elevate the research, development, and innovation (RDI) landscape, positioning Saudi Arabia as a global leader within its national priorities:

- Energy and Industrials
- Health and Wellness
- Sustainability and Essential Needs
- Economies of the Future

His Royal Highness Prince Mohammed bin Salman bin Abdulaziz Al Saud has declared Saudi Arabia's goal of becoming a global frontrunner in science, technology, and innovation. The Kingdom targets investing 2.5% of its GDP in RDI by 2040. Establishing the Research, Development, and Innovation Authority (RDIA) in 2021 marked a pivotal step in steering RDI initiatives.

RDIA is committed to steering and executing the Kingdom's RDI strategies across the four national priorities. RDIA has led the organization of capacity-building activities, equipping Saudi leaders and practitioners with the vital skills needed for energy and industrials innovation. It has crafted specialized strategies to identify numerous relevant research topics within national priorities. The authority's initiatives nurture local talent and foster global collaborations to develop an RDI infrastructure that benefits public and private sector innovation across this sector.

Energy and Industrials is a broad sector encompassing varied topics from hydrogen production to Industry 4.0. Strategic partnerships between universities, established and emerging companies, and international collaborations ensure effective alignment with global energy and industrials advances to accelerate local deployment of impactful solutions for now and the future. These efforts by RDIA are critical to Saudi Arabia enhancing its global leadership in energy and industrials innovation. This will best place the Kingdom's industrial sector to meet the growing demands of the Saudi and global population. By aligning research output with national priorities, RDIA can ensure optimal return on investment, prioritize high-impact sectors, and position Saudi Arabia as an energy and industrials leader for years to come.

This study will draw upon the analysis undertaken in the enhancing cooperation and partnership between academia and companies in research capacity and technology readiness in Saudi Arabia's program of work:

1. Assessment of Academic-Corporate Partnerships in Saudi Arabia
2. Insights into Saudi Arabia's Research and Innovation Ecosystem
3. Accelerating Technology Transfer from the Lab to the Market in Saudi Arabia

This study, focused on Energy and Industrials, will evaluate the level of Academic-Corporate Partnerships and the research capacity within Saudi Arabia Academic organizations.

The complete list of technologies that define the national priority area of Energy and Industrials within this study, with global volumes across research publications and inventions, is shown in Figure 1.

Figure 1: Number of research publications and inventions within Energy and Industrials 2014-2023

The key RDI Missions related to the Energy and Industrials national priority are found below, and this study will focus on Missions 3.2 and 3.4:

- Mission 3.1 Increase the share of renewable energy sources to ~50% by 2030
- Mission 3.2 Develop cost-effective technologies to achieve 80-85% conversion of crude oil to chemicals by 2030
- Mission 3.3 30% reuse of raw materials and products in industry by 2040
- Mission 3.4 Reduce the cost of clean Hydrogen to <1$/kg by 2030
- Mission 3.5 Promote establishing and operating the first net-zero carbon mine with partial use of autonomous technology by 2050

- Mission 3.6 Become the 4th largest producer of EVs and EV batteries by 2035
- Mission 3.7 Develop multi-purpose industrial robots that understand and adapt to their changing environment by 2035
- Mission 3.8 Demonstrate commercial scale Small Modular Reactor (SMR) nuclear fission power plant by 2040

The selected research topics within Energy and Industrials to be further analyzed in this study are defined as follows:

1. Crude-Oil-To-Chemicals (COTC) Processes: methods turning low-value crude oil into high-value chemicals
2. Crude-Oil-To-Chemicals (COTC) Products: compositions made of chemicals derived from low-value crude
3. Sustainable Mining Waste Management: methods to derive valuable materials generated as by-products in the mining process
4. Industry 4.0—Digital Twins are virtual replicas of real-world objects, such as machines or entire factories, that can be monitored remotely as the digital model captures real-time data from the physical object.
5. Net Zero - Industrial Emissions: methods and technologies to minimize emissions and/or off-set them in an industrial environment
6. Smart Grids: using sensors, computers, and communication systems to monitor and manage the flow of electricity in real-time
7. Hydrogen Production: methods and technologies to synthesize hydrogen
8. Hydrogen Storage and Transportation: methods and technologies to store or transport hydrogen safely.

As this study, and the wider program of research, intends to analyze the National Priorities under the wider Vision 2030 policy, a dataset has been created that allows a detailed review of both the research activities occurring within the Kingdom as well as comparisons to that activity globally.

To facilitate this program of study, a technical analysis was undertaken to identify key research topics under each National Priority. In addition, these research topics then go on to define the datasets of the National Priority Areas themselves.

The creation of these content sets is based on two primary sources of information:

1. The published documentation by RDIA and other agencies in Saudi Arabia concerning the national priorities themselves.
2. The study's technology analyst team, comprising STEM professionals with many years of experience performing innovation and technology research intelligence projects.

This multi-part study aimed to create a comprehensive overview of the significant aspects of the research ecosystem in Saudi Arabia. This study is intended to provide a baseline dataset of the capabilities of the Saudi research ecosystem. Seven (7) discrete studies were commissioned to establish this baseline, of which this study is one part. The reader is encouraged to read this study in full and explore the other studies to understand how the research ecosystem has developed over the past decade. The deep national priority studies available under this comprehensive review are:

- Energy and Industrials
- Health and Wellness
- Sustainability and Essential Needs
- Economies of the Future

In total, 167 topics were identified and collated across both research publications (gathered from the Web of Science) and patented inventions (sourced from the Derwent World Patents Index), using traditional keyword and technology classification search techniques.

Topics were reviewed by the project technology analyst team for review of completeness, introduction of error, or need for further definition and extraction. This is performed via an iterated review and amendment process using the scientific and engineering expertise of the project's technical analyst team.

Once these data extraction strategies were finalized, the records associated with each research topic category were aggregated, and the names were normalized and ring-fenced into a project-specific data lake ready for analytical workup. The process is illustrated in Figure 2.

The finalized data structure for this study is summarized as follows:

- Over 9 million research publications.
- Over 5.5 million patented inventions.
- This data is then structured into 167 research topic categories across both research publications and inventions.
- The 167 research topics themselves then define the 4 National Priority Areas.

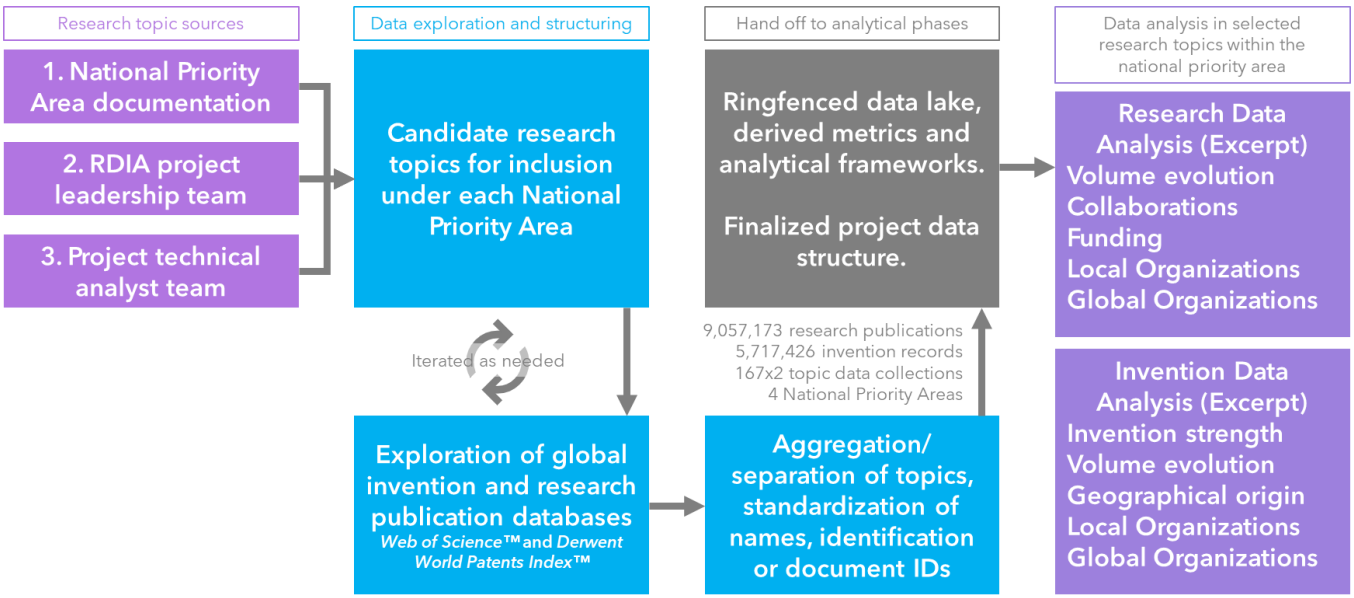


Figure 2: Study data curation process

Energy and Industrials is a mature but constantly evolving technology domain. More recent impacts of green chemistry, hydrogen, and catalytic processes have brought new approaches to traditional ways of producing core outputs driving the energy and industrials sector. Applying sustainability goals to conventional mechanical and chemical processes will be essential to continuing to bring efficient new technologies to market.

2 Executive summary

2.1 Overview

The Energy and Industrials priority area of RDIA represents an opportunity to further extend Saudi Arabia's leadership position through research topics such as, but not limited to, Autonomous Mining, Energy Storage, Hydrogen, Industry 4.0, Renewables and Sustainable Mining.

The Energy and Industrials priority has a wide variety of research topics. Notably, only three technologies fall into Technology Readiness Level (TRL) 1-3: Digital Twins and Intelligent Manufacturing and Small Modular Nuclear Reactor (SMR). Technologies in TRL 7-9 include COTC Products and Processes, along with PV Modules, Solar Farms, and Wind Turbines. Saudi Arabian invention alignment to commercial potential is well aligned, especially for high TRL technologies (for more information on TRL, please see the section Definitions). This displays a preference for near-term return on investment innovation.

- Saudi Arabia has very high invention output and volume in COTC Processes, Products and Hydrogen production. All three of these fields are led by the significant research, development and innovation power of Saudi Aramco.
- Saudi Arabia has relatively low research and invention strength performance in the scorecard in this study in fields such as Net Zero – Industrial Emissions and Industry – Digital Twins. International organizations operating in this space also have lower levels of invention; however, they also appear to specialize in different research topics compared to Saudi Arabia's academic institutions and local corporations.

Saudi Arabia is set up for success by leveraging corporations such as Saudi Aramco, which has research synergies across Hydrogen, Net Zero, Renewables and Industry research topics.

2.2 Key opportunities within Energy and Industrials

- **Leverage Saudi Aramco's academic-corporate partnership (ACP) excellence:** Saudi Aramco has a significant number of local ACPs, also spanning Economies of the Future, Sustainability and Essential Needs. Saudi Aramco's research, innovation, collaboration and economic success require continued diversification and expansion into new areas, such as applying AI to existing business units.
- **Expand into non-traditional research topics via the creation of further start-ups:** Qudra Energy's work in PV Modules and NOMADD Energy and Industrials ACP start-up creation, showcases Saudi Arabia's entrepreneurial foundations. To achieve industrial leadership, a greater number of private organizations are required, as well as a focus on all research topics within Energy and Industrials.
- **Prioritize higher-performing and higher-commercial-potential research topics: COTC Processes, COTC Products, Hydrogen Production, Hydrogen Storage and Transportation and Sustainable Mining—Waste Management:** Combined, these topics have the potential to generate $2.09bn for the Saudi Arabian economy if 5,833 inventions are protected, generating the expected yield of very high-strength inventions, and are subsequently successfully commercialized.
- **Continue to fund local academics in key research topics with lower TRL:** Research topics with lower TRL requiring both more academic research funding and more ACPs include: Digital Twins and Hydrogen Storage and Transportation. Further research topics requiring sustained research funding include: Net Zero – Industrial Emissions, Power Distribution – Smart Grid and Sustainable Mining – Waste Management.

Saudi Arabia particularly shows innovation strength in more mature technologies. Therefore, the Kingdom should continue to foster Academic-Corporate Partnerships between Saudi Aramco and local Academic Institutions such as but not limited to King Abdulaziz University, King Fahd University of Petroleum and Minerals (KFUPM), King Abdullah University of Science and Technology (KAUST) and King Saud University.

The interplay between Energy and Industrials research topics and Sustainability and Essential Needs research topics should not be underestimated, with many research topics being combined or transitioned from one to another across national missions such as: 2.4 Achieve net-zero emissions by 2060, 2.6 Reduce summer surface temperatures by 4°C by 2040, 3.1 Increase the share of renewable energy sources to ~50% by 2030, and 3.6 Become the 4th largest producer of EV's and EV batteries by 2035. The complex transformation related to the world's energy production and consumption may be underpinned by the next wave of Saudi Arabian technologies. This could be achieved by setting up cross-functional centers of excellence, including incubators to build specialist private organizations to supply cutting-edge innovation.

This study's insight provides a multidimensional evaluation of research topics within the Energy and industrials priority area to provide key actions and options to consider and benchmarks against global leadership. Subsequently, the tailored insight, metrics and findings, can enhance both foundational research within academia and commercially applied innovation to achieve Saudi Arabia's national missions and aspirations.

3 Overview of research publication and patent performance in Energy and Industrials

This section provides an overview of Saudi Arabia's research publication and patent performance within the Energy and Industrials National Priority. This study is part of a wider program of analysis across research output, the research ecosystem and technology commercialization, and therefore the analysis presented here includes extracted data from several studies across these wider studies, now focused within this national priority area.

3.1 Overview of performance in research

In this section, we evaluate the research performance of Saudi Arabia in the national priority area of Energy and Industrials in the period 2014-2023. The aim here is to examine the evolution as well as the status in terms of research volume and impact.

For this, we start by examining the evolution of the number of papers in the priority area over this period and benchmark it with the global baseline and other countries/regions. Afterwards, we examine the citation impact. For this, we will use the Category Normalized Citation Impact (CNCI). CNCI is a valuable and unbiased indicator of impact irrespective of age, subject focus, or document type. Therefore, it allows comparisons between entities of different sizes and different subject mixes. A CNCI value of 1 represents performance at par with the global average when considering the same document type, year and subject.

A value above 1 reflects a performance higher than the global average, while a value below 1 reflects a performance below the global average (for more information, see Metrics). To further understand the research dynamics in the national priority area we also look at top 20 countries in terms of number of papers collaborating with Saudi Arabia and top 20 funding organizations in terms of number of papers in each of the priority areas. Looking at the top 20 funders will allow to identify key organizations funding Saudi Arabia research in the national priority area.

We also investigate the research performance of Saudi Arabia in this national RDI priority area with a specific focus on research performed within an industry collaboration. A paper with industry collaboration is a paper that contains two or more Organizations with at least one organization listing its organization type as corporate or global corporate (see Metrics). This gives us insights into the Academic-Corporate Partnership status currently in Saudi Arabia within this national priority area. However, it is important here to differentiate that a paper published as an output of research performed through a collaboration between academic affiliated researchers and corporations does not necessarily underpin a long-term or strategic partnership. Nevertheless, investigating papers with an industry collaboration gives insights into academic-corporate activity. To provide an overview of the academic-corporate activity in Saudi Arabia, we investigate several domains: the evolution of the percentage and number of papers with industry collaboration, funding of papers with industry collaboration, corporates collaborating with Saudi affiliated researchers and top Saudi academic institutions in terms of number of papers with industry collaboration.

Finally, we analyze the research output and impact of the priority area on a more granular level by performing a SWOT analysis of the categories constituting the national priority area. This allows us to have an overview of research performance in the research topics constituting this area before investigating the chosen priority research topics in the following sections in more detail. This allows classifying the underlying categories into strength, weakness, opportunity and threat areas. Accordingly, all the above analyses will create a relatively detailed overview of Saudi Arabia's research performance in the priority area.

Main Findings

- Over the last 10 years, Saudi Arabia’s research output within the national priority area of Energy and Industrials increased very rapidly, with an average annual growth rate higher than that of the comparator countries/regions considered with an average annual growth rate of ~ 23%.

- In the area of Energy and Industrials, Saudi Arabia's citation impact was 64% higher than the global average, matching that of the United States and higher than that of all other considered countries/regions.
- The number, as well as percentage of Saudi Arabian papers with industry collaboration in the area Energy and Industrials decreased between 2014 and 2023. This reflects that the efforts to increase research output did not focus on increasing in parallel, with the academic-corporate collaborations.
- Only 28% of Saudi Arabian papers with industry collaborations are performed with a local corporation. This has the advantage of gaining international visibility and expertise from international corporations. On the other hand, having more local corporations that collaborate with Saudi-affiliated researchers would further enhance local knowledge transfer and build local expertise.
- When investigating Saudi Arabia's performance in the research topics in the national priority area Energy and Industrials, we notice that out of the 37 research topics, there are 22 strength research topics, 12 opportunity research topics, two weakness research topics and one threat area. One should focus on increasing the research output in the opportunity areas, improving the research quality in the threat areas and improving both research output and quality in weakness areas.

3.1.1 Research volume analysis

The number of Saudi Arabian papers published in the national priority area of Energy and Industrials grew continuously from 621 papers in 2014 to 3816 papers in 2023, as shown in Figure 3. This reflects a double-digit growth for almost all years, for some years the growth rate was above 40%, and a much higher growth rate than the global rate in the same area. It is worth highlighting that although globally there was a negative growth rate between 2022 and 2023, in Saudi Arabia we still observe a double-digit growth rate of 13.3%.

In the considered period, Saudi Arabia had a yearly average growth rate not only three times the average global rate but also higher than all the other considered benchmark countries/regions, as shown in Figure 4. It is worth mentioning that this growth rate not only higher than countries with more almost saturated research output such as Japan, Germany and the USA, but also higher than that of countries/regions with growing research output such as Mainland China and the GCC, excluding Saudi Arabia. All the above indicates, the focus nationally of increasing the research activity in this national priority area.

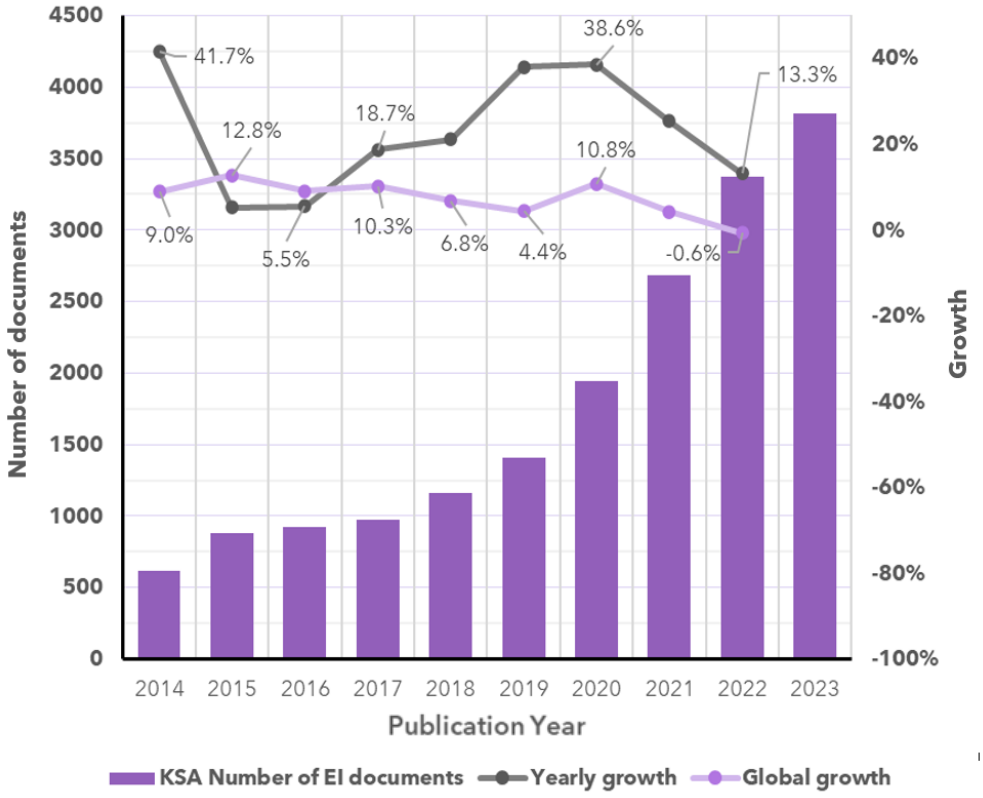


Figure 3: Saudi Arabia's number of papers and growth in the national priority area of Energy and Industrials

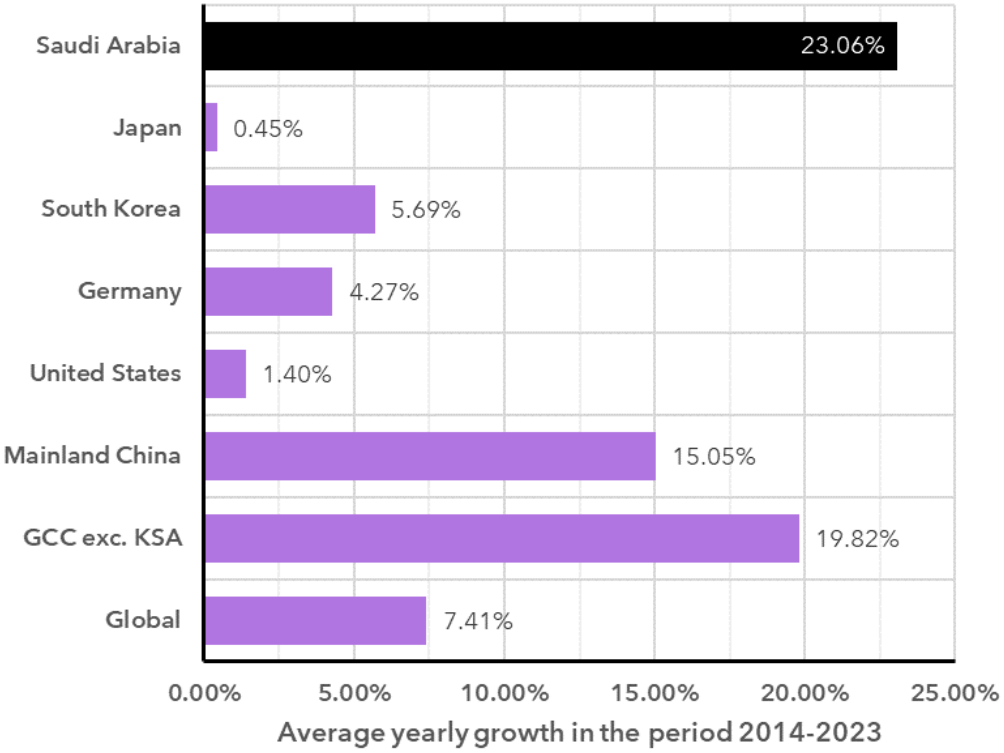


Figure 4: Average yearly growth of the number of papers in the area of Energy and Industrials in the period 2014-2023

3.1.2 Citation impact analysis

The category normalized citation impact (CNCI) of Saudi Arabia in the period 2014-2023 was always above 1.4, indicating a citation impact performance at least 40% higher than the global average, as shown in Figure 5.

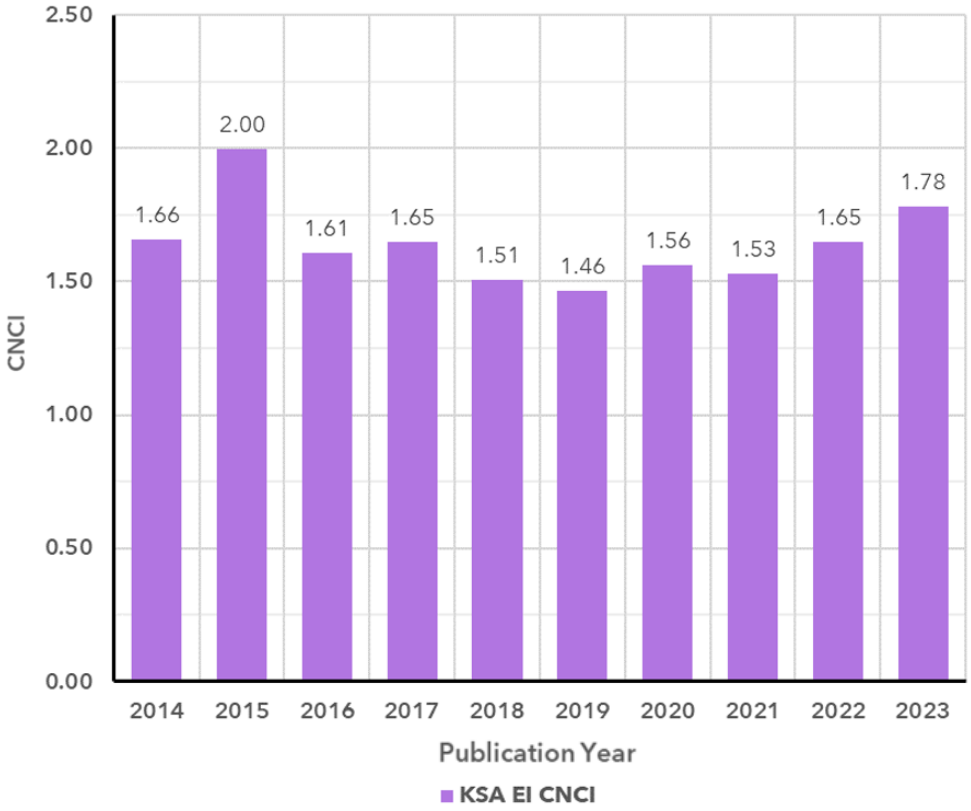


Figure 5: Saudi Arabia's yearly category normalized citation impact (CNCI) in the area of Energy and Industrials

The CNCI fluctuated slightly in this same period, between 1.46 and 2.0. Saudi Arabia also achieved a CNCI, in this period and in this area, on par with the USA and higher than that of all the considered benchmark countries/regions, as shown in Figure 6. This indicates a very high citation impact performance. It is also worth noting that the high citation impact footprint was maintained during a high research output growth period.

Usually, we notice citation impact decreases in periods with high volume growth because, during such periods, the expanded researcher base accumulates knowledge and expertise.

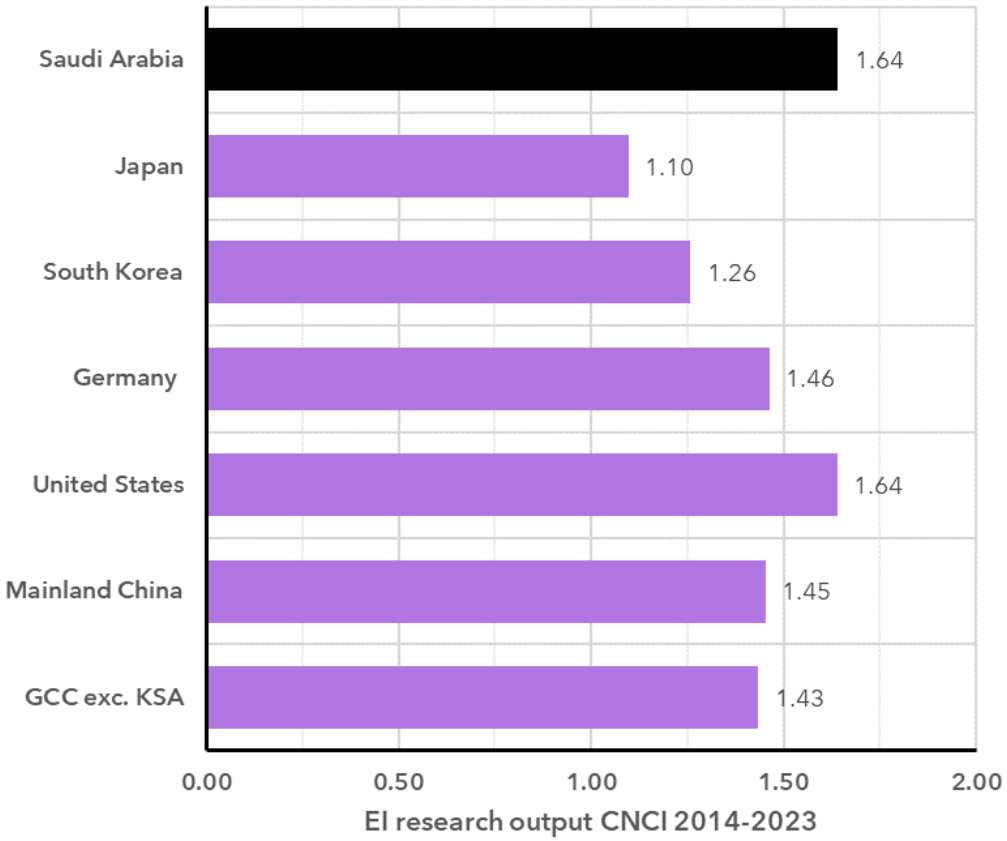


Figure 6: Energy and Industrials research output CNCI in the period 2014-2023

3.1.3 Funding dynamics analysis

The top 3 funding organizations mentioned in the funding text of Saudi Arabian publications in the area of Energy and Industrials in the period 2014-2023 are King Saud University, National Natural Science Foundation of China (NSFC) and King Abdullah University of Science & Technology with 1610, 1057 and 766 publications respectively as shown in Figure 7.

Research in collaboration with Saudi Arabia in the area Energy and Industrials, that was funded by National Basic Research Program of China, resulted in the highest citation impact measured by CNCI followed by National Key Research & Development Program of China and United States Department of Energy (DOE) with a CNCI of 4.8, 3.72 and 3.67 respectively.

The lowest CNCI is observed in papers funded by the Higher Education Commission of Pakistan, with a CNCI of 0.95, reflecting a performance of 5% lower than the global average. We observe that there are three funding organizations based in Saudi Arabia that are among the top 20. This reflects the ability of Saudi-affiliated researchers to attract international funding.

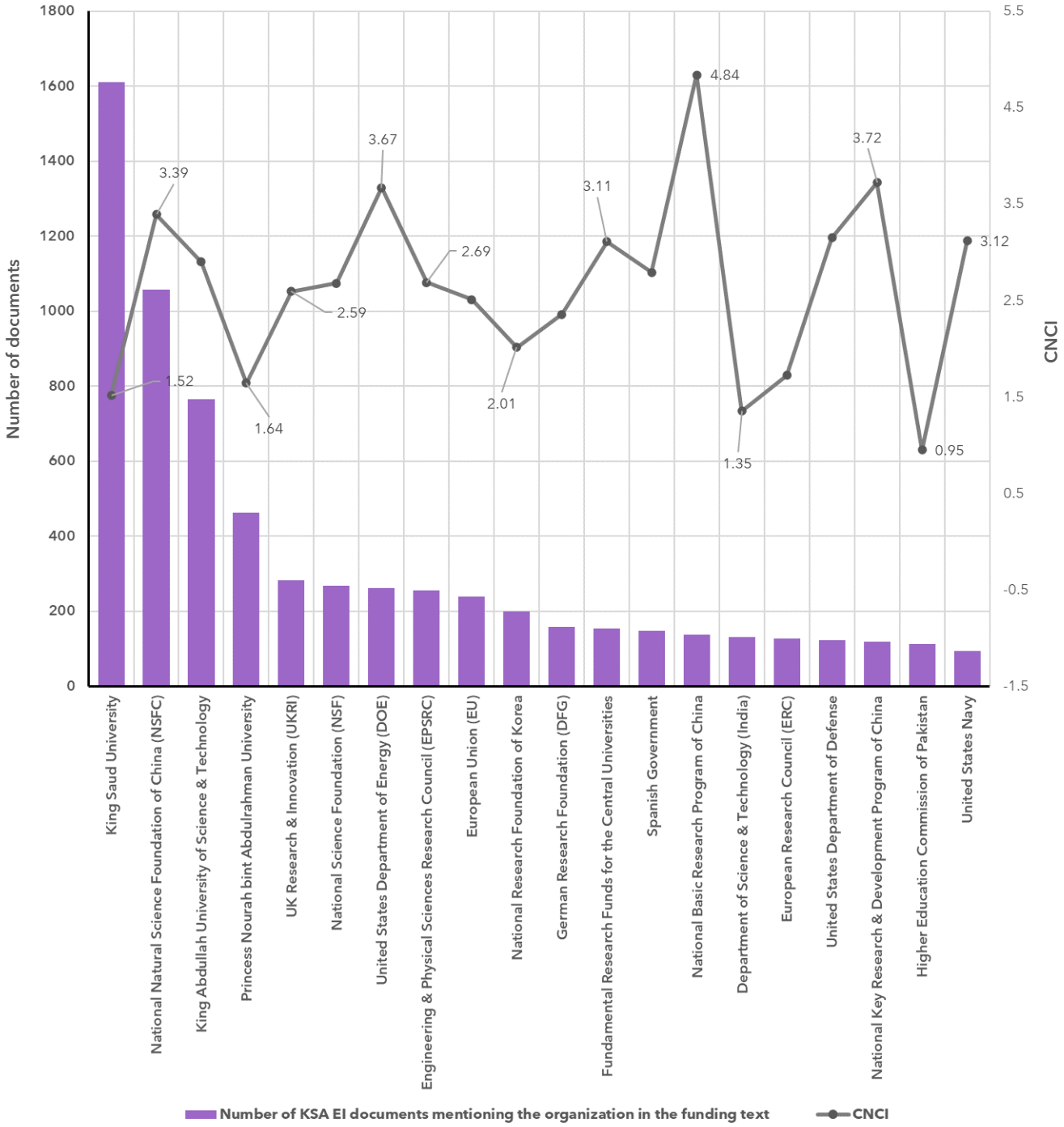


Figure 7: Top 20 funding organizations mentioned in the funding text of Saudi Arabian Energy and Industrials papers in the period 2014-2023

3.1.4 Collaboration dynamics analysis

Egypt, followed by Mainland China and India, had the highest number of publications in collaboration with Saudi Arabia-affiliated researchers in the national priority area Energy and Industrials in the period 2014-2023 with 3381, 2410 and 2323 publications, respectively, as shown in Figure 8. Regarding citation impact measured by the CNCI, papers in collaboration with Canada followed by Mainland China and Australia with a CNCI of 2.78, 2.68 and 2.33, respectively.

Nevertheless, research with all the top 20 collaborating countries with Saudi Arabia in this area resulted in a CNCI higher than the global average performance of ~1.

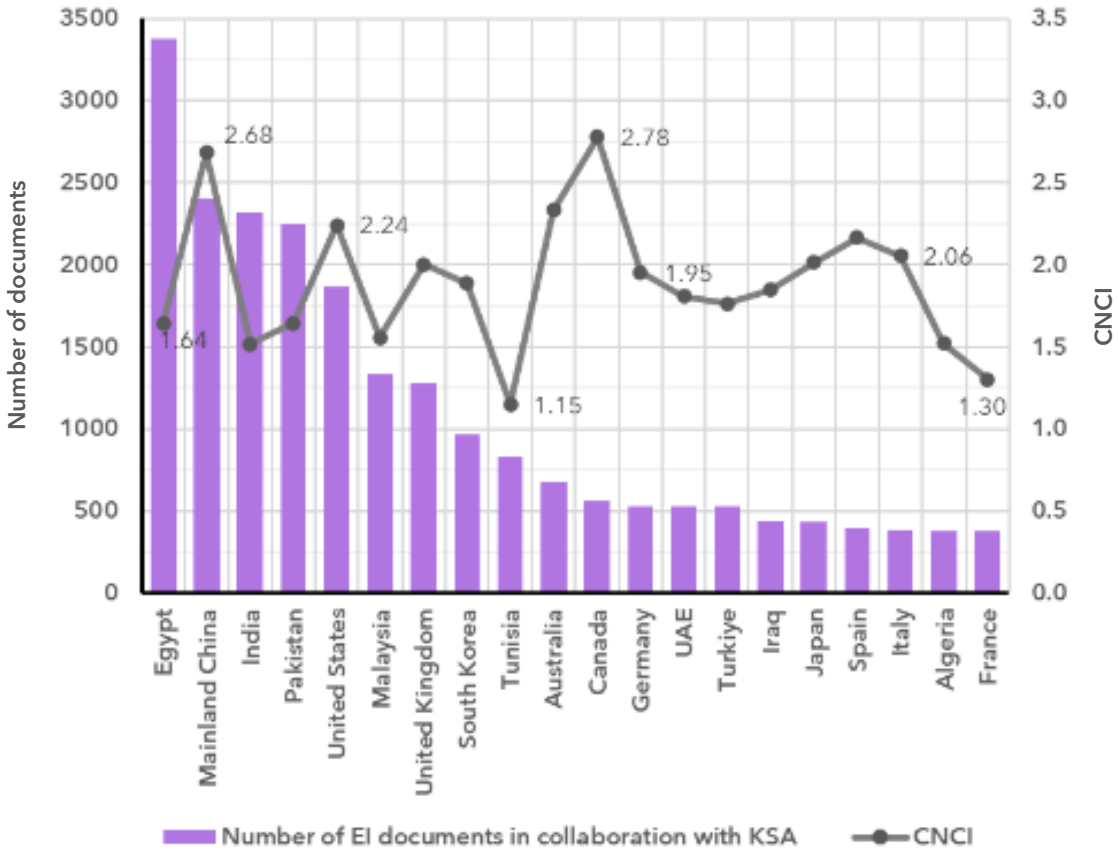


Figure 8: Top 20 collaborating countries with Saudi Arabia in the area of Energy and Industrials in the period 2014-2023

3.1.5 Academic-corporate collaboration in Saudi Arabia identified from research publications in the area of Energy and Industrials.

The percentage of Saudi Arabian papers with industry collaboration in the area of Energy and Industrials increased continuously from 2014 to 2016, reaching 4.5% to decrease afterward continuously to 0.7% in 2023, as shown in Figure 9. The number of Saudi Arabian papers in the area of Energy and Industrials with industry collaborations also increased between 2014-2016 and afterward decreased till 2019 and, since then, stayed constant with small fluctuations. The reason behind the decrease in the percentage of Saudi Arabian papers in the area of Energy and Industrials is that while overall Saudi Arabian research output in the priority area of Energy and Industrials was growing, the number of papers with industry collaborations was decreasing or stagnating.

One possible explanation for such dynamics is that the implemented efforts of increasing the research output in Energy and Industrials did not focus on increasing in parallel the academic-corporate collaborations via building on existing collaborations. Considering that this is a national priority area, one could consider deriving appropriate initiatives that could increase the percentage of industry collaborations in this area. One could leverage the increased research output in this area and, accordingly, the local expertise gained. Additionally, one could build on collaborations that happened in the past years and resulted in relatively high percentages of Saudi Arabian papers with industry collaborations in the area of Energy and Industrials.

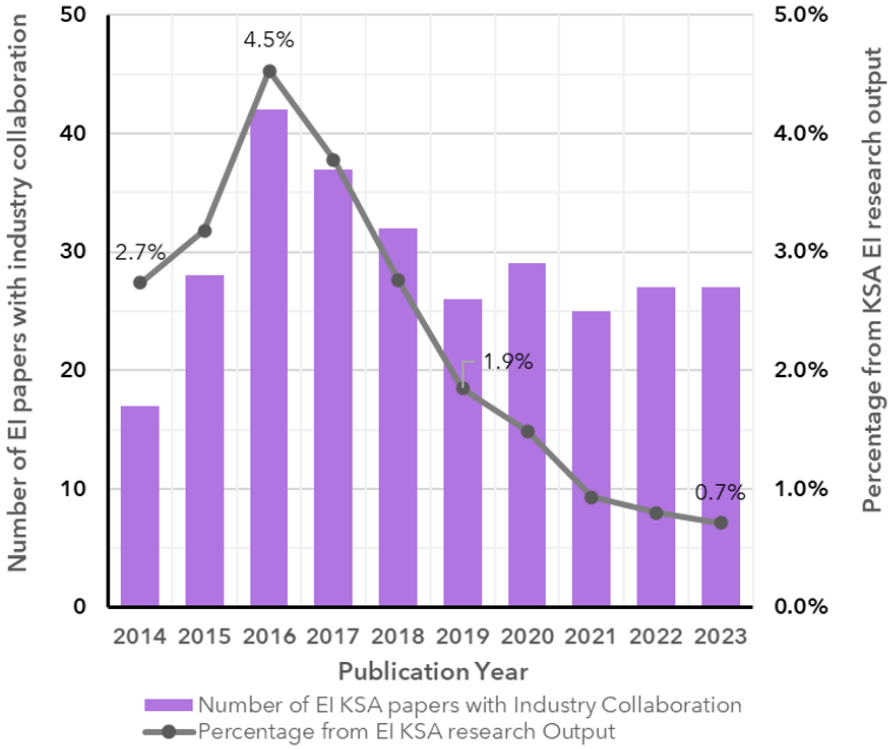


Figure 9: Number and percentage of Saudi Arabian publications that have been performed with an industry collaboration in the national priority area Energy and Industrials

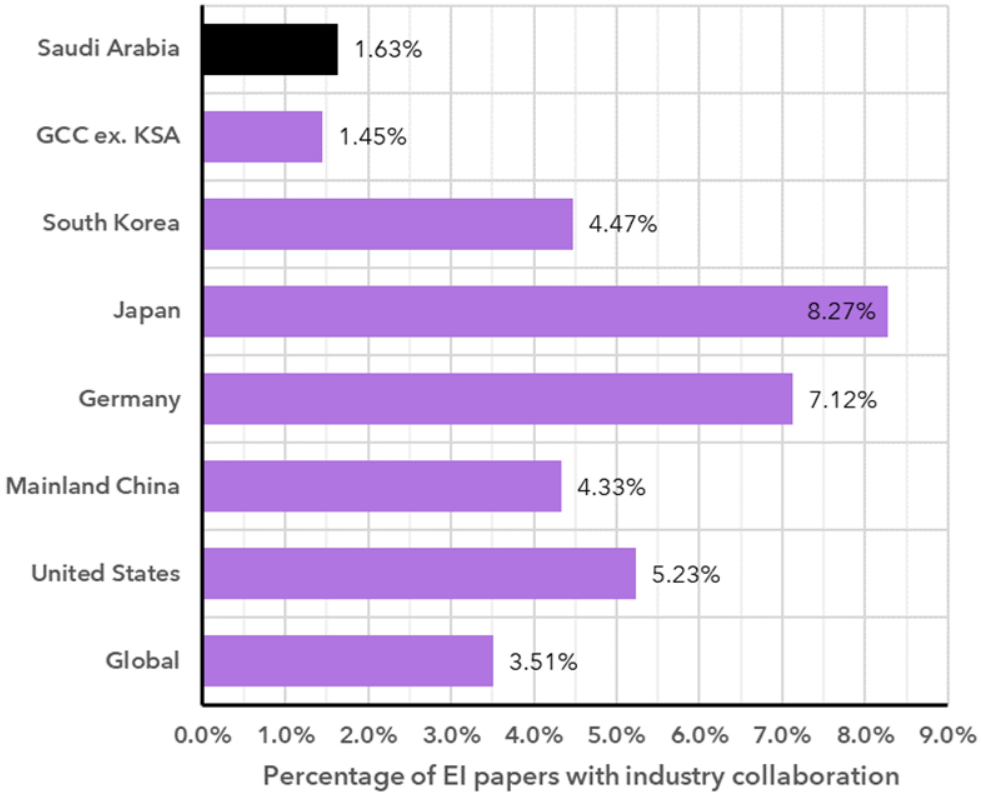


Figure 10: Percentage of papers that have been performed with and industry collaboration in the period 2014-2023 in the national priority area Energy and Industrials

When benchmarking the percentage of papers with industry collaborations in the area of Energy and Industrials in the period 2014-2023 of Saudi Arabia with the considered benchmark countries, we notice that it is lower than the global baseline

and then that of all considered countries/regions except GCC excluding Saudi Arabia as shown in Figure 10. The highest percentage of papers with industry collaborations among the considered countries/regions is observed in Japan with ~8.2% followed by Germany with 7.12% and USA with 5.23%. Considering that Energy and Industrials is a national priority area, as a first step achieving percentages of papers with industry collaborations close to the global baseline.

In Figure 11, the top 20 funding organizations of Saudi Arabian publications with industry collaborations in the area Energy and Industrials ranked by number of funded collaborations is shown. The top 3 funding organizations are the National Natural Science Foundation of China (NSFC), followed by the United States Department of Energy (DOE) and King Abdullah University of Science & Technology, with 27, 23 and 16 publications, respectively. Among the top 20 funding organizations, there is only one Saudi organization. Among the funding organizations, we notice two corporates, namely Huawei Technologies and Solvay SA.

We notice a domination of international funding organizations among the top 20. This shows the ability of Saudi affiliated researchers to attract international funding and/or collaborate with corporates in an international context.

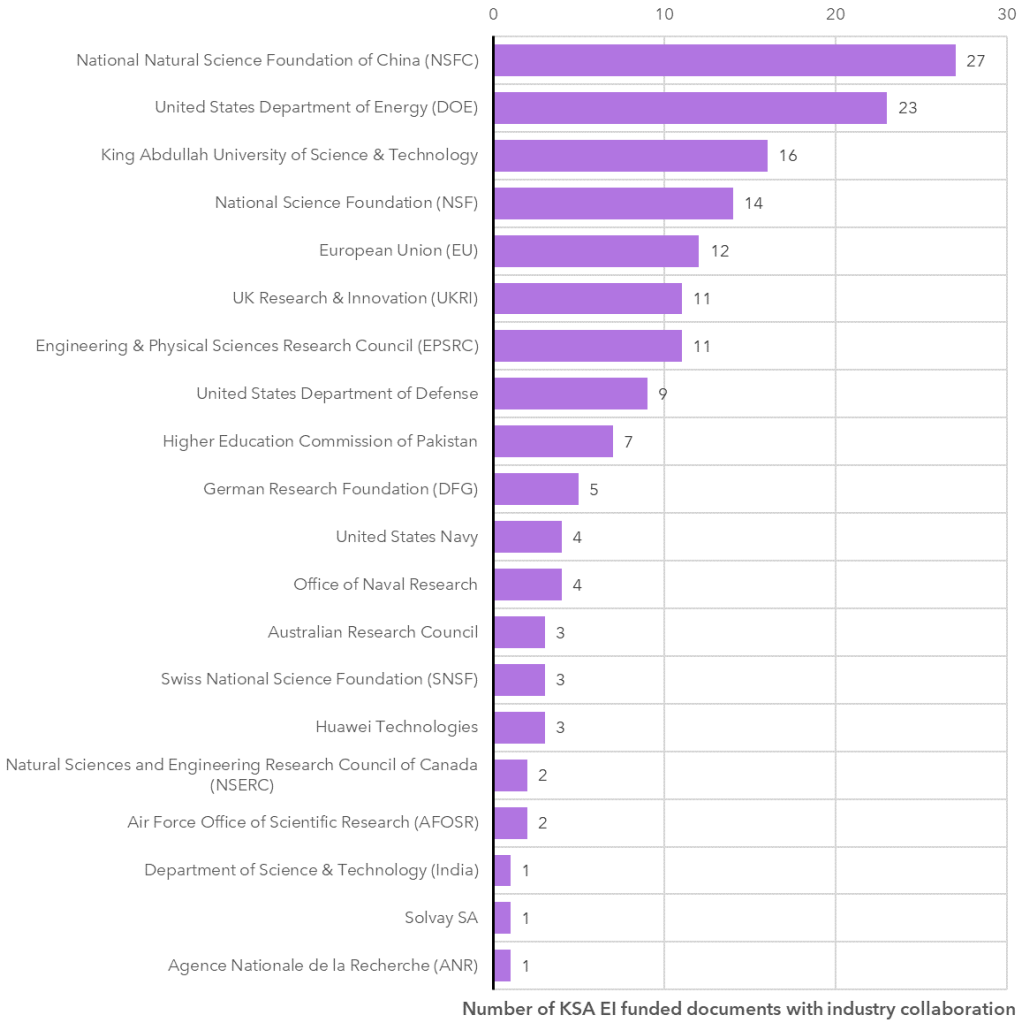


Figure 11: Saudi Arabia's top 20 funding organizations of research with industry collaboration in the national priority area Energy and Industrials in terms of the number of publications and in the period 2014-2023

In Figure 12, we investigate the top 40 corporations collaborating with Saudi Arabia-affiliated researchers in terms of a number of publications in the area of Energy and Industrials. Specifically, the share of a specific corporation from the overall Saudi Arabian publications in Energy and Industrials with industry collaborations is plotted on the y-axis. A logarithmic scale is used because of the significant difference between the top 3 and the rest of the corporates. On the x-axis, the CNCI of those

publications is plotted. Corporates that have a share above 1% of the overall Saudi Arabia papers with industry collaborations lie above the null on the y-axis. Corporates that have a CNCI above 1 lie right to the dotted line, marking a citation impact higher than the global average when considering the same document type, year of publication and subject area. Accordingly, all corporates lying in the upper quadrate are corporates that have more than 1% share of Saudi Arabian papers with industry collaborations and an impact performance higher than the global average measured by the CNCI. These corporates lie in the upper quadrate, and their output is listed in Table 1. As these corporates have a relatively high share of Saudi Arabia's overall publications with industry collaborations, and their impact is higher than the global average, there is an opportunity to further develop these collaborations into partnerships. Here, it is important as well to consider other criteria, such as alignment with national priorities and goals of the partnerships.

The top three corporates collaborating with Saudi affiliated researchers in the period 2014-2023 in the area of Energy and Industrials are Saudi Basic Industries Corporation (SABIC) followed by Polyera, Aramco Services Company (ASC) and Swiss Center for Electronics & Microtechnology (CSEM) sharing the same number of publications followed by State Grid Corporation of China sharing the same number of publications with Huawei Technologies with ~22%, ~4.1% and ~3.4% from the overall Saudi Arabian publications with industry collaborations in Energy and Industrials. Among the top three, there are two national corporates. Having two local corporations among the top three is important to ensure local knowledge transfer.

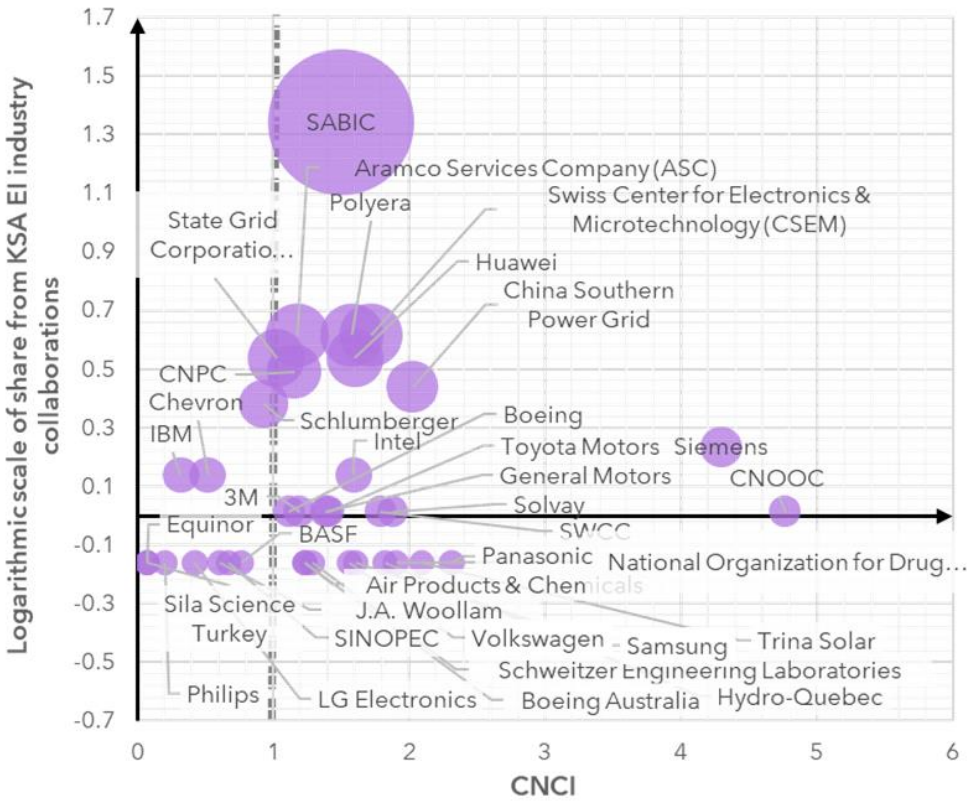


Figure 12: Top 40 corporates that have paper collaborations with Saudi affiliated researchers in terms of the number of papers in the period 2014-2023 in the area of Energy and Industrials. The figure plots the share of papers with industry collaboration in the area of Energy and Industrials in a logarithmic scale that an organization has versus the CNCI.

Though among the top 40, there are only three local corporations, and the others are international ones. 72% of Saudi Arabia Energy and Industrials papers with an industry collaboration are performed with an international corporation as seen in Figure 13. Having more local corporations that collaborate with Saudi affiliated researchers would further enhance local knowledge transfer and building local expertise.

Table 1: Corporates having at least 1% share from Saudi papers with industry collaboration in the area of Energy and Industrials and have at least an impact on par with the global average (CNCI 1 or above)

Corporate	Number of papers	Share	CNCI
Saudi Basic Industries Corporation (SABIC)	64	22.07%	1.50
Polyera	12	4.14%	1.58
Aramco Services Company (ASC)	12	4.14%	1.18
Swiss Center for Electronics & Microtechnology (CSEM)	12	4.14%	1.72
State Grid Corporation of China	10	3.45%	1.02
Huawei Technologies	10	3.45%	1.60
China National Petroleum Corporation	9	3.10%	1.15
China Southern Power Grid	8	2.76%	2.02
Siemens AG	5	1.72%	4.30
Intel Corporation	4	1.38%	1.59
3M	3	1.03%	1.19
Boeing	3	1.03%	1.11
General Motors	3	1.03%	1.39
China National Offshore Oil Corporation (CNOOC)	3	1.03%	4.77
Solvay SA	3	1.03%	1.88
Saline Water Conversion Corporation (SWCC)	3	1.03%	1.79
Toyota Motor Corporation	3	1.03%	1.41

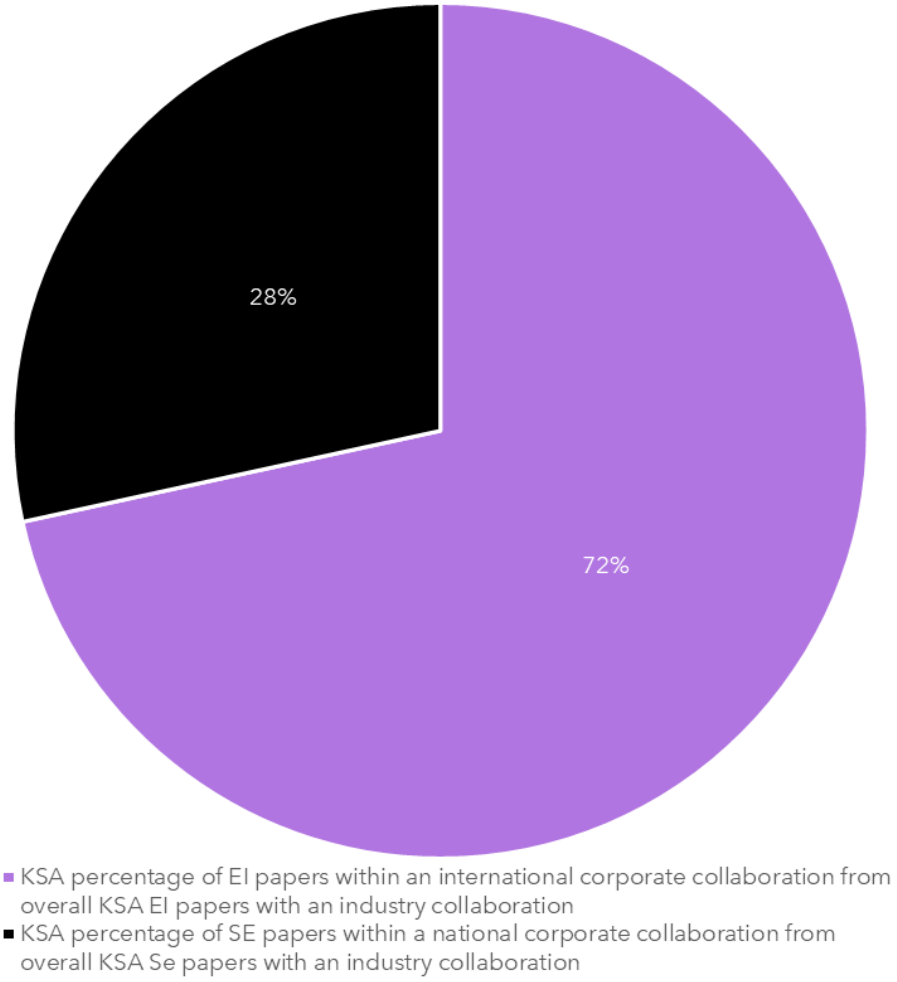


Figure 13: Percentage of Saudi Arabia Energy and Industrials papers with an industry collaboration with national versus international corporates from overall papers with an industry collaboration

3.1.6 SWOT Analysis of Underlying Research Topics in the Area Energy and Industrials

In this part, we have a more granular look by analyzing the research performance of Saudi Arabia in the underlying categories that constitute the national priority area of Energy and Industrials. To achieve this, we perform a Strength, Weakness, Opportunity and Threat (SWOT) analysis.

The analysis is based on two main metrics: productivity relative to the global productivity and impact measured by the category normalized citation impact. The productivity relative to global productivity is measured by the number of Saudi Arabian papers in a specific research topic divided by the number of global publications in the same research topic and period.

This is then normalized by the share of Saudi Arabia's overall research from the global research in the same period. Thus, a value in this indicator above 1 indicates that Saudi Arabia has a share of the global research in this research topic higher than the share of Saudi Arabia from the global research in the same period.

Similarly, a CNCI above 1 indicates a citation impact footprint in the research topic higher than that of the global average. Accordingly, we can classify the research topics into four regions:

- Strength: Productivity relative to global productivity is above 1, and the CNCI is above 1
- Threat: Productivity relative to the global productivity is above 1 and CNCI less than one

- Opportunity: Productivity relative to global productivity is less than 1, but CNCI is above 1
- Weakness: both the productivity relative to the global productivity and CNCI are less than 1

When investigating Saudi Arabia's performance in the research topics in the national priority area Energy and Industrials, we notice that out of the 37 research topics, there are 22 strength research topics listed in Table 2, 12 opportunity research topics listed in Table 3, two weakness research topics listed in Table 4 and one threat area, as shown in Table 5 as also shown in Figure 14.

As all these research topics are of national priority, one should try to conserve the high performance in the strength research topics, increase the productivity in the opportunity areas by leveraging on the gained expertise that is evident with the CNCI being higher than 1, improve the quality and accordingly the citation impact in the threat areas as well as increase the citation impact and productivity in the weakness research topics.

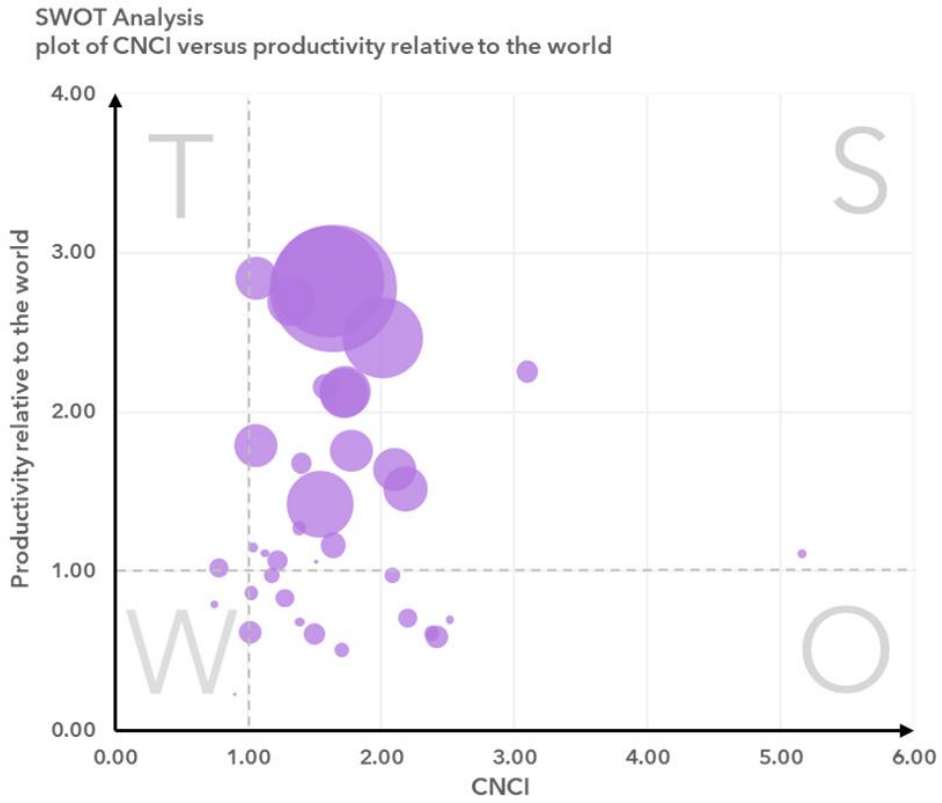


Figure 14: SWOT analysis of the national priority area Energy and Industrials. The y-axis shows the productivity relative to the world (share of Saudi Arabia from the global productivity in the research topic normalized by Saudi Arabia's share of global productivity when considering overall research). The x-axis shows the impact relative to the global average.

Table 2: Saudi Arabia's "strength" research topics in the national priority area of Energy and Industrials

Research topic	CNCI	Productivity relative to global productivity
PV Modules	1.64	2.78
Solar Farms	1.60	2.82
Hydrogen Production	2.01	2.47
Wind Turbines	1.54	1.42
Grid Integration	1.73	2.13
Smart Grids	1.72	2.12
COTC Products	1.32	2.69
Lithium-Sulphur Battery	2.18	1.52
Hydrogen Storage and Transportation	1.78	1.76
Intelligent Manufacturing	2.10	1.64
COTC Processes	1.06	1.79
Oil Reuse	1.06	2.84
Rare-Earth Use	1.59	2.16
Battery Management	1.64	1.16
Energy from Ammonia	3.10	2.25
Mining Automation Software	1.22	1.07
Sustainable Mining Waste Management	1.40	1.68
Autonomous Mining - Smart Drilling	1.38	1.27
Bladeless Wind Turbines	1.04	1.15
Rare-Earth Recovery	5.16	1.11
Smart HVAC	1.13	1.11
Sodium-Sulphur Battery	1.51	1.06

Table 3: Saudi Arabia's "opportunity" research topics in the national priority area of Energy and Industrials

Research topic	CNCI	Productivity relative to global productivity
Industry Predictive maintenance	1.01	0.62
Solid State Battery	2.42	0.59
Tidal/Wave Energy	1.50	0.61
Sodium Ion Battery	2.20	0.71

Autonomous Mining - Remotely Operated Equipment	1.27	0.83
Industrial Emissions	2.08	0.98
Vehicle Emissions	1.18	0.98
Digital Twins	2.38	0.61
Industrial Robots	1.70	0.51
Small Modular Nuclear Reactor (SMR)	1.03	0.86
Sustainable Mining - Water Conservation	1.39	0.68
Sustainable Mining - Low Emissions	2.52	0.69

Table 4: Saudi Arabia's "weakness" research topics in the national priority area of Energy and Industrials

Research topic	CNCI	Productivity relative to global productivity
Autonomous Mining - Self-driving Vehicles	0.75	0.79
Construction Robots	0.90	0.23

Table 5: Saudi Arabia's "threat" research topics in the national priority area of Energy and Industrials

Research topic	CNCI	Productivity relative to global productivity
Production Planning & Lean Manufacture	0.78	1.02

3.2 Overview of performance in patents

In this section, we summarize all datan collated during the study Assessment of Academic-Corporate Partnerships in Saudi Arabia of the program that are specific to the Energy and Industrials National Priority.

This section is related to the benchmarking of invention volumes, strength and Academic-Corporate Partnerships in Saudi Arabia against globally relevant comparison.

3.2.1 Percentage of academic-corporate invention activity

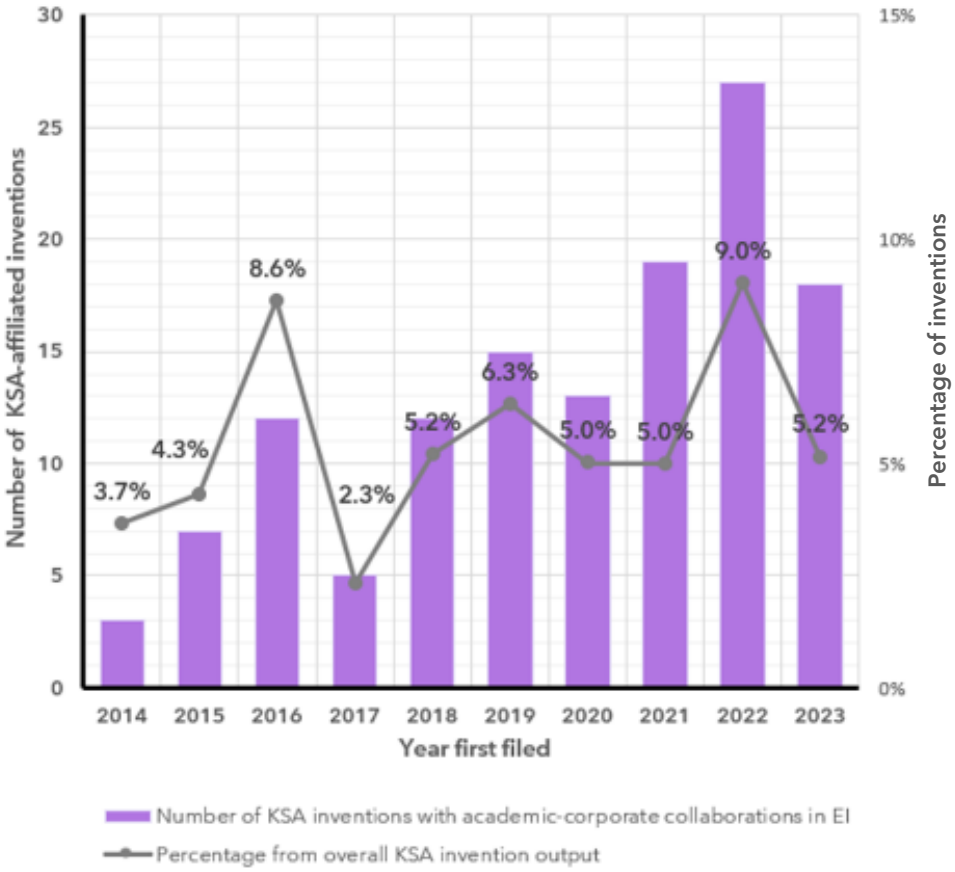


Figure 15: Timeline and trend of Saudi Arabia-affiliated inventions with industry collaboration in Energy and Industrias, 2014–2023

Energy and Industrials in Saudi Arabia have consistently been the largest in terms of absolute invention volume, with Saudi Arabian-affiliated inventions growing 4x from 82 in 2014 to 349 in 2023. This reflects a commitment to leveraging petrochemical capabilities and ongoing industrialization.

These capabilities are established, and hence, the proportion of academic-corporate partnerships has remained relatively stable at around 5% of overall activity (Figure 15). However, there is a notable exception in 2022, when activity peaked at 9% before dropping back to 5.2% in 2023, a sign of some fluctuation despite steady invention growth. Stable but moderate levels of collaboration in the Kingdom suggest that while partnerships are integral to energy-related innovation, they are not growing at the same pace as total invention output.

Energy and Industrials trends towards mature on the maturity index, suggesting that the state of innovation throughput is developed and possibly less partnership dependent.

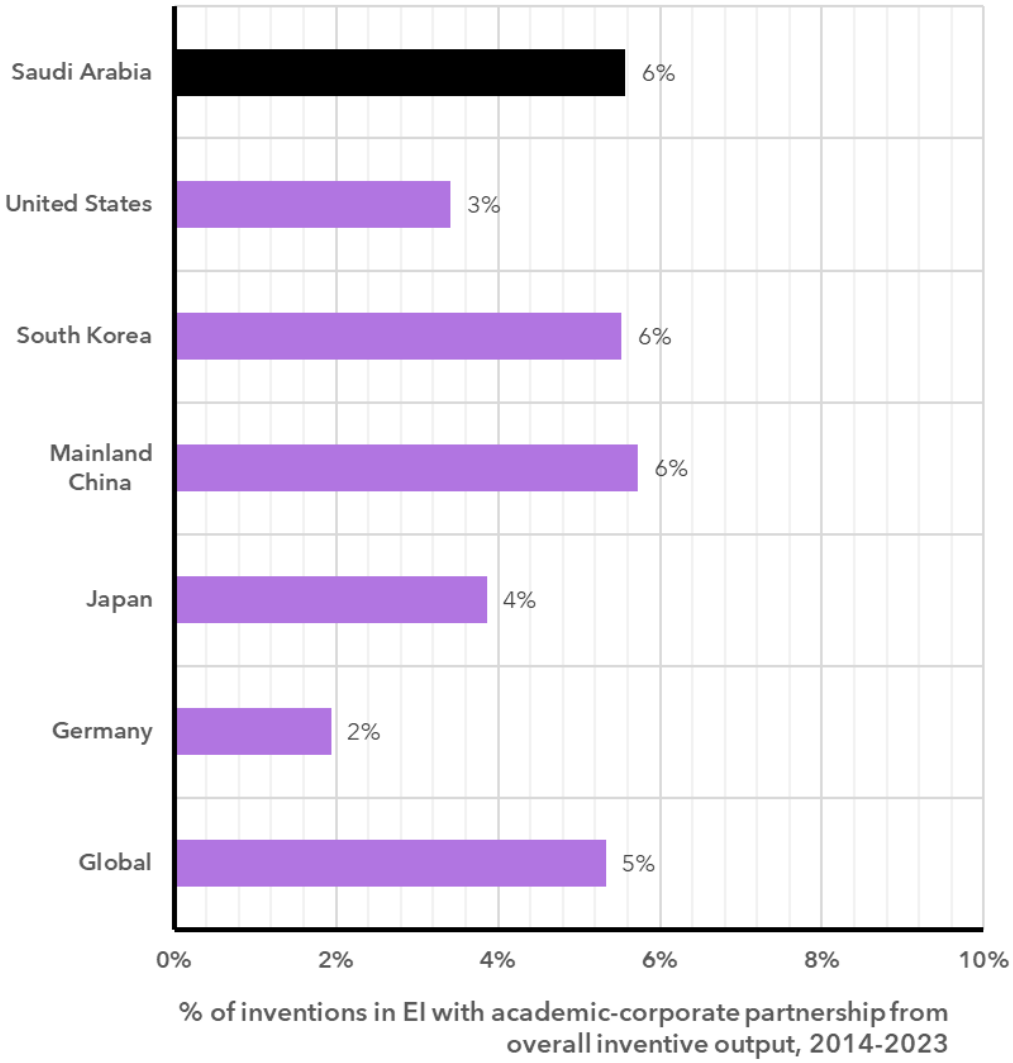


Figure 16: Academic and industry collaboration in inventions in Energy and Industrials by major countries, compared to global baseline, 2014–2023

In Energy and Industrials, more than 5% of Saudi Arabia's invention activity (2013-2024) comes from academic-corporate partnerships, on par with Mainland China and South Korea, both surpassing the global benchmark of ~5% (Figure 16).

This high level of collaboration underscores Saudi Arabia's focus on energy innovation, a key sector for the country's long-term development. In contrast (Figure 16), Germany shows only ~2% of patent activity from partnerships, suggesting a more self-reliant or mature industrial approach. The United States and Japan also lag with ~3% and ~4%, respectively, despite their significant patent outputs. Saudi Arabia's ability to foster partnerships at a rate that compares favorably with larger economies demonstrates the country's commitment to innovation in the energy and industrials sectors.

Despite being Saudi Arabia's most established capability, Energy and Industrials has still experienced growth, with output increasing fourfold (2014-2024). The continued expansion reflects Saudi Arabia's industrialization efforts.

Overall, academic-corporate partnerships in Energy and Industrials have remained relatively stable, accounting for around 5% of overall activity, with a peak of 9% in 2022. This indicates that while partnerships play a role in energy innovation, the sector is mature and perhaps less dependent on collaboration for growth. Globally,

Saudi Arabia's ~5% partnership rate in Energy and Industrials aligns with Mainland China and South Korea, both of which surpass the global benchmark. This strong collaboration contrasts with Germany, the US, and Japan, where partnerships constitute only 2-4% of invention activity despite higher patent volumes. Saudi Arabia's robust partnership engagement, combined with a developed innovation ecosystem in Energy and Industrials, highlights its strategic focus on maintaining leadership in this critical sector.

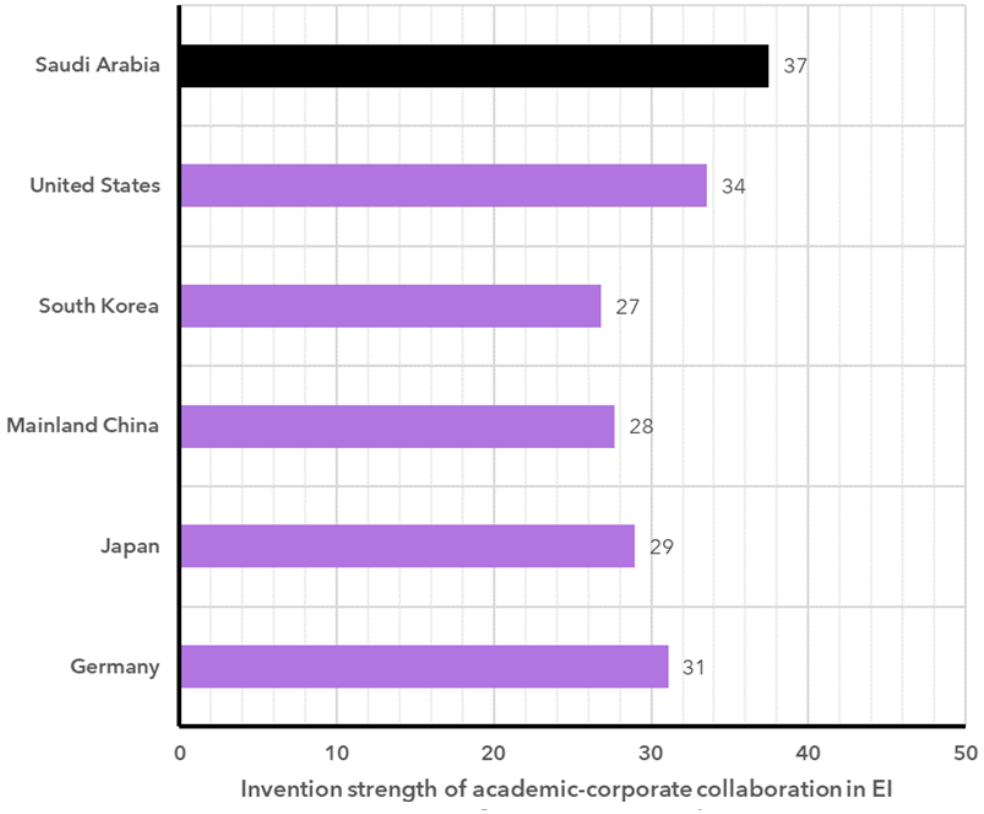


Figure 17: Strength of academic and industry collaboration inventions in Energy and Industrials by major countries, 2014–2023

Saudi Arabia outpaces peer nations in Energy and Industrials invention strength, highlighting the quality and impact of academic-corporate partnerships in this domain as shown in Figure 17. The United States follows closely, reflecting Saudi Arabia's continued strength in energy-related innovation, which positions it ahead of global benchmarks. Despite China's vast patent output, its lower invention strength highlights the higher quality of Saudi Arabia's collaborations. This strong, inventive performance suggests that Saudi Arabia is well-positioned to continue leading in energy innovation, particularly as it builds on its well-established industrial base.

3.2.2 Invention impact analysis

In Energy and Industrials, Saudi Arabia has a clear advantage in invention strength, outpacing key global competitors like the United States and Germany, as shown in Figure 18. This strong, inventive performance reflects the high quality of Saudi Arabia's Academic-Corporate Partnerships, notably driven by Saudi Aramco and KAUST, which have consistently positioned the Kingdom at the forefront of energy innovation.

While Mainland China demonstrates a vast patent output, it lags in invention strength. The United States, with a more balanced approach, follows closely behind Saudi Arabia in invention strength.

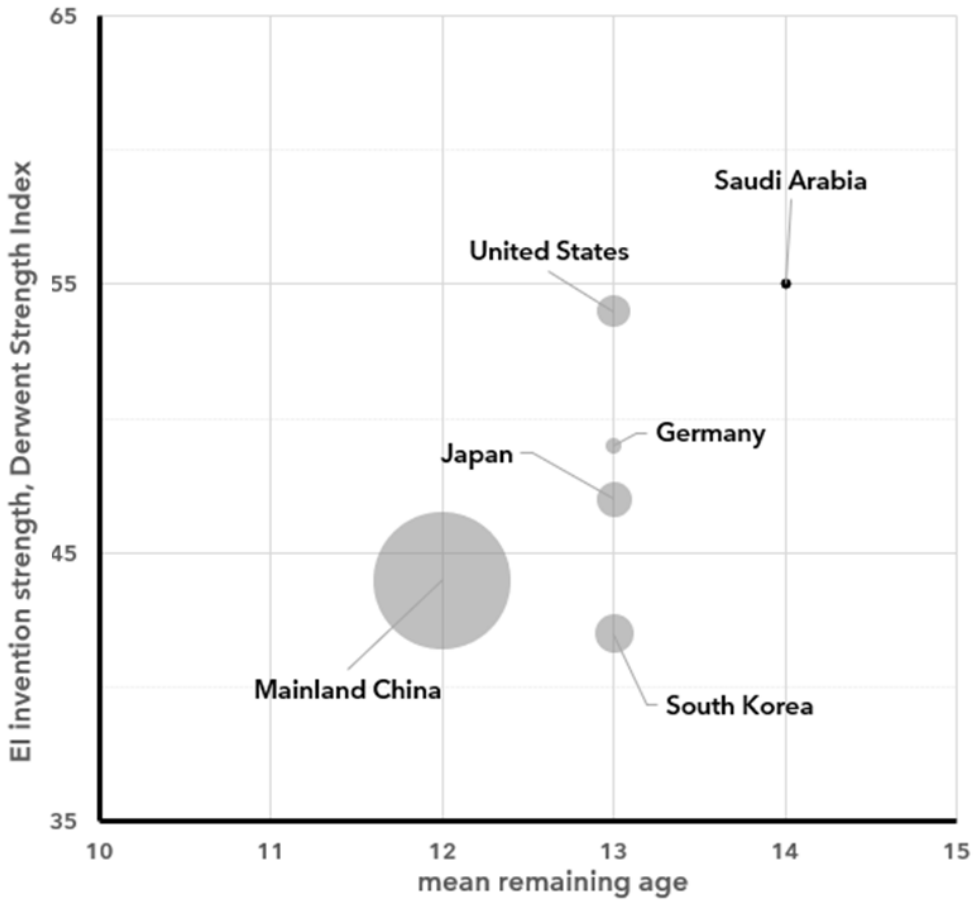


Figure 18: Invention strength dynamics of academic and industry collaboration in Energy and Industrials by major countries and Saudi Arabia, 2014–2023

As anticipated, Saudi Aramco leads in academic-corporate partnerships, demonstrating the highest volume of collaborations and a robust invention strength (DSI of 57.4), as shown in Figure 19. These partnerships, built on slightly older capabilities, reinforce Aramco's crucial role in driving innovation within the sector. KAUST and KFUPM, two top academic institutions, also make significant contributions, with invention strength scores approaching 60.

These collaborations tend to revolve around moderately mature technologies. Although not represented in the primary data visualization, an example from the emerging Saudi start-up scene, is the Saudi start-up NOMADD (Non-Mechanical Autonomous Dusting Devices). NOMADD has demonstrated an impressive invention strength of over 70.

NOMADD has a long-term partnership with KAUST and has filed patents related to solar panel maintenance, highlighting innovation in energy management and efficiency. NOMADD Overall, academic-corporate partnerships in the Energy and Industrials area reflect a blend of legacy strengths and future-focused capabilities.

The involvement of global partners such as KAERI (Korea Atomic Energy Research Institute) and CSIC (Spain) underlines Saudi Arabia's strategy of leveraging international expertise while continuing to build on its established energy leadership.

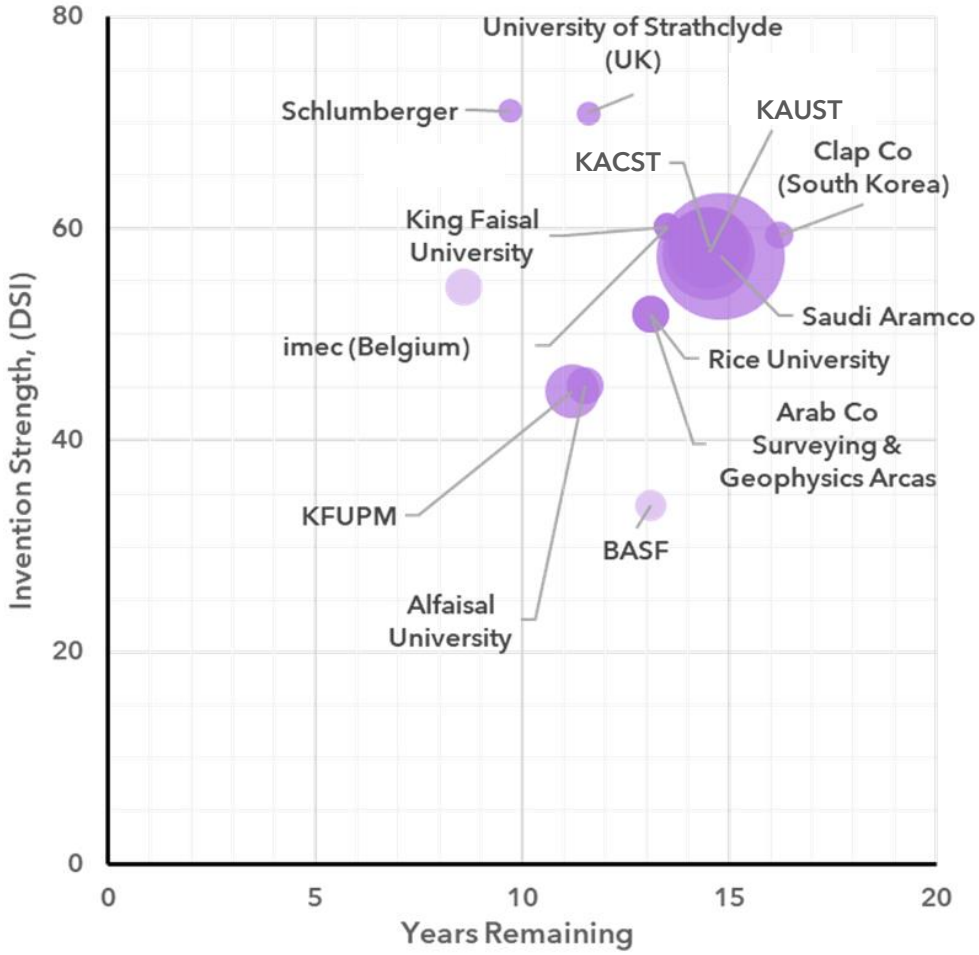


Figure 19: Invention strength dynamic of top collaborating entities in Saudi Arabia in Energy and Industrials, 2014–2023

3.3 Overview of technology maturity, readiness and commercialization

In this section, we summarize and review information collated within the Accelerating Technology Transfer from the Lab to the Market in Saudi Arabia study, focused specifically to the Energy and Industrials national priority area.

This analysis focuses on the invention levels globally and in Saudi Arabia due to the strong link between research and commercial activity inherent to the patent process, as well as the role of patent protection in the ownership and usage of technology in commercial contracts and processes.

Inherent to this analysis is a review of several key measures:

1. The evaluation of the overall technical maturity of research (on a scale of basic theory through to full market commercialization) within a specific research topic.
2. Evaluation of Saudi Arabian research commercialization activity within the National Priority, as compared to global levels. This also includes an assessment of the current depth and strength of invention levels currently occurring within the Saudi Research & Innovation ecosystem.
3. The future commercial potential of individual research topics within the National Priority Area

Using these criteria, we can describe the dynamics of research within Energy and Industrials, how it meets commercial application, where Saudi Arabia contributes today, and how future research funding policy in the National Priority can be tailored to these dynamics.

At a global level (Figure 20), Energy and Industrials research topics sit second-most mature of the four National Priorities. Like Health & Wellness and Sustainability and Essential Needs, no research topics in the National Priority sit at the very earliest TRL levels of 1-2.

Notably, there is also no research category at the most mature TRL 9. Areas of maturity in the priority include wind and solar renewable research themes, and crude-oil-to-chemical products and processes. More immature research areas include Industry 4.0 topics such as digital twins and intelligence manufacture, as well as the development of small modular reactors in the nuclear energy sector.

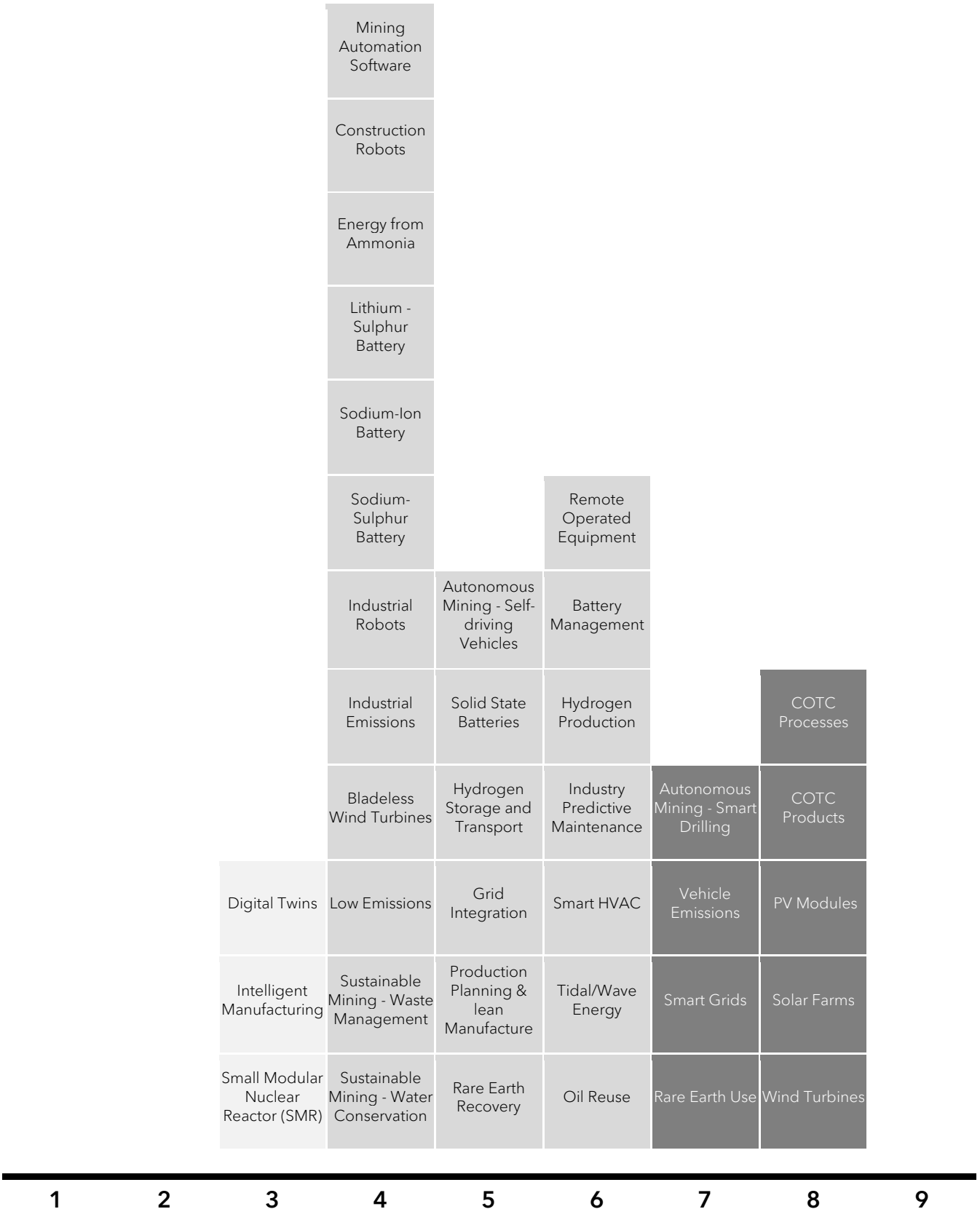


Figure 20: Technology Maturity Index result for research topics within the Energy & Industrial Leadership National Priority Area; vertical axis represents count of categories in each tier

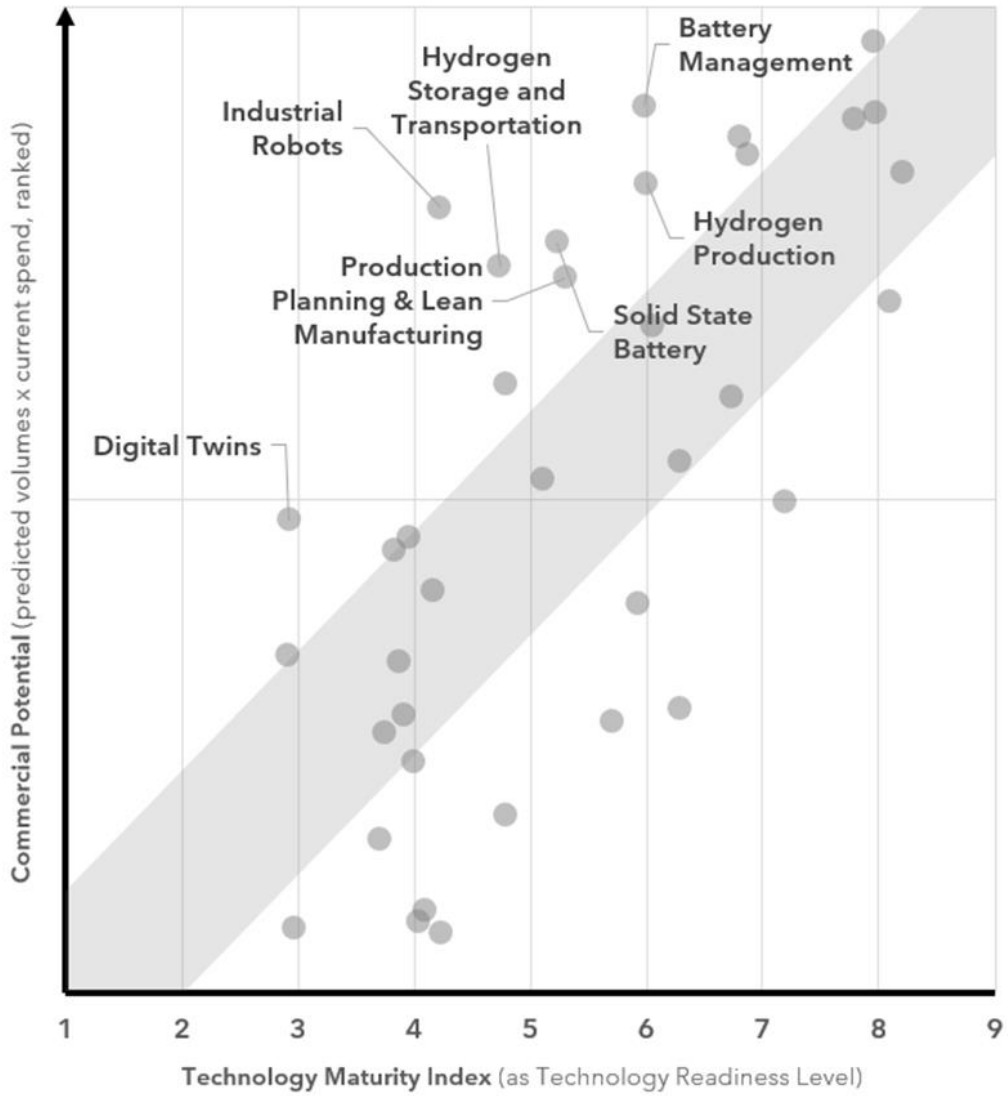


Figure 21: scatterplot of Technology Maturity Index for each research topic (represented on a technology readiness scale) and commercial potential (a ranked axis based on the future predicted invention volumes in each topic, multiplied by the current relative level of investment In Intellectual property protection)

Also shown in the analysis (Figure 21), and a profile that is exhibited in all four National Priorities, is a strong relationship between the future commercial potential of the research topics and their evaluated TRL maturity. This is, to a degree, inherent in the modeling of technology maturity itself and, therefore, an expected result.

Within the energy and industrials priority, several topics break out from this general trend of potential mapping to maturity, a position which suggests a high level of commercial need or desire for a solution but exhibits a current lack of applied research needed to ensure the technology is applicable in a commercial setting. These include:

- Digital twins
- Industrial robots
- Hydrogen storage and transportation, as well as hydrogen production itself.
- Solid state battery technology and general battery management
- In the manufacturing sector, production planning and lean technologies.

Moving to Saudi Arabian applied research within the Energy and Industrials sector, a review of predicted commercial potential versus the depth of Saudi invention levels shows a correlation, but with significant variation (Figure 22). While the Saudi research and innovation ecosystem tends to focus on research topics that are also

more likely to be in demand in future years, there are areas where this relationship is weaker.

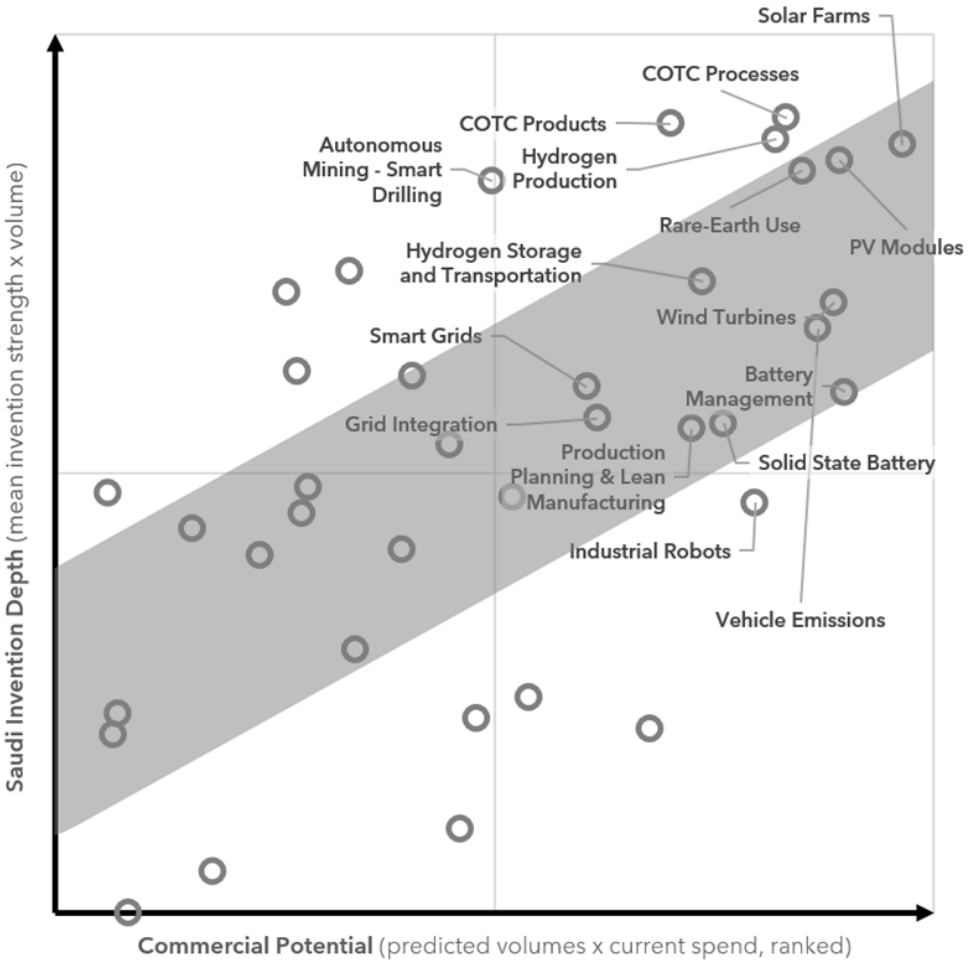


Figure 22: views Energy and Industrials research topics arrayed by the level of Saudi Arabian research strength and depth vs the commercial potential of the research topic; high potential/high invention depth topics are labeled

The very highest commercial potential fields in Energy and Industrials surround renewables (solar and wind), potentially related battery technologies (battery management and solid-state energy storage. Of these only solar farms and photovoltaic modules are also major areas of Saudi Arabian invention strength.

The highest area of Saudi Arabian invention depth (measured as a combined measure of both the volume of inventions and their relative strength) occurs within the COTC products and processes categories. The high commercial strength of the Saudi Arabian economy in the oil and gas sector is strongly exhibited in the invention strength and depth characteristics that align with that sector in the National Priorities. To a degree, this energy sector expertise is also shown in other areas of priority, such as a high focus on smart drilling and hydrogen production.

Further summarising the commercialization directions potentially available to the Saudi research ecosystem, an analysis was performed using the Technology Maturity/Technology Readiness spectrum against a hybrid metric that combines various factors of recommendation for Saudi Arabia.

Performed as a topic recommendation score, this metric combines the predicted commercial potential measured across the topics, the depth of Saudi Arabian research today, the level of academic-corporate partnership exhibited to date from Saudi Arabian activity and finally, a check of expert opinion across the research topics.

Arraying the topic recommendation against TRL levels provides a good decision matric surrounding modes of research intervention (Figure 23).

For example, areas of low-level recommendation for Saudi Arabia, regardless of TRL level, can be de-prioritized for either ad hoc academic research selection or, if already highly mature, for the private sector to choose to intervene.

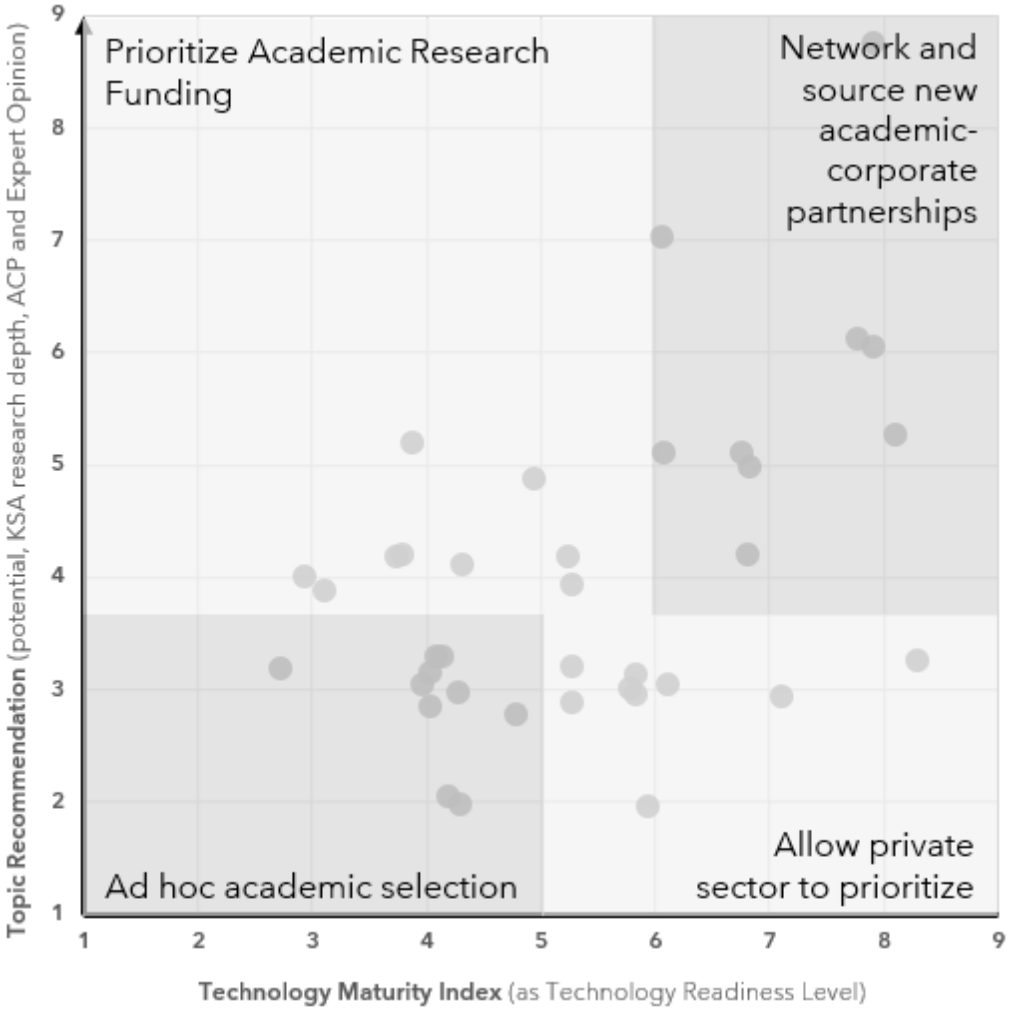


Figure 23: summary scatterplot view of the Part 3 recommendations of research topics based on the commercial potential measure, the depth of research within Saudi Arabia, the level of academic/corporate potential, and the views of RDIA experts for interest/impact; all arrayed on the Technology Maturity Index spectrum; limited to the Energy and Industrials National Priority

Where research topics already exhibit a track record of applied research intensity in Saudi Arabia, the TRL spread can be used to recommend either the prioritization of further academic research (for more immature topics, where research is needed to transition to more maturity), or where occurring in more mature fields, the transfer of Saudi academic research to the private sector should be strengthened.

This view is summarised for the Energy and Industrials national priority and highlights:

1. Within earlier TRLs (Figure 24), a focus on applied research in hydrogen technologies (both production and storage/transport), smart drilling and waste management in industrial settings, as well as battery management technologies.
2. Within higher TRL areas (Figure 25), where the commercialization of existing research pathways should be prioritised via further partnership by Saudi Arabian academic researchers with private enterprise: solar farm technologies, as well as toa lesser degree photovoltaic modules. Finally, the

strength of Saudi Arabia in the oil and gas sector should be used as an opportunity within COTC products and processes research area.

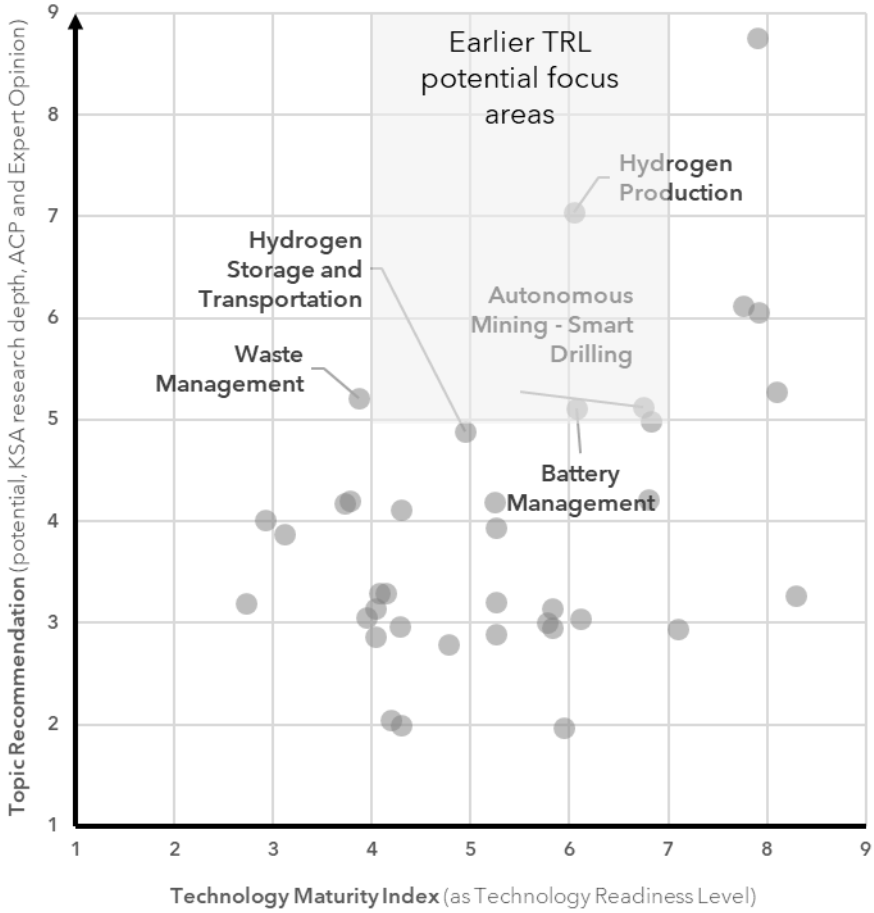


Figure 24: scatterplot of Technical Maturity Index versus Topic Recommendation in the Energy and Industrials National Priority, annotation for research topics categories of >5 in recommendation and sitting in TRLs 4 - 7.

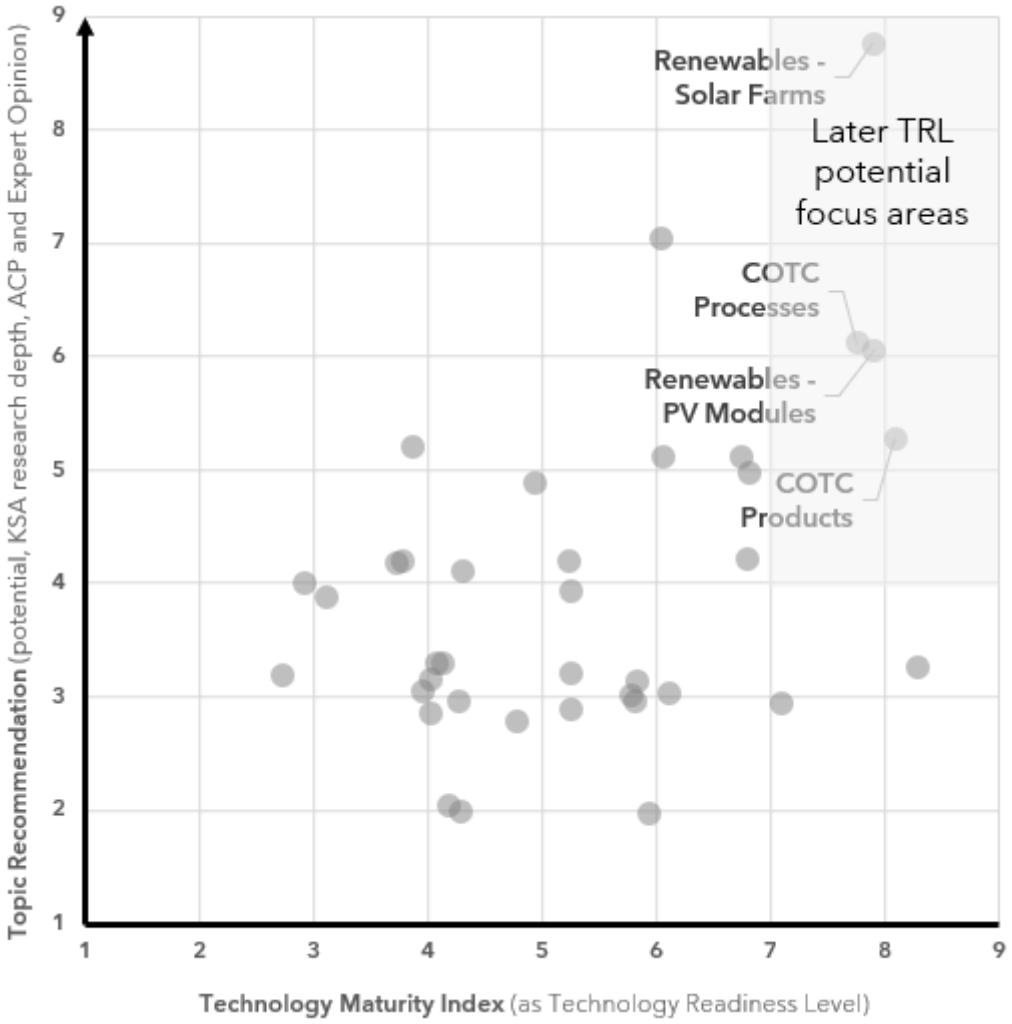


Figure 25 - scatterplot of Technical Maturity Index versus Topic Recommendation in the Energy & Industrial Leadership National Priority, annotation for research topics categories of >5 in recommendation and sitting in TRLs 8 - 9.

Finally in this section, the relative ranking and mode of research topics within the Energy and Industrials National Priority is shown in Table 6, ranked by the confluence of topic recommendation factors, and by action/recommendation quadrant they fall within based on the evaluated TRL level.

This list can be used to assess the specificity of research topics to the Saudi Arabian research ecosystem at present, alongside the assessed technology maturity index of the global research within that same topic, so that areas where Saudi Arabia can contribute further innovation that produce competitive, commercial, technologies are identified.

Table 6: Outcome scorecard for Energy and Industrials research topic categories, ranked by recommendation level; includes Technology Maturity Index/TRL score. Circle fill denotes a metric from highest quartile evidenced (full) to lowest quartile (single quarter).

Category	TMI as TRL	Commercial Potential	Saudi Arabia Research Depth	Level of Partnership	Expert Opinion	Recommended mode
Renewables - Solar Farms	8	●	●	●	●	Prioritize tech transfer
Hydrogen Production	6	◑	●	◕	●	Prioritize tech transfer
COTC Processes	8	◑	●	●	◔	Prioritize tech transfer
Renewables - PV Modules	8	◑	◕	◕	◕	Prioritize tech transfer
COTC Products	8	◔	●	●	◔	Prioritize tech transfer
Autonomous Mining - Smart Drilling	7	◔	◕	◑	●	Prioritize tech transfer
Energy Storage - Battery Mgt	6	◑	◑	◑	●	Prioritize tech transfer
Hydrogen Storage and Transportation	5	◔	◕	◑	●	Prioritize academic funding
Sustainable Mining - Waste Mgt	4	◔	◕	◑	●	Prioritize academic funding
Reuse & Recycle - Rare-Earth Use	7	◑	◕	◑	◑	Prioritize tech transfer
Industry 4.0 - Industrial Robots	4	◑	◔	◑	●	Prioritize academic funding
Power Distribution - Grid Integration	5	◔	◑	◑	●	Prioritize academic funding
Smart Grids	7	◔	◑	◔	●	Prioritize tech transfer
Sustainable Mining - Low Emissions	4	◔	◑	◑	●	Prioritize academic funding
Energy Storage - Solid State	5	◔	◑	◔	●	Prioritize academic funding
Industry 4.0 - Digital Twins	3	◔	◔	◑	●	Prioritize academic funding
Small Modular Nuclear Reactor (SMR)	3	◔	◔	◑	●	Prioritize academic funding
Sustainable Mining - Water Conservation	4	◔	◔	◑	●	Prioritize academic funding
Net Zero - Vehicle Emissions	7	◑	◑	◑	◔	Private sector led
Construction Robots	4	◔	◑	◑	◑	Ad hoc academic activity
Autonomous Mining - Mining Automation Software	4	◔	◔	◑	◕	Ad hoc academic activity
Autonomous Mining - Remotely Operated Equipment	6	◔	◔	◑	◕	Private sector led
Energy from Ammonia	4	◔	◔	◑	◕	Ad hoc academic activity
Production Planning & Lean Manufacture	5	◔	◑	◔	◕	Ad hoc academic activity
Autonomous Mining - Self-driving Vehicles	5	◔	◔	◔	●	Ad hoc academic activity
Energy Storage - Sodium Ion	4	◔	◔	◔	●	Ad hoc academic activity
Energy Storage - Sodium-Sulphur	4	◔	◔	◔	●	Ad hoc academic activity
Industry 4.0 - Intelligent Manufacturing	3	◔	◔	◔	●	Ad hoc academic activity
Power Distribution - Smart HVAC	6	◔	◔	◔	●	Private sector led
Renewables - Wind Turbines	8	◑	◑	◔	◔	Private sector led
Industry 4.0 - Predictive maintenance	6	◔	◔	◑	◑	Private sector led
Reuse & Recycle - Oil Reuse	6	◔	◑	◔	◑	Private sector led
Reuse & Recycle - Rare-Earth Recovery	5	◔	◔	◑	◑	Ad hoc academic activity
Renewables - Bladeless Wind Turbines	4	◔	◔	◔	◕	Ad hoc academic activity
Energy Storage - Lithium-Sulphur	4	◔	◔	◑	◔	Ad hoc academic activity
Net Zero - Industrial Emissions	4	◔	◔	◑	◔	Ad hoc academic activity
Renewables - Tidal/Wave	6	◔	◔	◔	◔	Private sector led

4 Deep-dive into selected Energy and Industrials research topics

Within this section, the following research topics, as they map to specific RDIA missions, will be explored in detail:

National Priority	Topic	3.1 Increase the share of renewable energy sources to ~50% by 2030	3.2 Develop cost-effective technologies to achieve 80-85% conversion of crude oil to chemicals by 2030	3.4 Reduce the cost of clean hydrogen to <$1/kg by 2030	3.5 Promote establishing and operating the first net-zero carbon mine with partial use of autonomous technology by 2050	3.7 Develop multi-purpose industrial robots that understand and adapt to their changing environment by 2035
Energy and Industrials	COTC Processes		✓			
	COTC Products		✓			
	Sustainable Mining – Waste Management		✓			
	Digital Twins					✓
	Net Zero – Industrial Emissions				✓	
	Smart Grids	✓				
	Hydrogen Production			✓		
	Hydrogen Storage and Transportation			✓		

4.1 Research performance in the selected priority research topics

In this section, we investigate the research output performance of selected priority research topics in Saudi Arabia and globally.

For each selected research topic, the research output performance for Saudi Arabia is investigated. First, the share of Saudi Arabian publications from global publications published on the research topic is investigated. Investigating the share of publications shows the evolution of the number of Saudi Arabian publications relative to the global share. If the share is increasing, this means that the number of Saudi Arabian publications on the research topic is increasing at a rate higher than the global one and vice versa. We also investigate the citation impact of Saudi publications in the research topic by looking at the Category Normalized Citation Impact (CNCI). The metric provides information on the citation impact relative to the global average citation impact for publications of the same type, year of publication and subject area (For more information, see Metrics). In general, a CNCI above 1.0 would reflect a citation impact performance above the global average.

Second, we investigate the top 10 countries collaborating with Saudi Arabia on the research topic, the top 20 funding organizations, the top 20 publishing organizations in Saudi Arabia, and the top 20 researchers in terms of the number of publications on

the research topic. This will provide insights about the research ecosystem in Saudi Arabia around this specific research topic. Identifying key players from this ecosystem will support deriving targeted initiatives to enhance research performance in those research topics. Also, here, all the indicators used are described in Metrics.

Third, we also investigate the top 10 global publishing countries, top 20 publishing entities globally, top 20 funding organizations globally and top 20 researchers globally in terms of the number of publications published on the research topic. This will provide insights into the global research ecosystem around this specific research topic. Also here, identifying key global players in the research ecosystem of a specific research topic will support enhancing Saudi Arabia's research performance by aiming to collaborate with those key players.

Finally, we identify emerging topics globally and within Saudi Arabia's research output in a specific research topic. This is identified by selecting the top topics in terms of growth in number of publications from 2014 to 2023. Although the Saudi Arabia research output within a research topic should focus on local and regional needs and priorities, it should not miss global trends that could become important in the future. Thus, we compare the emerging trends within Saudi Arabia to the global ones. Global trends provide insights to Saudi-affiliated researchers on topics that one should monitor and/or that could also be of local importance.

Main Findings

- The share of Saudi Arabian publications in each of the research topics from the global publications in the research topic increased almost continuously in several of the investigated research topics in the period 2020-2023. This shows that for the majority of the research topics, the growth in Saudi Arabia's publications was higher than the global average.
- For the research topics COTC Products and Sustainable Mining Waste Management we notice a similar trend but with a slight decrease in the share in 2023. Whereas for the research topic Digital Twins we observe fluctuations in the share of publications but with a slight increase in the last couple years.
- As these are national priority research topics, one should aim to increase the research output continuously while preserving good research quality. One possibility to perform this is by collaborating with identified key publishing organizations and researchers as well as collaborating with top funding organizations identified in those research topics.
- In several of the investigated research topics, at least five of the top 10 collaborators with Saudi Arabia in terms of number of publications were also among the top 10 globally in terms of number of publications. This shows that Saudi Arabia is collaborating with key global players on the research topics.
- In half of the investigated research topics, at least 8 of the Top 20 funders of Saudi Arabian publications in terms of number of publications are also among the top funders globally. This again shows that Saudi-affiliated researchers are collaborating with key global players on research topics and can attract funding from key global funders in those research topics. In the other half, at least 5 of the top 20 funders of Saudi Arabian publications are also among the top funders globally.
- In several of the research topics we observe King Saud University, King Abdulaziz University, King Abdullah University of Science & Technology (KAUST) and King Fahd University of Petroleum & Minerals (KFUPM) among the top 5 publishing entities in Saudi Arabia.
- Keeping in mind that global emerging trends could be of greater importance in the future, one should monitor identified trends as well as check their relevancy for local priorities.

4.1.1 COTC Processes

4.1.1.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications in the research topic decreased from 2.42% in 2015 to 1.56% in 2017, then increased to 2.87% in 2023, as shown in Figure 26. This shows that Saudi Arabia was not only able to increase the number of publications in this research topic but also having a growth higher than the global growth rate in the period 2020-2023.

This is evident as the share of Saudi Arabian publications in the research topic are growing. The CNCI of Saudi Arabian publications in this research topic were in all years since 2020 higher than 1, indicating a citation impact performance higher than the global average.

In the years 2014-2019 the CNCI fluctuated between 0.76 and 1.24. Afterwards the CNCI recovered to reach 1.19 in 2023.

Overall, Saudi Arabia's publications increased with a higher growth rate than the global average in this research topic and had a relatively good citation impact, as measured by the CNCI. Nevertheless, after this high growth rate in terms of publications, one should focus on increasing/preserving the relatively good citation impact.

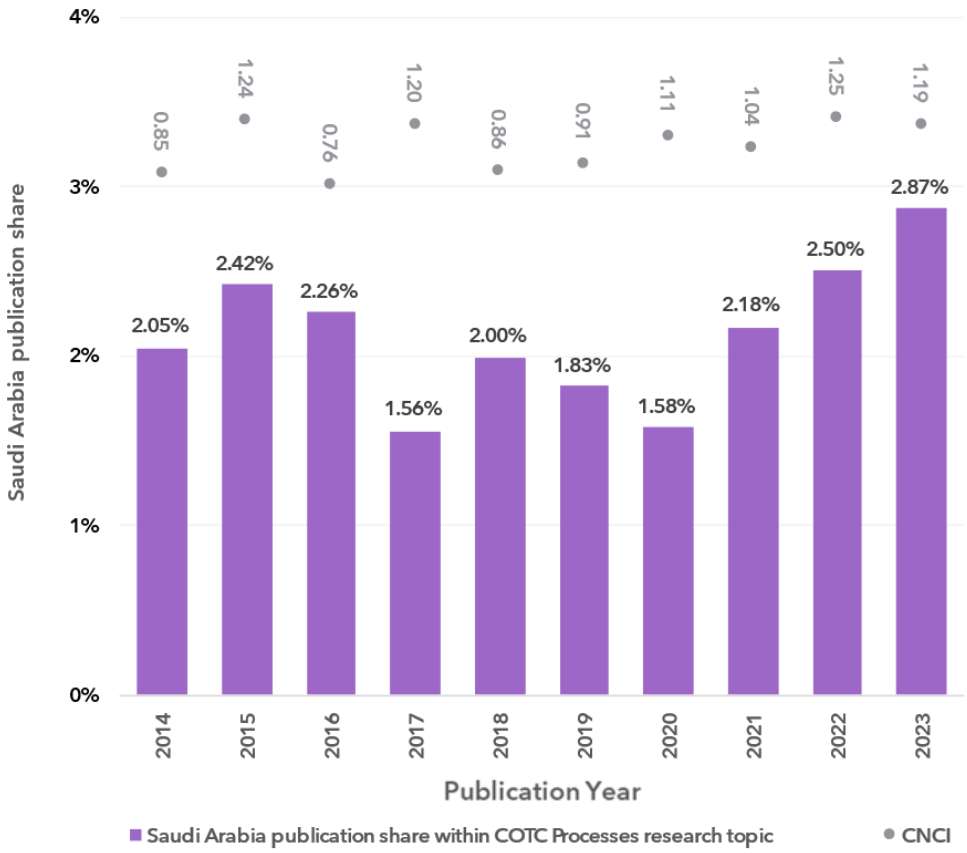


Figure 26: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.1.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is India, followed by Mainland China and the United States with 67, 62, and61 publications, respectively, as shown in Figure 27. In terms of citation impact measured by the CNCI publications published in collaboration with Mainland China followed by Japan and United States had the highest CNCI with 2.01, 1.52 and 1.44 respectively. Nevertheless, all publications with the top 10 collaborating countries had a CNCI higher than 1 reflecting a performance higher than the global average.

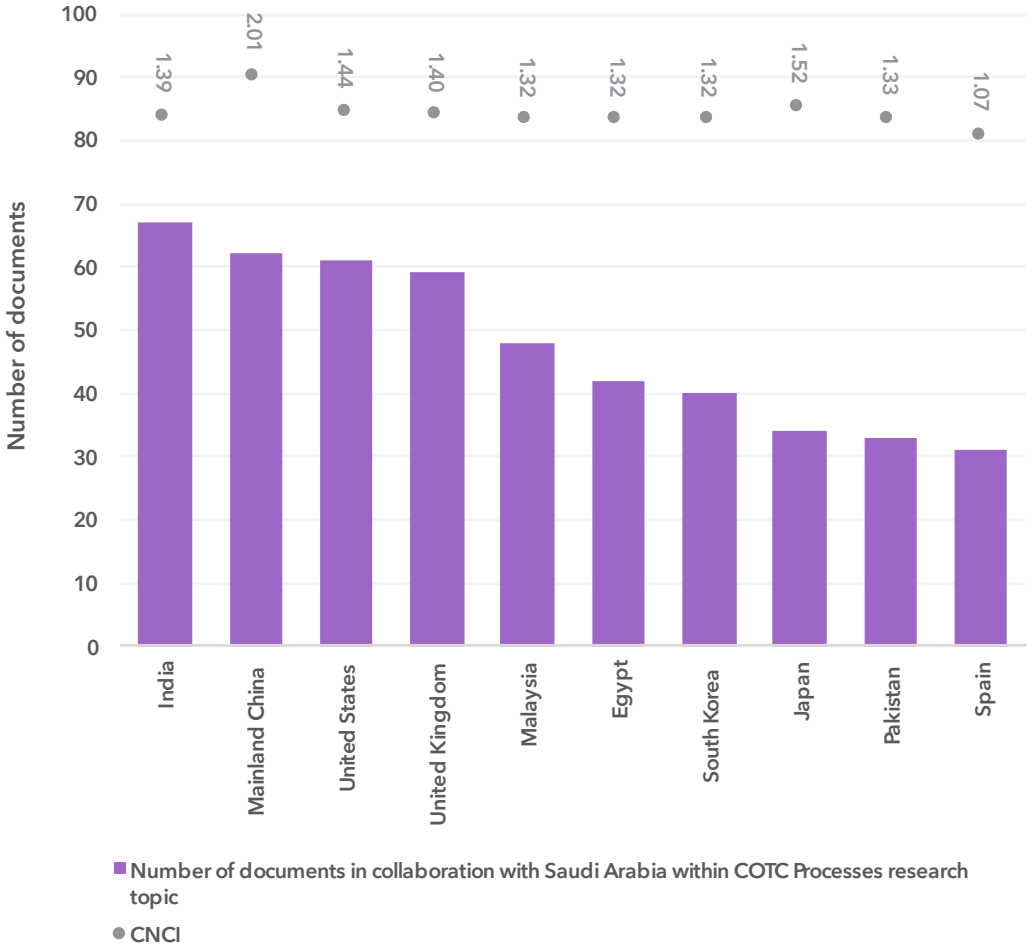


Figure 27: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic COTC Processes in the period 2014-2023

4.1.1.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by King Abdullah University of Science & Technology and National Natural Science Foundation of China (NSFC) with 77, 33 and 28 publications respectively as shown in Figure 28.

Documents funded by United States Department of Energy (DOE), followed by National Research Foundation of Korea and National Natural Science Foundation of China (NSFC) had the highest citation impact measured by the CNCI with 2.69, 2.53 and 1.78 respectively.

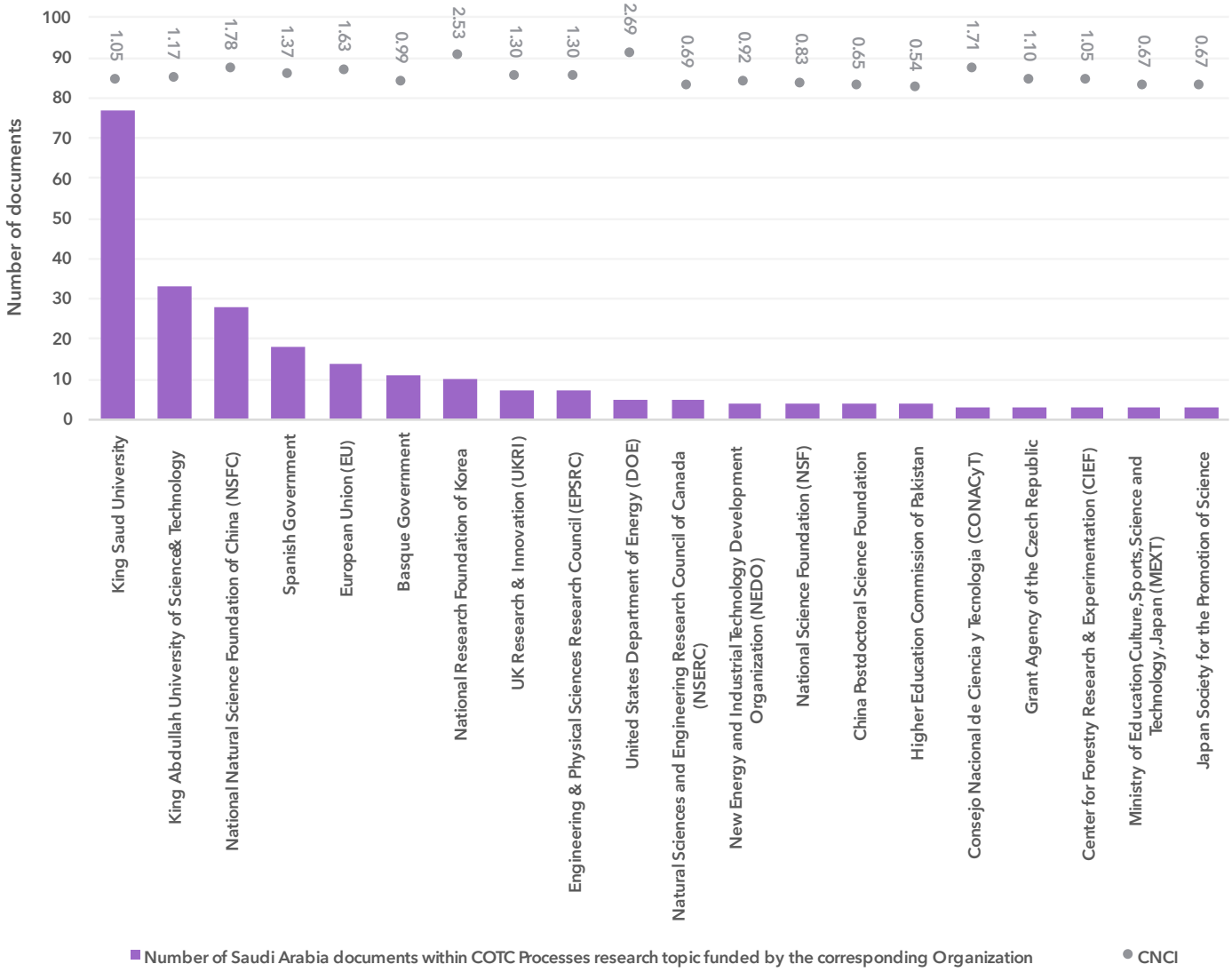


Figure 28: Top 20 funding organizations of Saudi Arabian publications in the research topic COTC Processes in terms of number of publications in the period 2014-2023

4.1.1.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published on this research topic and in the period 2014-2023 are King Fahd University of Petroleum & Minerals, followed by King Saud University and King Abdullah University of Science & Technology, with 186, 121 and 110 publications, respectively as shown in Figure 29.

In terms of citation impact as measured by the CNCI, Imam Mohammad Ibn Saud Islamic University (IMSIU), followed by Prince Mohammad Bin Fahd University and Imam Abdulrahman Bin Faisal University, had the highest CNCI with 2.29, 2.26 and 1.98, respectively.

It is worth mentioning that the top 3 organizations in terms of CNCI have much less publications than the top organizations in terms of number of publications.

Nevertheless, 14 of the top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

Organizations with a CNCI lower than 1 are Taif University, King Fahd University of Petroleum & Minerals, King Abdulaziz City for Science & Technology, Najran University, King Faisal University and Taibah University.

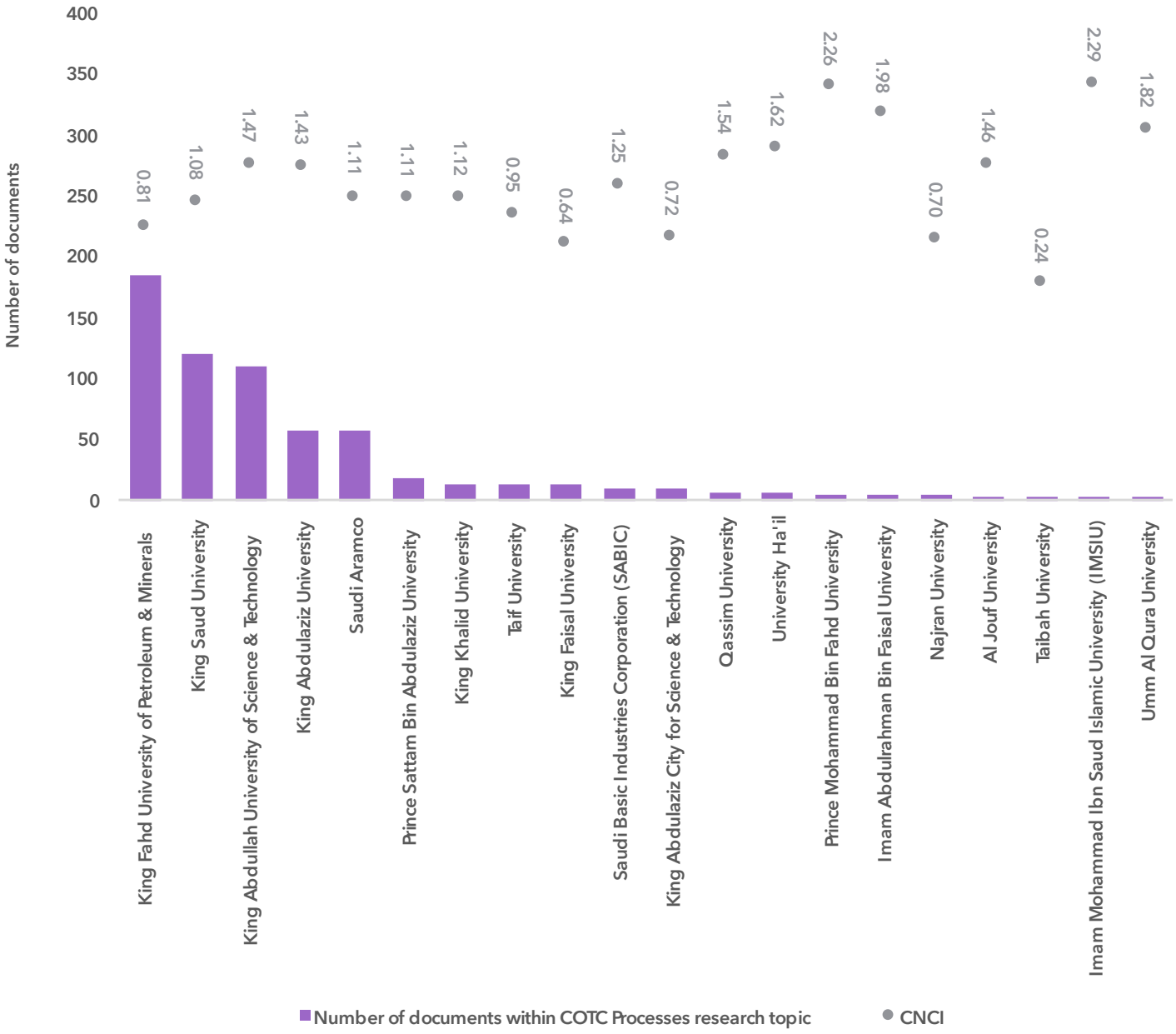


Figure 29: Top 20 Saudi organizations in terms of publications published in the research topic COTC Processes in the period 2014-2023 and their corresponding CNCI

4.1.1.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Oki. Muraza is affiliated with King Fahd University of Petroleum & Minerals, followed by Ahmed S. Al-Fatesh, affiliated with King Saud University, and Anis H. Fakeeha, affiliated with King Saud University, with 47, 38 and 37 publications, respectively, as shown in Table 7.

The highest CNCI is achieved by publications published by Samy Ould-Chikh, affiliated with King Abdullah University of Science & Technology, with a CNCI of 1.36. None of the Top 20 researchers in terms of number of publications has a Top 1% document.

Ahmed Sadeq Al-Fatesh, affiliated with King Saud University, has the highest number of publications in the top 10%, with seven publications.

Table 7: Top 20 researchers affiliated to Saudi organizations in terms of number of publications published in the research topic COTC Processes in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Muraza, Oki	King Fahd University of Petroleum & Minerals	47	0.80	0	0
Al-Fatesh, Ahmed S.	King Saud University	38	1.25	0	6
Fakeeha, Anis H.	King Saud University	37	1.24	0	6
Ibrahim, Ahmed A.	King Saud University	36	1.27	0	6
Al-Fatesh, Ahmed Sadeq	King Saud University	32	1.23	0	7
Abasaeed, Ahmed E.	King Saud University	31	1.29	0	6
Fakeeha, Anis Hamza	King Saud University	28	1.18	0	5
Abasaeed, Ahmed Elhag	King Saud University	26	1.10	0	4
Ibrahim, Ahmed Aidid	King Saud University	22	1.26	0	6
Hossain, Mohammad M.	King Fahd University of Petroleum & Minerals	21	0.55	0	0
Mokheimer, Esmail M. A.	King Fahd University of Petroleum & Minerals	15	0.77	0	0
Basset, Jean-Marie	King Abdullah University of Science & Technology	14	1.18	0	2
Gascon, Jorge	King Abdullah University of Science & Technology	13	1.24	0	1
Al-Khattaf, Sulaiman S.	King Fahd University of Petroleum & Minerals	12	0.76	0	0
Ould-Chikh, Samy	King Abdullah University of Science & Technology	12	1.36	0	1
Yamani, Zain H.	King Fahd University of Petroleum & Minerals	12	0.80	0	0
Kasim, Samsudeen Olajide	King Saud University	11	1.23	0	3
Ali, Syed A.	King Fahd University of Petroleum & Minerals	11	0.67	0	0
Bakare, Idris A.	King Fahd University of Petroleum & Minerals	11	0.77	0	0
Sanhoob, Mohammed A.	King Fahd University of Petroleum & Minerals	10	0.89	0	0

4.1.1.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (10,750 publications), followed by the United States (3,631 publications) and South Korea (1,574 publications), as shown in Figure 30.

The highest citation impact measured by the CNCI is achieved by publications published by the United Kingdom, Spain and the United States with a CNCI of 1.21, 1.14 and 1.13, respectively. Seven of the top 10 countries, in terms of the number of publications published on the research topic, are also among the top 10 collaborators with Saudi Arabia. These are Mainland China, the United States, South Korea, Japan, United Kingdom, India and Spain.

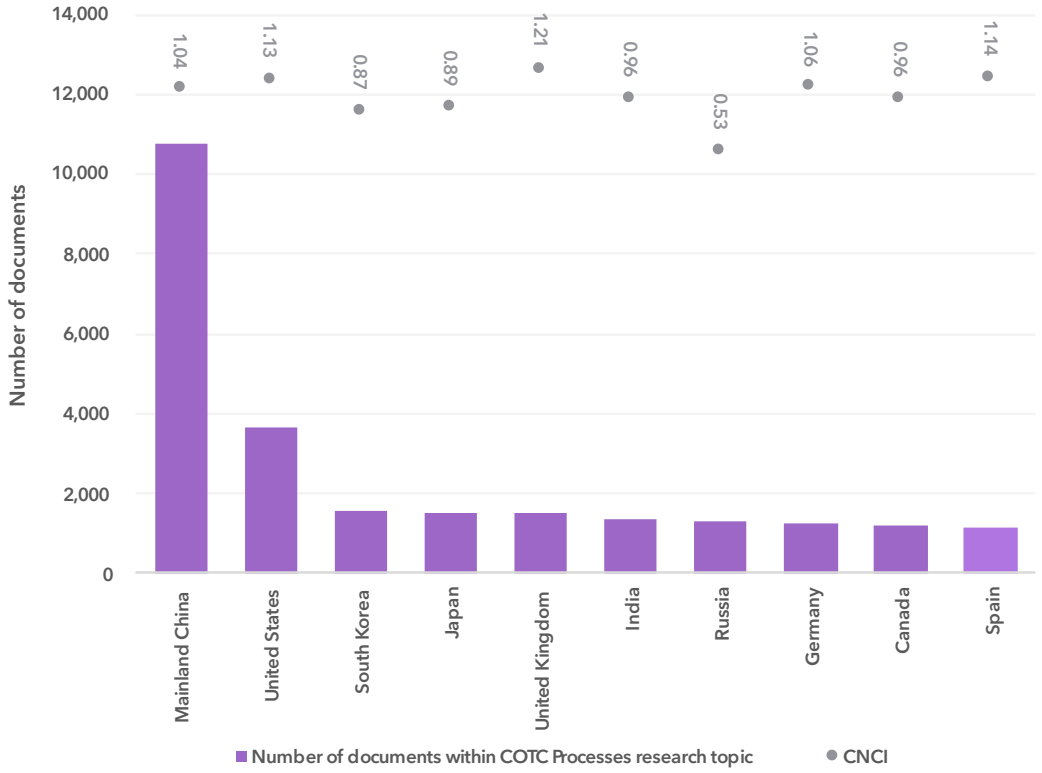


Figure 30: Top 10 countries in terms of the number of publications in the research topic COTC Processes in the period 2014-2023 and their corresponding CNCI

4.1.1.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are the Chinese Academy of Sciences (1,295 publications) followed by the China University of Petroleum (907 publications) and the Russian Academy of Sciences (663 publications) respectively as shown in Figure 31.

In terms of citation impact measured by the CNCI, University of Basque Country and United States Department of Energy (DOE) with the same CNCI followed by China University of Mining & Technology and Chinese Academy of Sciences had the highest CNCI with 1.38, 1.27 and 1.25 respectively.

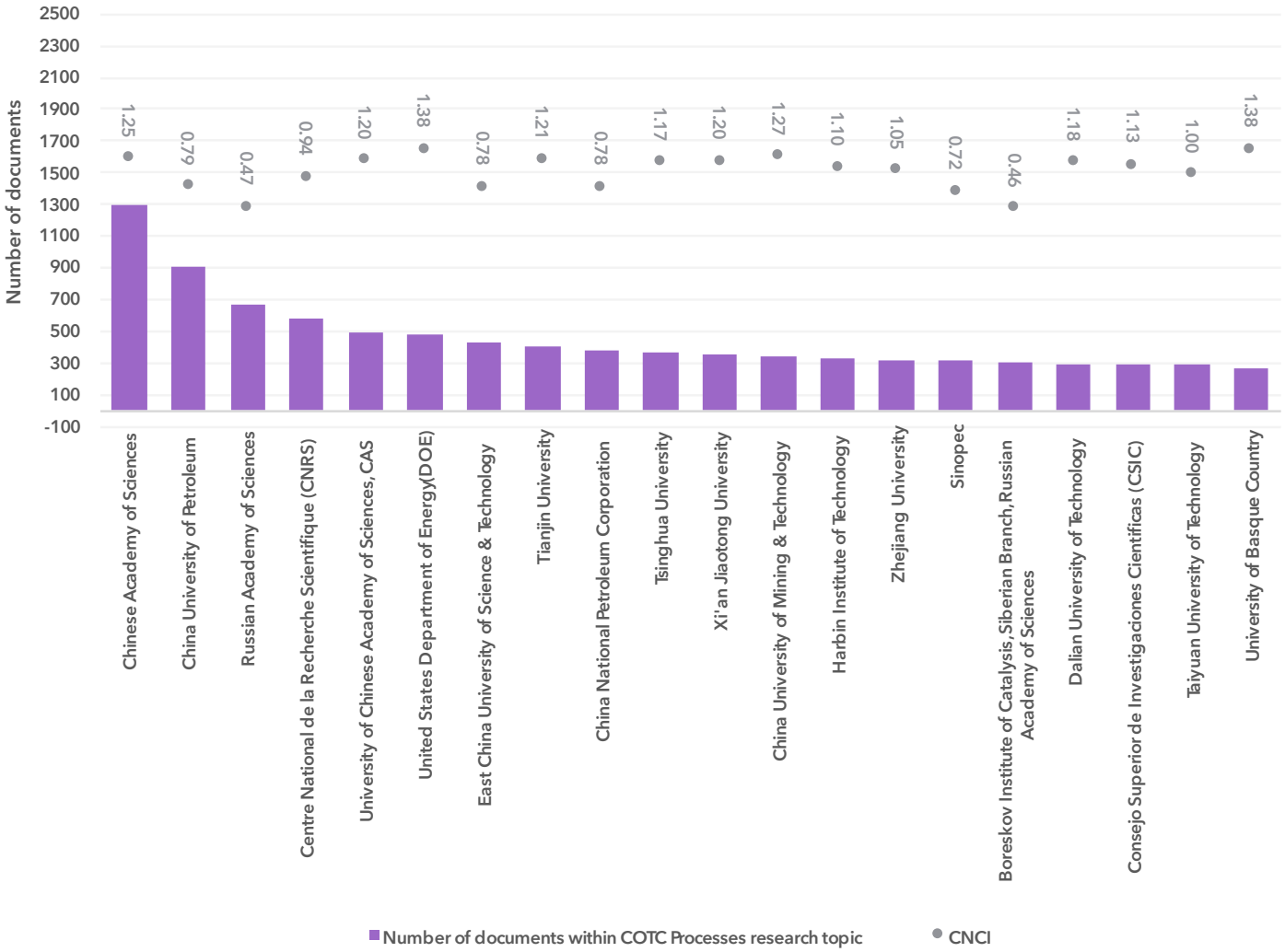


Figure 31: Top 20 organizations globally in terms of number of publications published in the research topic COTC Processes in the period 2014-2023 and their corresponding CNCI

4.1.1.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications on this research topic are Bilbao, Javier, affiliated with the University of Basque Country, with 150 publications, followed by Kevin M. Van Geem, affiliated with Ghent University, with 93 publications and Guy B. Marin affiliated with Ghent University, with 84 publications as shown in Table 8. The highest CNCI among the top 20 researchers globally is achieved by Yalin Wang, affiliated with Central South University, with a CNCI of 2.67.

The latter also had the highest Top 1% publications, amounting to 4 publications. Bilbao, Javier has the highest number of Top 10% publications, amounting to 38 publications.

Table 8: Top 20 researchers globally in terms of the number of publications published in the research topic COTC Processes in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Bilbao, Javier	University of Basque Country	150	1.56	1	38	Spain
Van Geem, Kevin M.	Ghent University	93	1.38	3	10	Belgium
Marin, Guy B.	Ghent University	84	1.46	2	9	Belgium
Hu, Xun	University of Jinan	76	1.21	0	11	Mainland China
Xu, Chunming	China University of Petroleum	74	0.72	0	3	Mainland China
Olazar, Martin	University of Basque Country	69	1.96	2	28	Spain
Kawi, Sibudjing	National University of Singapore	68	2.15	3	25	Singapore
Wei, Xian-Yong	China University of Mining & Technology	68	0.98	0	10	Mainland China
Liu, Guozhu	Tianjin University	67	0.93	0	2	Mainland China
Gao, Jinsen	China University of Petroleum	59	0.62	0	1	Mainland China
Gayubo, Ana G.	University of Basque Country	58	1.59	0	17	Spain
Kwon, Eilhann E.	Sejong University	57	1.26	0	5	South Korea
Zhang, Shu	Nanjing Forestry University	56	1.03	0	3	Mainland China
Zhang, Xiangwen	Tianjin University	56	0.90	0	3	Mainland China
Williams, Paul T.	University of Leeds	53	1.98	1	18	England
Park, Young-Kwon	University of Seoul	52	0.96	0	5	South Korea
Palma, Vincenzo	University of Salerno	52	1.14	0	6	Italy
Wang, Yalin	Central South University	50	2.67	4	26	Mainland China
Yang, Chaohe	China University of Petroleum	48	0.60	0	1	Mainland China
Rahimpour, Mohammad Reza	Shiraz University	47	0.94	0	3	Iran

4.1.1.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC), with 7,039 publications, followed by Fundamental Research Funds for the Central Universities, with 1,046 publications, and the European Union (EU) with 786 publications as shown in Figure 32.

The highest citation impact measured by the CNCI is observed in publications funded by the United States Department of Energy (DOE), followed by the China Scholarship Council and National Science Foundation (NSF) with 1.49, 1.38 and 1.35, respectively. Among the top 20 global funding organizations, 12 are also among the top 20 funding organizations of Saudi publications in this research topic.

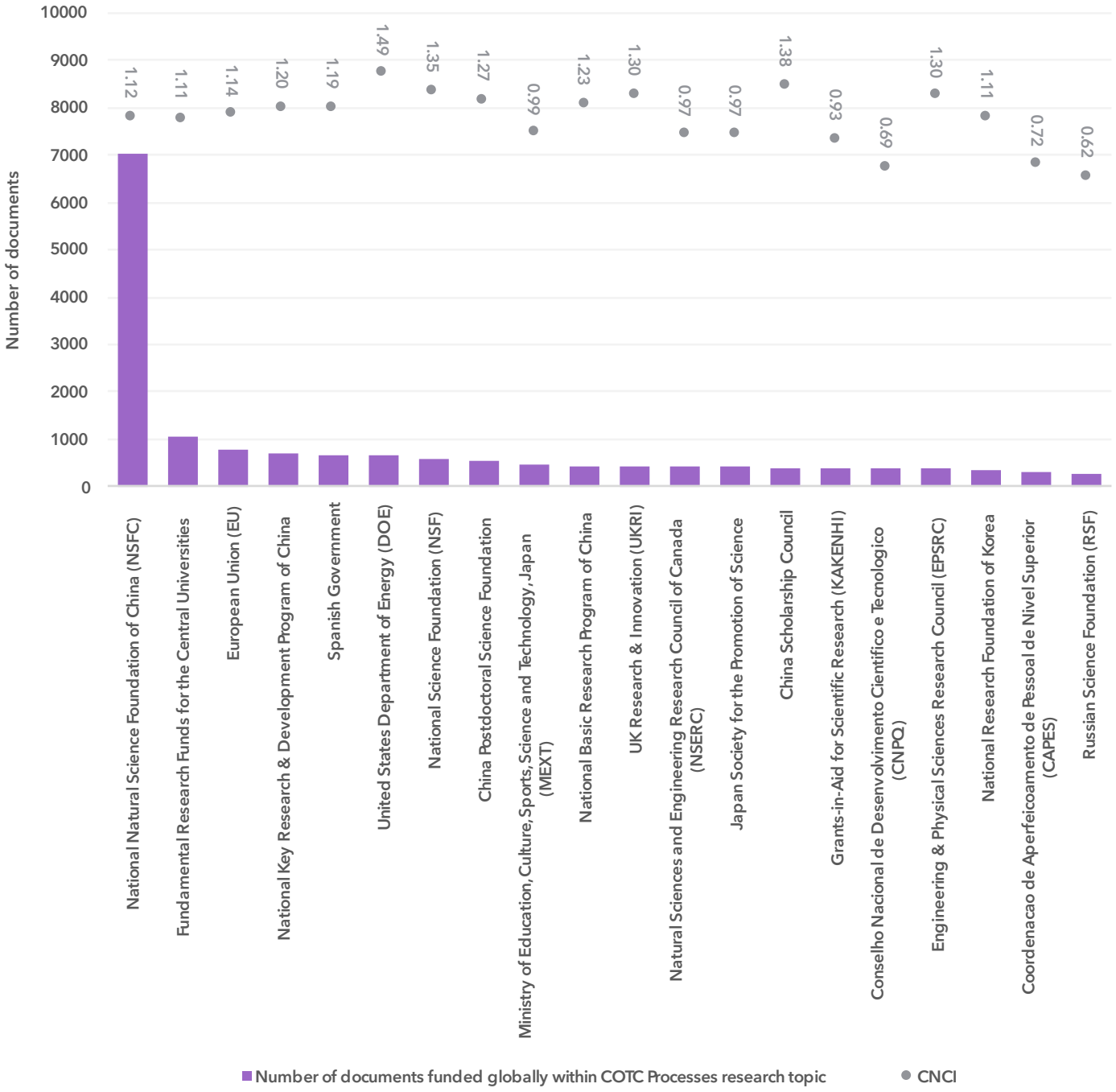


Figure 32: Top 20 funding organizations globally publications in the research topic COTC Processes in terms of number of publications in the period 2014-2023

4.1.1.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section we investigate the emerging trends globally and in Saudi Arabia in the research topic COTC Processes. For more information on the methodology used to identify emerging trends, please see the definitions section for Emerging Trends.

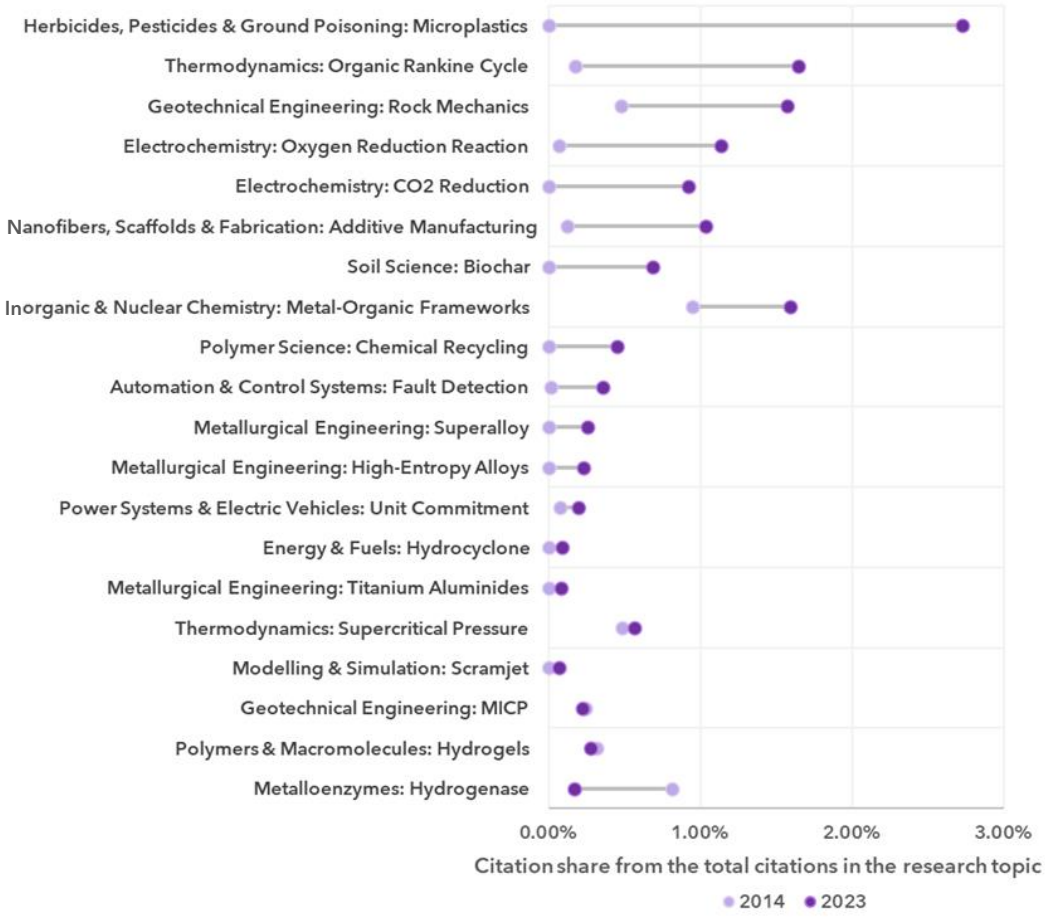


Figure 33: Top 20 emerging micro-topics globally in the research topic COTC Processes in the period 2014-2023

The top 3 emerging micro-topics globally in this research topic are Herbicides, Pesticides & Ground Poisoning, Microplastics followed by Thermodynamics: Organic Rankine Cycle and Geotechnical Engineering: Rock Mechanics, as shown in Figure 33.

Table 9 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic.

Table 9: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic COTC Processes in the period 2014-2023

Topic	Number of Saudi Arabian publications 2014-2023
COTC Processes	651
Catalysts: Fischer-Tropsch Synthesis	219
Catalysts: Zeolites	108
Energy & Fuels: Gasification	55
Water Resources: Asphaltenes	26
Catalysts: Selective Catalytic Reduction	19
Catalysts: Hydrodesulfurization	17
Concrete Science: Compressive Strength	11
Combustion: Combustion Simulation	8
Plasma Physics: Dielectric Barrier Discharge	8
Photocatalysts: Photocatalysis	7

4.1.2 COTC Products

4.1.2.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications on the research topic increased almost continuously from 2014 till 2023, as shown in Figure 34. This shows that Saudi Arabia was not only able to increase the number of publications in this research topic but also having a growth higher than the global growth rate.

This is evident as the share of Saudi Arabian publications in the research topic are growing. Though the share decreased from 5.89% in 2022 to 5.31% in 2023. This reflects a growth rate lower than the global growth rate in the research topic in 2022-2023.

The CNCI of Saudi Arabian publications in this research topic was in almost all years higher than 1, indicating a citation impact performance higher than the global average. Although the CNCI decreased from 1.69 in 2017 to 1.12 in 2018 and then it increased to 1.48 in 2022 and then decreased slightly to 1.38 in 2023.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic and had a relatively good citation impact as measured by the CNCI.

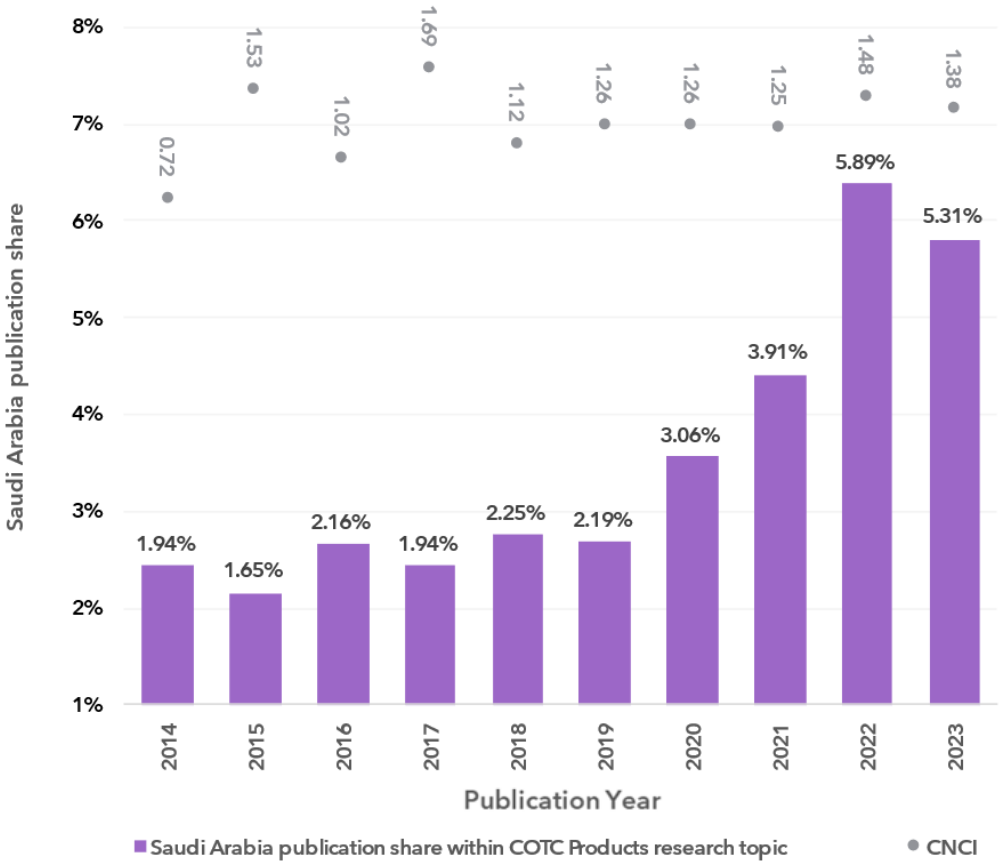


Figure 34: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.2.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is Egypt, followed by India and Pakistan with 197, 88 and 84 publications, respectively, as shown in Figure 35.

In terms of citation impact measured by the CNCI publications published in collaboration with Pakistan followed by India and United States had the highest CNCI with 1.93, 1.72 and 1.66 respectively. Except for publications in collaboration with

Tunisia, all publications with the top 10 collaborating countries had a CNCI higher than 1 reflecting a performance higher than the global average.

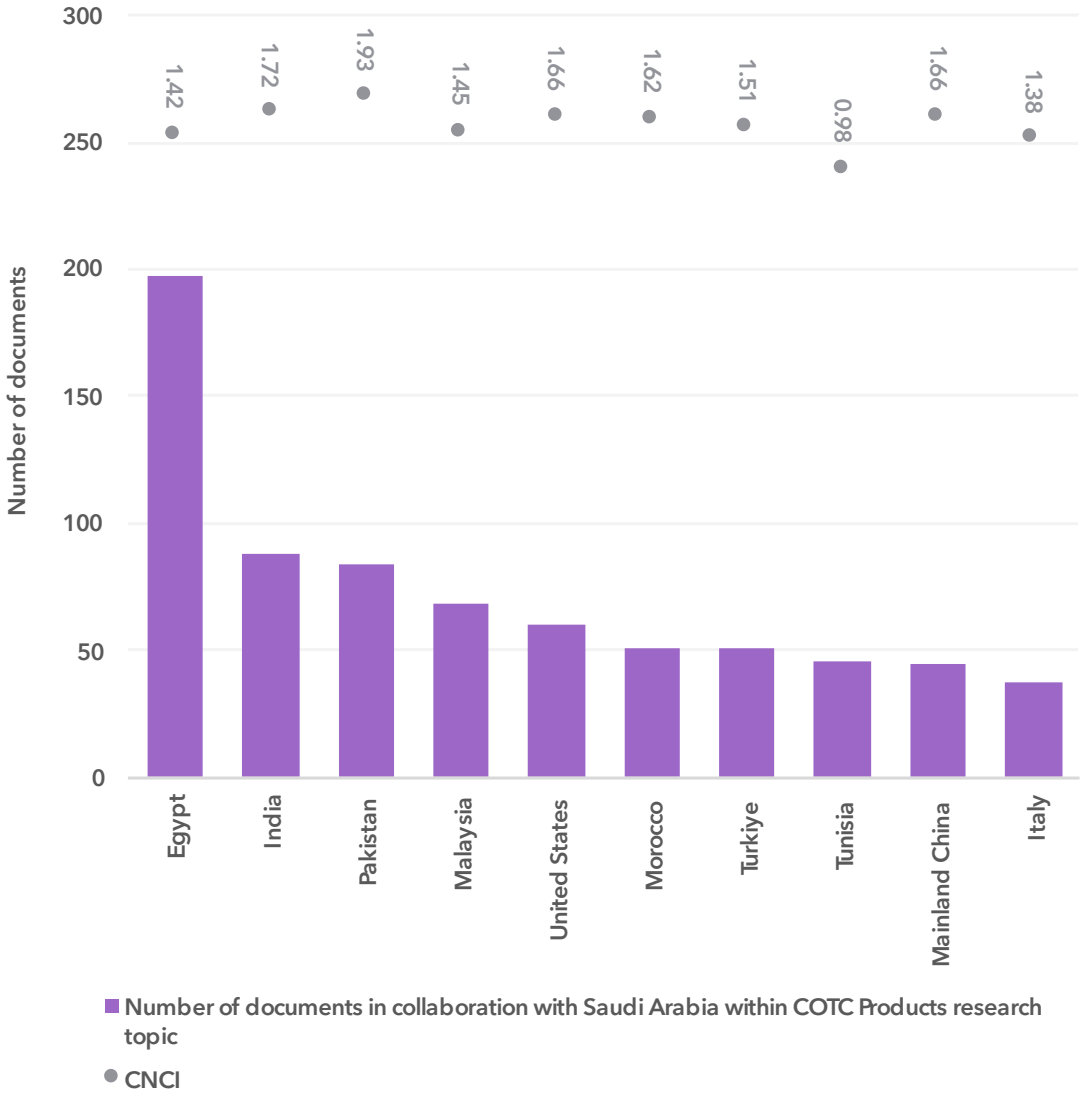


Figure 35: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic COTC Products in the period 2014-2023

4.1.2.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by Princess Nourah bint Abdulrahman University and King Abdullah University of Science & Technology with 156, 26 and 11 publications respectively as shown in Figure 36.

Documents funded by the Ministry of Education Malaysia, followed by the United States Department of Agriculture (USDA) and the National Natural Science Foundation of China (NSFC), had the highest citation impact measured by the CNCI with 2.34, 2.32 and 2.24, respectively.

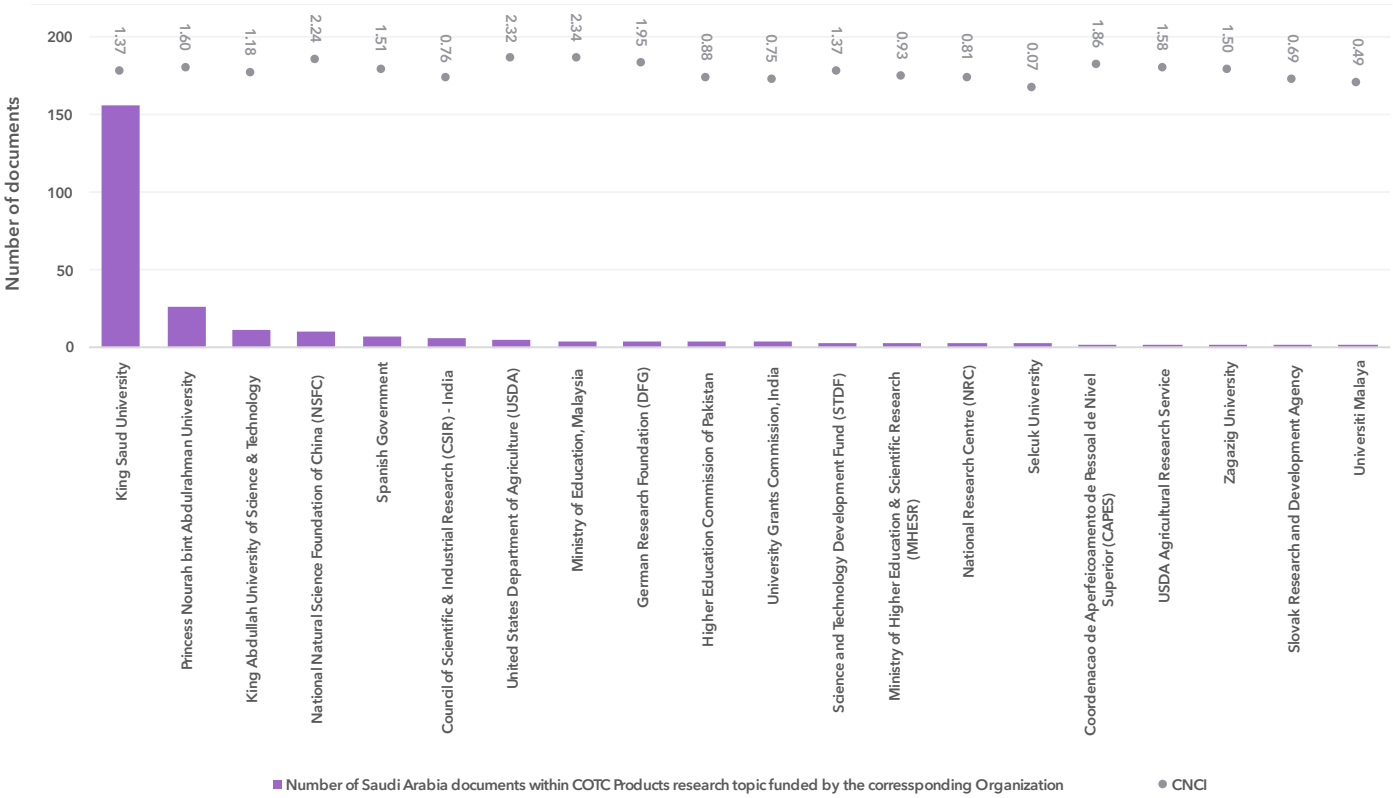


Figure 36: Top 20 funding organizations of Saudi Arabian publications in the research topic COTC Products in terms of number of publications in the period 2014-2023

4.1.2.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations, in terms of publications published in this research topic and in the period 2014-2023, are King Saud University followed by King Fahd University of Petroleum & Minerals and King Abdulaziz University, with 237, 138 and 84 publications, respectively, as shown in Figure 37.

In terms of citation impact as measured by the CNCI, Qassim University, followed by King Abdulaziz University and King Khalid University, had the highest CNCI with 1.82, 1.78 and 1.66, respectively.

Nevertheless, all top 20 organizations, except Saudi Aramco and the University of Jeddah, had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

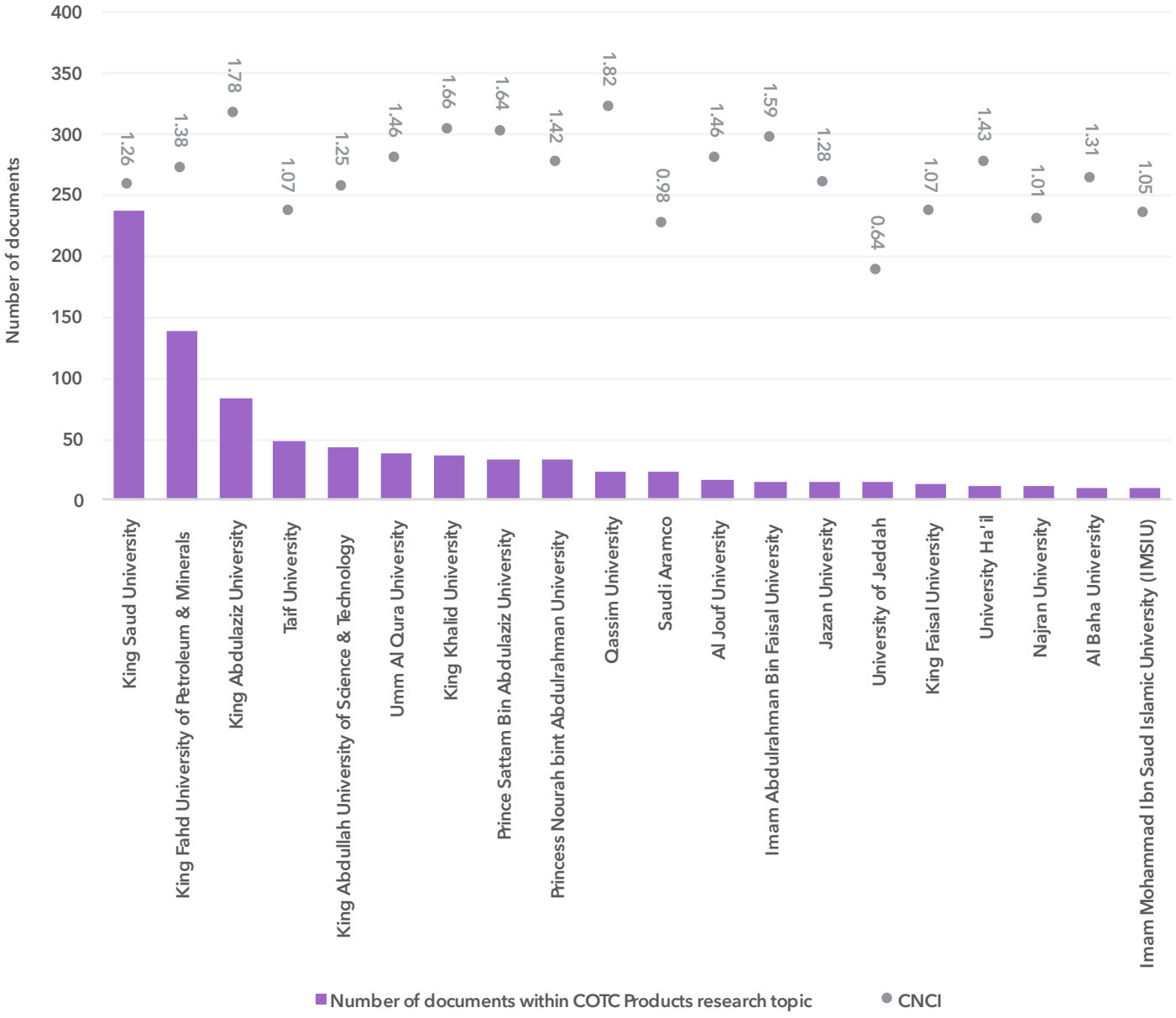


Figure 37: Top 20 Saudi organizations in terms of publications published in the research topic COTC Products in the period 2014-2023 and their corresponding CNCI

4.1.2.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Muhammad Shahzad Kamal, Shirish Patil, and Mohamed Mahmoud, and all are affiliated with King Fahd University of Petroleum & Minerals, with 33, 18 and 15 publications, respectively, as shown in Table 10.

The highest CNCI is achieved by publications published by Hafiz Muhammad Ali, affiliated with King Fahd University of Petroleum & Minerals, with a CNCI of 4.14.

The latter researcher, Shams Kalam also affiliated to King Fahd University of Petroleum & Minerals, have the highest number of Top 1% amounting to 2 publications. Muhammad Shahzad Kamal has also the highest number of Top 10% publications amounting to 6 publications.

Table 10: Top 20 researchers affiliated to Saudi organizations in terms of number of publications published in the research topic COTC Products in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Kamal, Muhammad Shahzad	King Fahd University of Petroleum & Minerals	33	1.70	1	9
Patil, Shirish	King Fahd University of Petroleum & Minerals	18	1.91	1	5
Mahmoud, Mohamed	King Fahd University of Petroleum & Minerals	15	1.41	0	4
Kalam, Shams	King Fahd University of Petroleum & Minerals	13	2.60	2	4
Sultan, Abdullah S.	King Fahd University of Petroleum & Minerals	13	1.48	0	4
Alam, Manawwer	King Saud University	13	0.77	0	2
Ghafoor, Kashif	King Saud University	10	1.01	0	1
Ali, Hafiz Muhammad	King Fahd University of Petroleum & Minerals	9	4.14	2	6
Aitani, Abdullah	King Fahd University of Petroleum & Minerals	9	1.02	0	1
Salamatullah, Ahmad Mohammad	King Saud University	9	1.85	0	4
Atta, Ayman M.	King Saud University	8	1.66	0	4
Hussain, Syed Muhammad Shakil	King Fahd University of Petroleum & Minerals	8	1.58	0	2
Abdullah, Mahmood M. S.	King Saud University	7	1.39	0	3
Al-Lohedan, Hamad A.	King Saud University	7	1.43	0	2
Abu-Khamsin, Sidqi A.	King Fahd University of Petroleum & Minerals	7	3.06	1	3
Hussain, S. M. Shakil	King Fahd University of Petroleum & Minerals	7	1.39	0	1
Abdallah, Emad M.	Qassim University	7	1.78	0	2
Harrath, Abdel Halim	King Saud University	7	0.61	0	0
Ali, Hayssam M.	King Saud University	7	2.19	0	4
Aboul-Soud, Mourad A. M.	King Saud University	7	2.23	0	4

4.1.2.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (5,432 publications), followed by the United States (2,549 publications) and India (2,404 publications), as shown in Figure 38.

It is worth noting that Saudi Arabia ranks 9th globally in this research topic and has the highest CNCI with 1.32. Six of the remaining top 10 countries, in terms of the number of publications published on the research topic, are also among the top 10 collaborators with Saudi Arabia.

These are Mainland China, the United States, India, Malaysia, Italy and Türkiye.

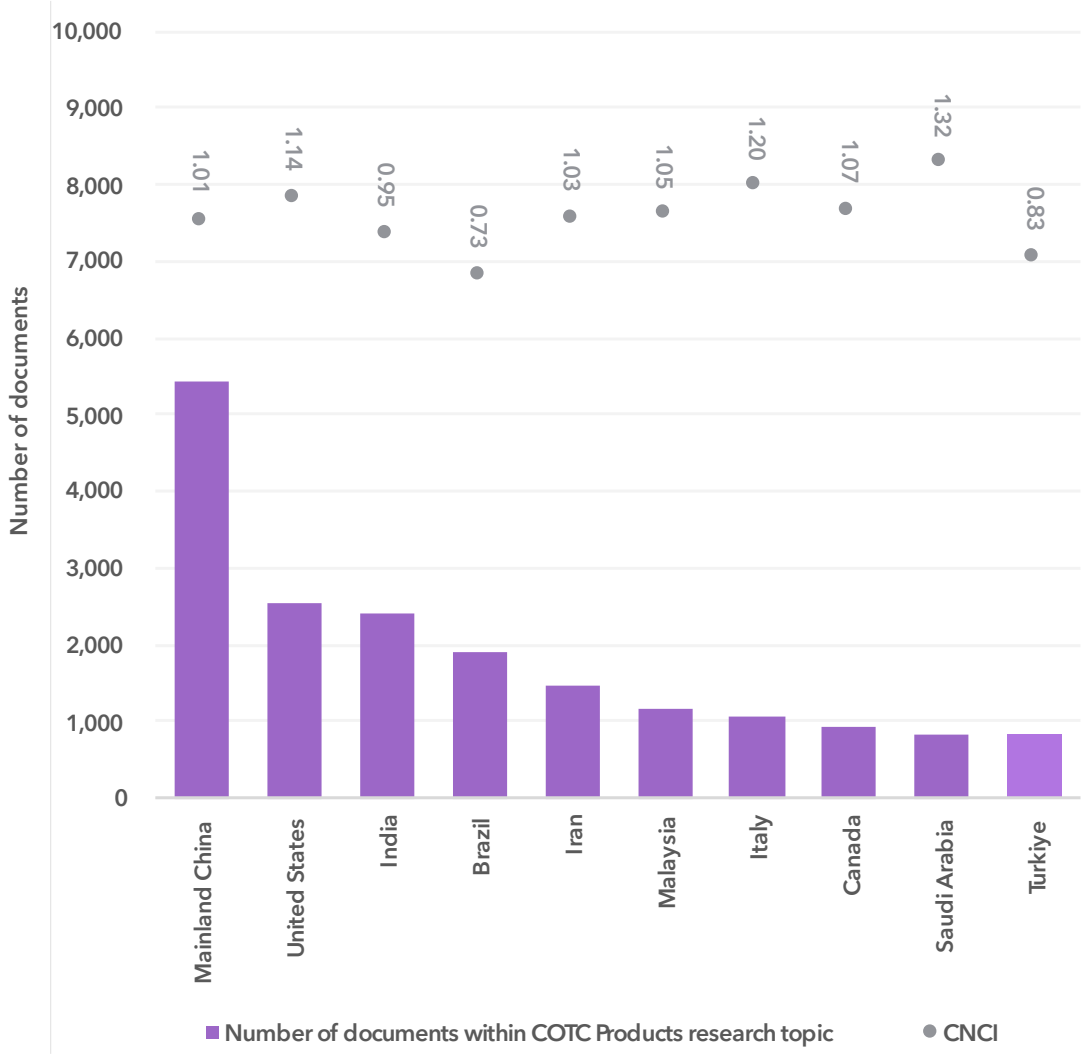


Figure 38: Top 10 countries in terms of number of publications in the research topic COTC Products in the period 2014-2023 and their corresponding CNCI

4.1.2.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are the China University of Petroleum (570 publications) followed by the Chinese Academy of Sciences (530 publications) and Centre National de la Recherche Scientifique (CNRS) (411 publications) respectively as shown in Figure 39.

In terms of citation impact measured by the CNCI, Universiti Teknologi Petronas followed by Universiti Teknologi Malaysia and Chinese Academy of Sciences had the highest CNCI with 1.27, 1.23 and 1.21 respectively.

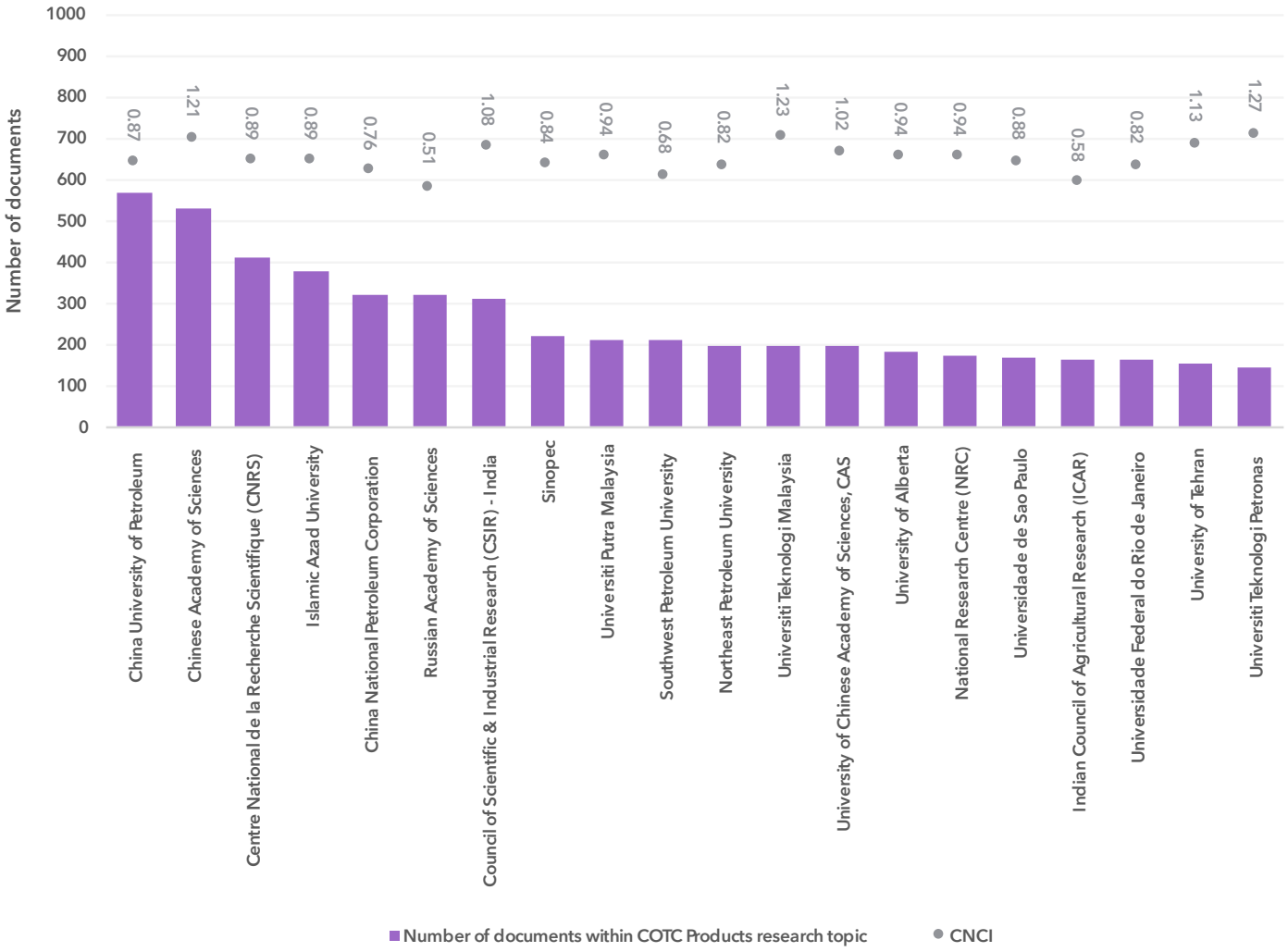


Figure 39: Top 20 organizations globally in terms of number of publications published in the research topic COTC Products in the period 2014-2023 and their corresponding CNCI

4.1.2.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications in this research topic are Maurizio Bruno, affiliated to the University of Palermo, with 71 publications, followed by Filippo Maggi, affiliated to the University of Camerino, with 64 publications, and William N. Setzer, affiliated to the University of Alabama Huntsville, with 56 publications as shown in Table 11.

The highest CNCI among the top 20 researchers globally is achieved by Ajay Mandal affiliated to Indian Institute of Technology System (IIT System) with a CNCI of 2.62.

The latter has the highest Top 1% publications, amounting to 3 publications, and the Top 10% publications, amounting to 20 publications.

Filippo Maggi, affiliated with the University of Camerino, also has 3 Top 1% publications.

Table 11: Top 20 researchers globally in terms of the number of publications published in the research topic COTC Products in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Bruno, Maurizio	University of Palermo	71	0.82	0	6	Italy
Maggi, Filippo	University of Camerino	64	1.57	3	14	Italy
Setzer, William N.	University of Alabama Huntsville	56	1.22	0	8	United States
Tomi, Felix	Centre National de la Recherche Scientifique (CNRS)	51	0.36	0	0	France
Flamini, Guido	University of Pisa	50	1.35	0	13	Italy
Ruan, Roger	University of Minnesota Twin Cities	44	1.72	0	16	United States
Ogunwande, Isiaka A.	Lagos State University	41	0.33	0	0	Nigeria
Mandal, Ajay	Indian Institute of Technology System (IIT System)	36	2.62	3	20	India
Badalamenti, Natale	University of Palermo	33	0.86	0	3	Italy
Demirci, Betul	Anadolu University	32	0.66	0	1	Turkiye
Pu, Wanfen	Southwest Petroleum University	32	0.88	0	3	Mainland China
Wang, Yunpu	Nanchang University	31	1.58	0	9	Mainland China
Casanova, Joseph	CNRS - Institute for Engineering & Systems Sciences (INSIS)	31	0.30	0	0	France
Lal, Mohan	Council of Scientific & Industrial Research (CSIR) - India	30	2.25	1	12	India
Liu, Yuhuan	Nanchang University	30	1.75	0	10	Mainland China
Zengin, Gokhan	Selcuk University	30	1.65	1	8	Turkiye
Pirbalouti, Abdollah Ghasemi	Islamic Azad University	30	1.26	0	7	Iran
De Feo, Vincenzo	University of Salerno	30	1.67	0	9	Italy
Mohammadi, Amir H.	University of KwaZulu Natal	29	2.00	2	12	South Africa
Blank, Arie Fitzgerald	Universidad Federal de Sergipe	29	0.52	0	1	Brazil

4.1.2.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC) with 2,712 publications, followed by Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPQ) with 923 publications, and Coordenacao de Aperfeicoamento de Pessoal de Nivel Superior (CAPES) with 892 publications as shown in Figure 40.

The highest citation impact measured by the CNCI is observed in publications funded by United States Department of Energy (DOE), China Scholarship Council and National Science Foundation (NSF) with 1.50, 1.46 and 1.41 respectively.

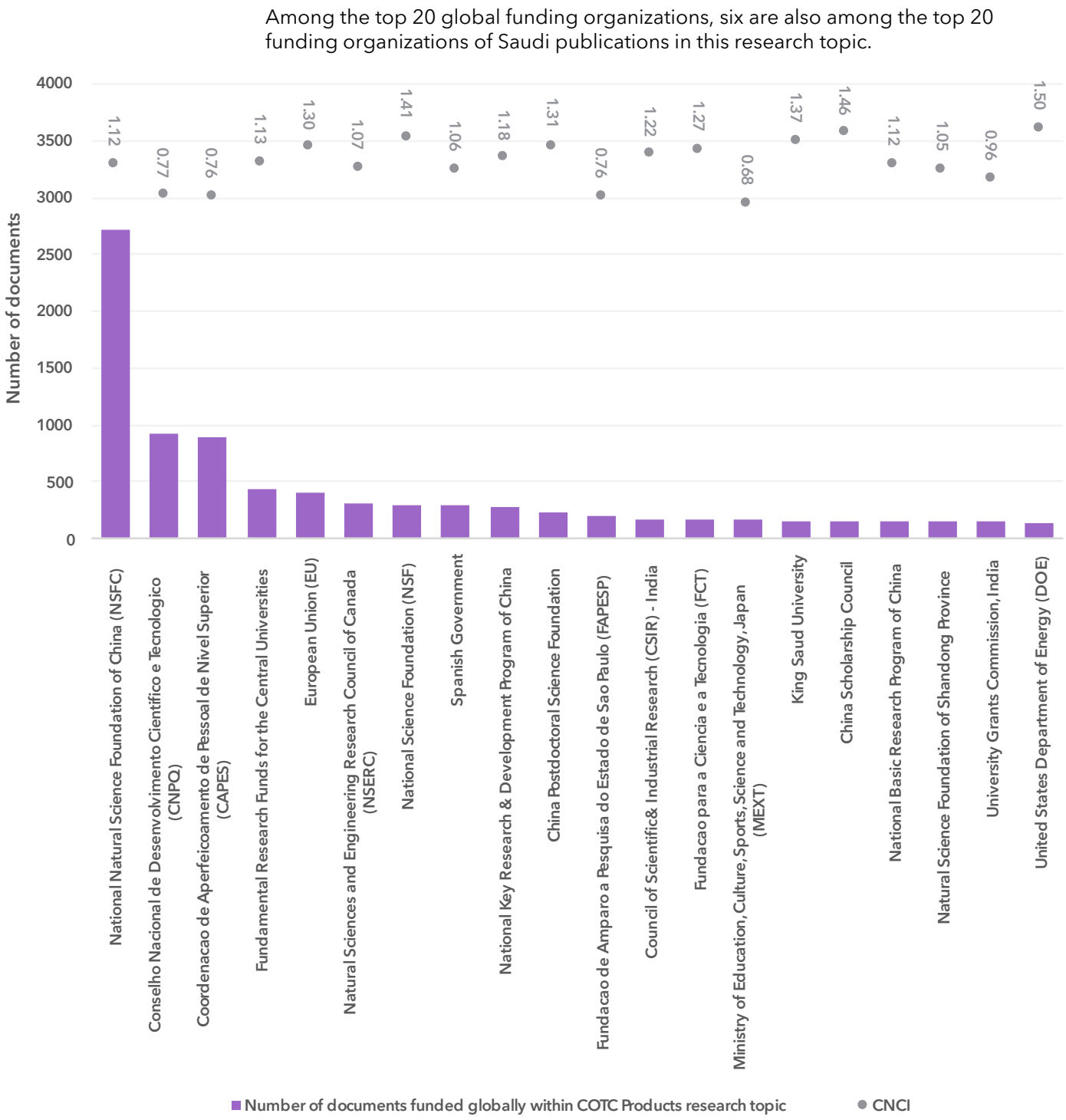


Figure 40: Top 20 funding organizations globally publications in the research topic COTC Products in terms of number of publications in the period 2014-2023

4.1.2.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section we investigate the emerging trends globally and in Saudi Arabia in the research topic COTC Products. For more information on the methodology used to identify emerging trends, please see the definitions section on Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Herbicides, Pesticides & Ground Poisoning: Microplastics, Polymers & Macromolecules: Hydrogels and Food Science & Technology: Chitosan as shown in Figure 41.

Table 12 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic. There are no Saudi Arabian publications on the identified global micro-topics.

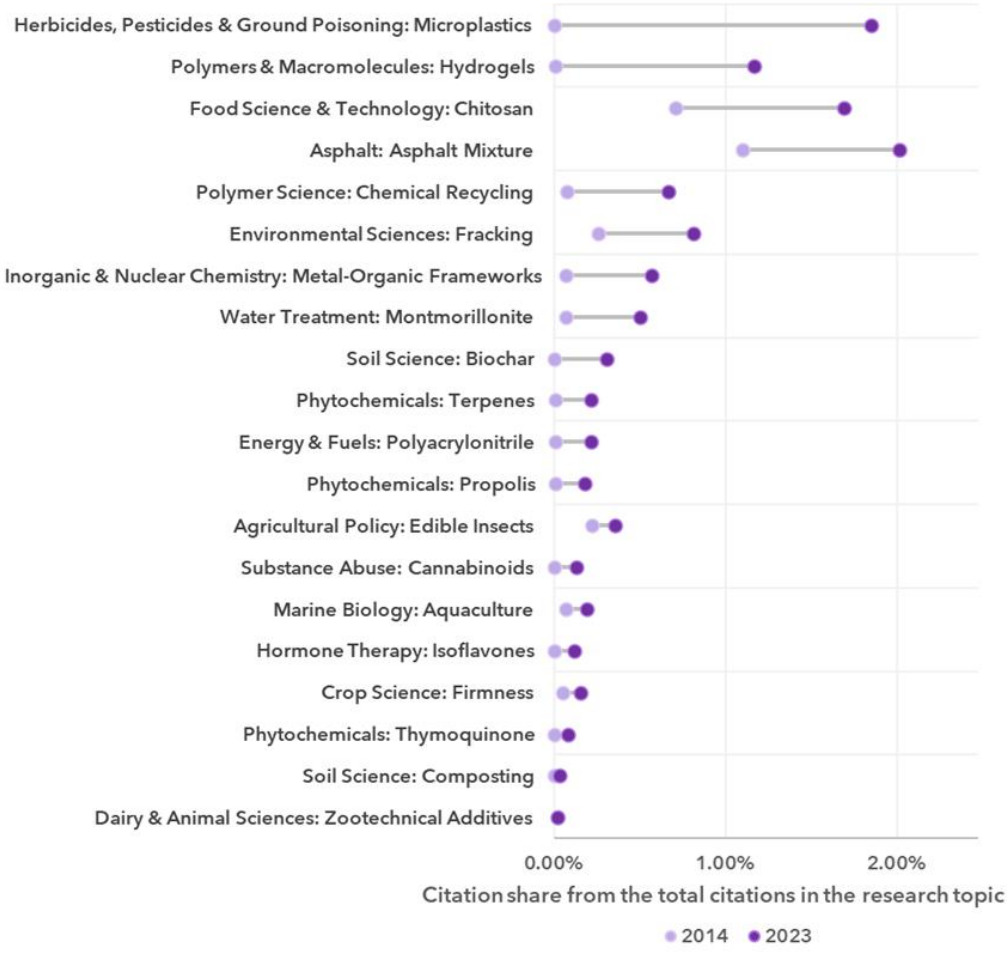


Figure 41: Top 20 emerging micro-topics globally in the research topic COTC Products in the period 2014-2023

Table 12: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic COTC Products in the period 2014-2023

Topic	Number of Saudi Arabian publications in the period 2014-2023
COTC Products	827
Phytochemicals: Essential Oil	194
Water Resources: Enhanced Oil Recovery	101
Thermodynamics: Nanofluid	37
Water Resources: Asphaltenes	33
Lipids: Virgin Olive Oil	29
Energy & Fuels: Gasification	24
Entomology: Limonoids	24
Catalysts: Zeolites	22
Combustion: Biodiesel	19
Phytochemicals: Antioxidant Activity	17

4.1.3 Sustainable Mining Waste Management

4.1.3.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications in the research topic fluctuated between 2014 and 2019 and then increased continuously till 2022 to then decrease slightly in 2023, as shown in Figure 42.

This shows that Saudi Arabia in the period 2019-2022 was not only able to increase the number of publications in this research topic but also having a growth higher than the global growth rate. This is evident as the share of Saudi Arabian publications in the research topic are growing.

The CNCI of Saudi Arabian publications in this research topic was in almost all years higher than 1, indicating a citation impact performance higher than the global average. Specifically, after the CNCI decreased to 0.95 in 2019 we observe a recovery afterwards reaching 1.76 in 2021 and 1.61 in 2023.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic in the period 2019-2023 and had a relatively good citation impact as measured by the CNCI.

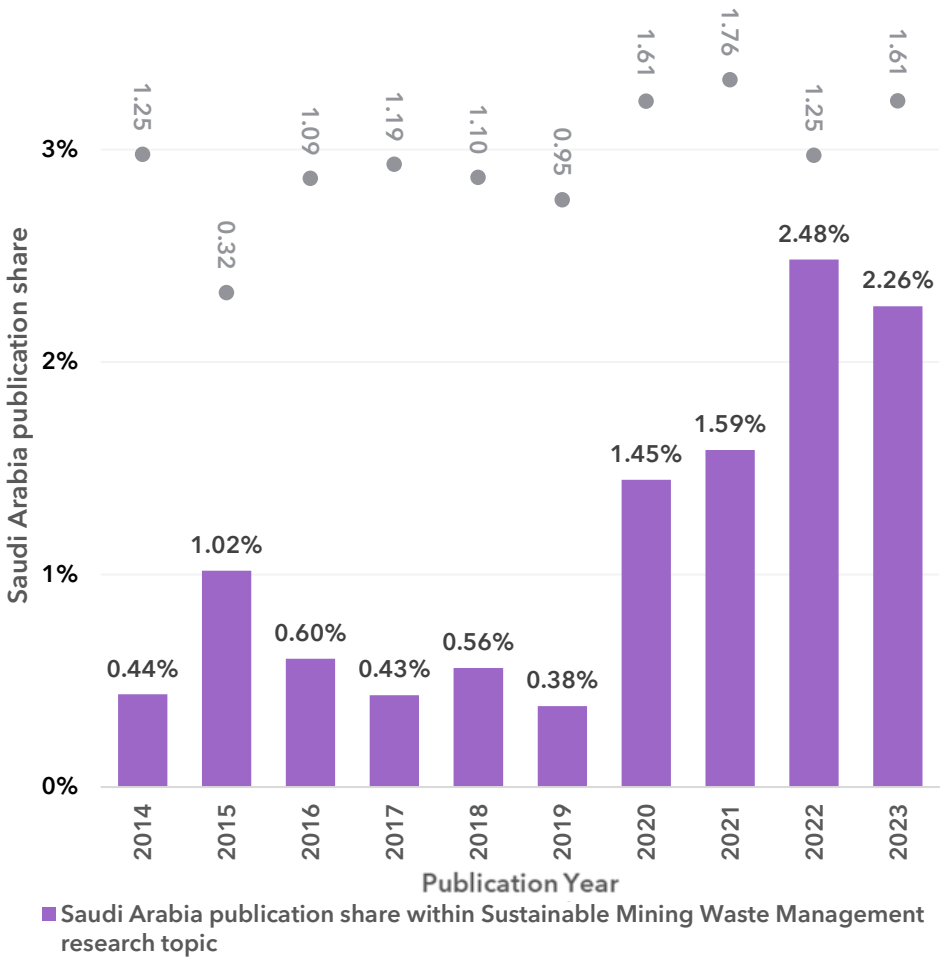


Figure 42: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.3.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating countries with Saudi Arabia in this research topic in the period 2014-2023 are Egypt, followed by India and Mainland China with 34, 29 and 18 publications, respectively, as shown in Figure 43.

In terms of citation impact measured by the CNCI publications published in collaboration with Pakistan followed by Malaysia and South Korea had the highest CNCI with 1.92, 1.50 and 1.46 respectively. Nevertheless, all publications with the top 10 collaborating countries, except with Egypt, Australia and United Arab Emirates, had a CNCI higher than 1 reflecting a performance higher than the global average.

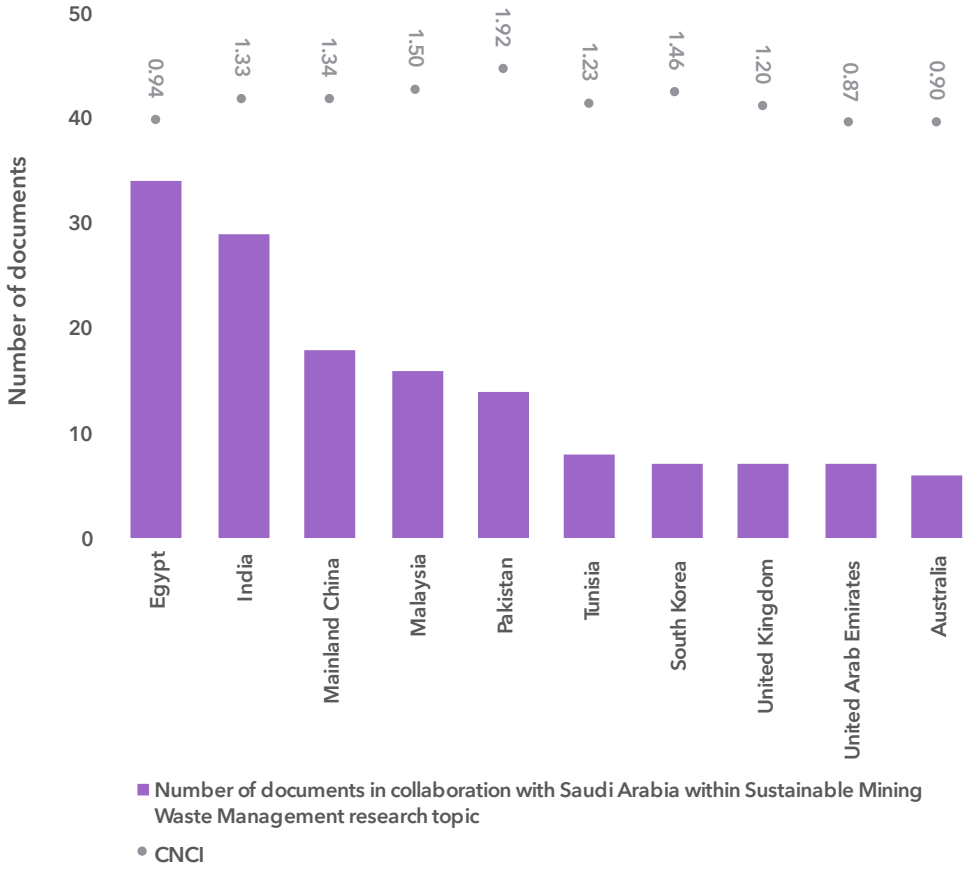


Figure 43: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications on the research topic Sustainable Mining Waste Management in the period 2014-2023

4.1.3.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by Princess Nourah bint Abdulrahman University and National Natural Science Foundation of China (NSFC) with 24, 5 and 4 publications respectively as shown in Figure 44.

Only four organizations of the funded publications had a CNCI higher than 1. The CNCI of the top funder in terms of the number of funded publications at King Saud University is 1.74. This reflects a citation impact 74% higher than the global average.

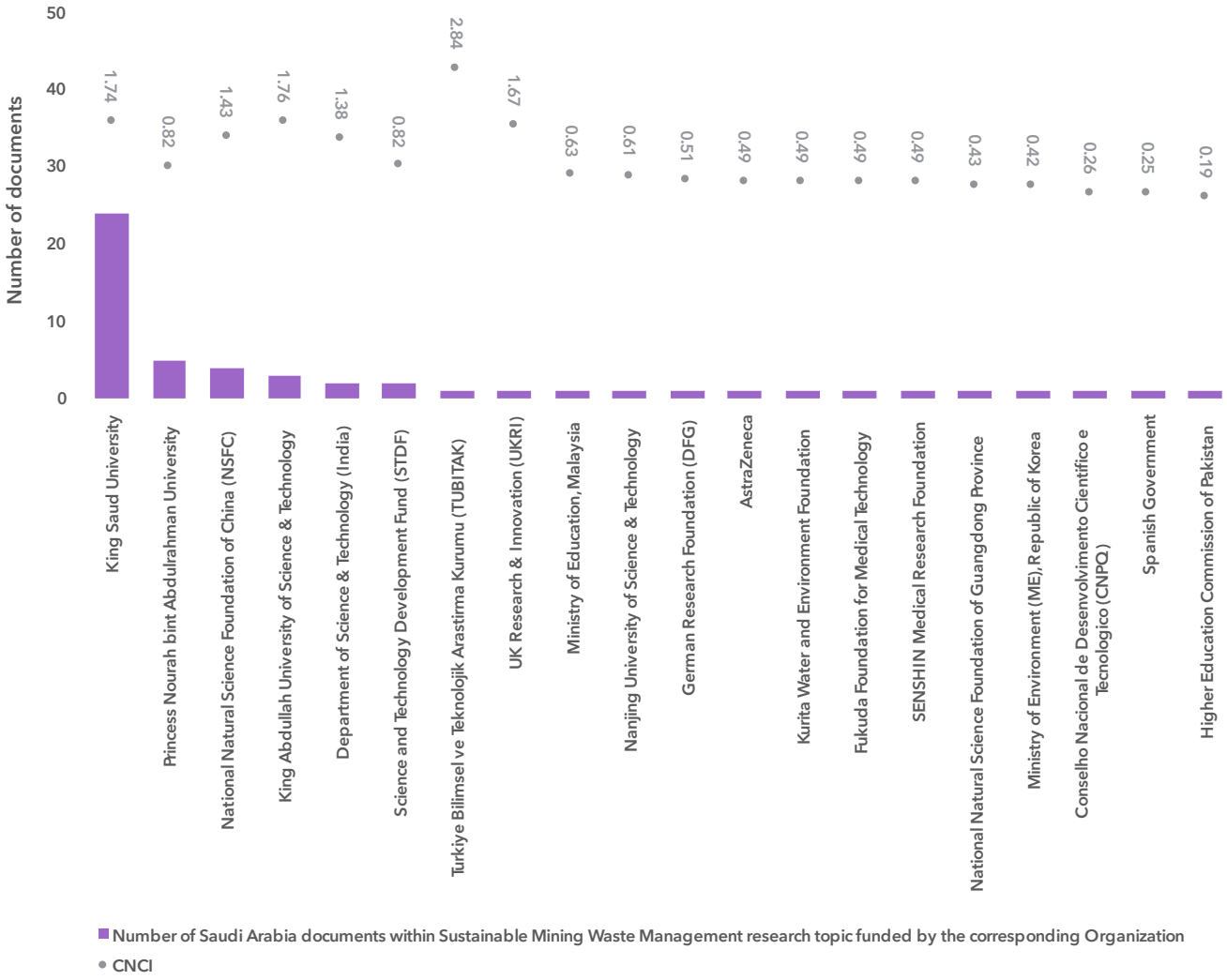


Figure 44: Top 20 funding organizations of Saudi Arabian publications in the research topic Sustainable Mining Waste Management in terms of number of publications in the period 2014-2023

4.1.3.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published in this research topic and in the period 2014-2023 are King Saud University, followed by King Abdulaziz University and King Fahd University of Petroleum & Minerals, with 42, 21 and 16 publications, respectively, as shown in Figure 45.

In terms of citation impact as measured by the CNCI, King Khalid University, followed by Jazan University and Prince Sattam Bin Abdulaziz University, had the highest CNCI with 2.91, 2.10 and 2.09, respectively.

Though the top 3 organizations in terms of CNCI had much fewer publications than the highest publishing organization in this research topic. 13 of the top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

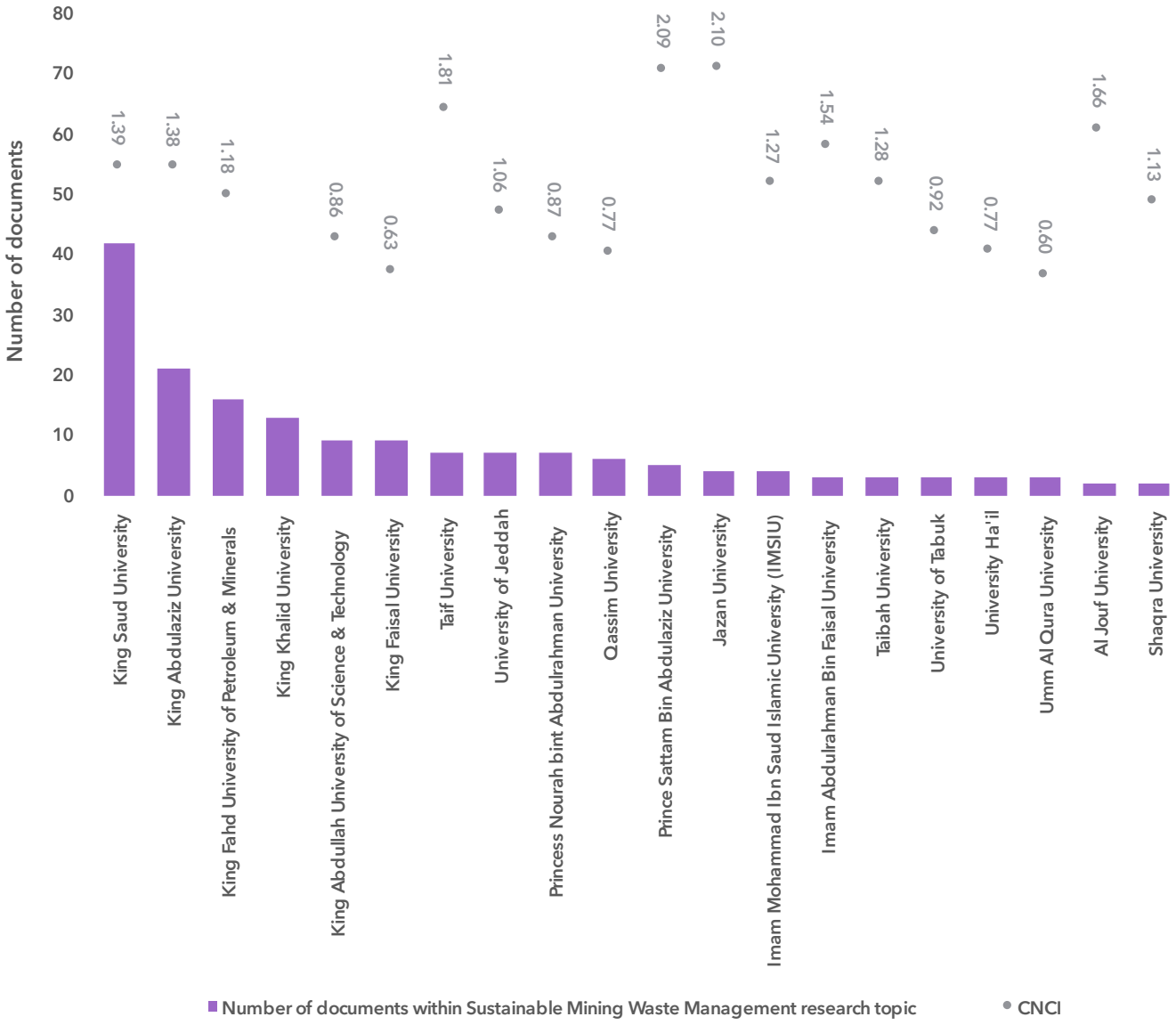


Figure 45: Top 20 Saudi organizations in terms of publications published in the research topic Sustainable Mining Waste Management in the period 2014-2023 and their corresponding CNCI

4.1.3.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

Four of the top 20 researchers in terms of the number of publications published in this research topic have three publications in this research topic, as shown in *Table 13*. Almost all the remaining have two publications.

The highest CNCI is achieved by publications published by T. M. Yunus Khan affiliated with King Khalid University with a CNCI of 2.41. The latter researcher has also the highest number of Top 10% amounting to 2 publications.

None of the researchers among the top 20 has a document among the Top 1%.

Table 13: Top 20 researchers affiliated with Saudi organizations in terms of the number of publications published on the research topic Sustainable Mining Waste Management in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Albidah, Abdulrahman S.	King Saud University	3	1.17	0	0
Khan, T. M. Yunus	King Khalid University	3	2.41	0	2
Ahmad, Shamsad	King Fahd University of Petroleum & Minerals	3	1.21	0	1
Saleh, Tawfik A.	King Fahd University of Petroleum & Minerals	3	1.21	0	1
Zaki, Magdi E. A.	Imam Mohammad Ibn Saud Islamic University (IMSIU)	2	1.84	0	0
Hong, Pei-Ying	King Abdullah University of Science & Technology	2	0.06	0	0
Al-Osta, Mohammed A.	King Fahd University of Petroleum & Minerals	2	0.37	0	0
Muraza, Oki	King Fahd University of Petroleum & Minerals	2	0.31	0	0
Al-Senani, Ghadah M.	Princess Nourah bint Abdulrahman University	2	0.26	0	0
Pugazhendi, Arulazhagan	King Abdulaziz University	2	0.69	0	0
Kheimi, Marwan	King Abdulaziz University	2	0.71	0	0
Ul-Hamid, Anwar	King Fahd University of Petroleum & Minerals	2	2.09	0	1
Khan, Moonis Ali	King Saud University	2	0.64	0	0
Saikaly, Pascal E.	King Abdullah University of Science & Technology	2	2.05	0	1
Ben Rebah, Faouzi	King Khalid University	2	1.49	0	1
Tahoon, Mohamed A.	King Khalid University	2	1.49	0	1
Hassan, Hassan M. A.	Al Jouf University	2	1.66	0	0
Galadima, Ahmad	King Fahd University of Petroleum & Minerals	2	0.31	0	0
Jamal, Mamdoh T.	King Abdulaziz University	2	0.69	0	0
Altamimi, Mohammad A.	King Saud University	1	0.00	0	0

4.1.3.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (3,364 publications), followed by India (1,106 publications) and the United States (973 publications), as shown in Figure 46.

The highest citation impact measured by the CNCI is achieved by publications published by Australia, United Kingdom and United States with a CNCI of 1.51, 1.42 and 1.26 respectively.

Also, India achieved a CNCI of 1.26 for this research topic. Four of the top 10 countries, in terms of the number of publications published on the research topic, are also among the top 10 collaborators with Saudi Arabia. These are Mainland China, India, Australia and the United Kingdom.

Figure 46: Top 10 countries in terms of the number of publications in the research topic Sustainable Mining Waste Management in the period 2014-2023 and their corresponding CNCI

4.1.3.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are the Chinese Academy of Sciences (296 publications) followed by Central South University (295 publications) and the Russian Academy of Sciences (216 publications) respectively as shown in Figure 47.

In terms of citation impact measured by the CNCI, KU Leuven, followed by the University of Science & Technology Beijing and Council of Scientific & Industrial Research (CSIR) - India had the highest CNCI with 1.81, 1.46 and 1.44, respectively.

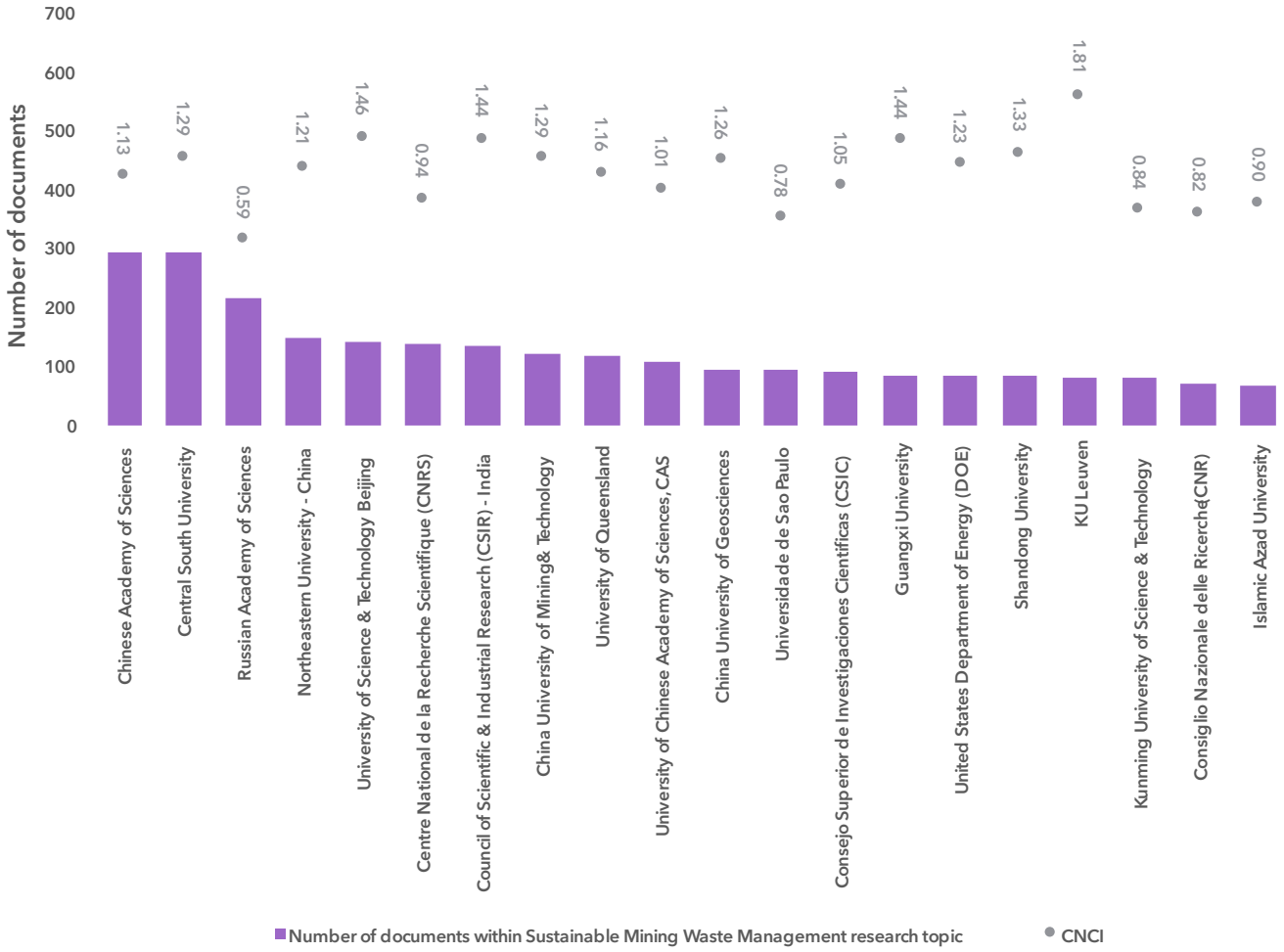


Figure 47: Top 20 organizations globally in terms of the number of publications published in the research topic Sustainable Mining Waste Management in the period 2014-2023 and their corresponding CNCI

4.1.3.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications on this research topic are Shengguo Xue, affiliated with Central South University, with 55 publications, followed by Feng Zhu, affiliated with Central South University, with 51 publications, and Xiaoming Liu, affiliated to University of Science & Technology Beijing with 39 publications sharing the same number of publications with William Hartley affiliated with Harper Adams University as shown in Table 14.

The highest CNCI among the top 20 researchers globally is achieved by Koen Binnemans affiliated to KU Leuven with a CNCI of 2.58.

The latter and Jiakuan Yang, affiliated with Huazhong University of Science & Technology, have the highest number of Top 1% publications, amounting to 3 publications.

Xiaoming Liu affiliated to University of Science & Technology Beijing has the highest number of Top 10% publications amounting to 16 publications.

Table 14: Top 20 researchers globally in terms of the number of publications published on the research topic Sustainable Mining Waste Management in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Xue, Shengguo	Central South University	55	1.70	1	13	Mainland China
Zhu, Feng	Central South University	51	1.54	1	8	Mainland China
Liu, Xiaoming	University of Science & Technology Beijing	39	2.11	2	16	Mainland China
Hartley, William	Harper Adams University	39	1.85	1	9	Wales
Yang, Jiakuan	Huazhong University of Science & Technology	28	2.54	3	11	Mainland China
Binnemans, Koen	KU Leuven	26	2.58	3	12	Belgium
Li, Zhaofeng	Shandong University	25	1.69	0	10	Mainland China
Jiang, Jun	Central South University	24	1.06	0	2	Mainland China
Pontikes, Yiannis	KU Leuven	24	2.25	2	8	Belgium
Zhang, Jian	Shandong University	24	1.74	0	10	Mainland China
Gao, Yifan	Shandong University	22	1.75	0	9	Mainland China
Sun, Wei	Central South University	22	1.11	0	3	Mainland China
Friedrich, Bernd	RWTH Aachen University	22	1.17	0	4	Germany
Zhang, Ting-an	Northeastern University - China	22	1.98	1	6	Mainland China
Wu, Chuan	Central South University	21	2.11	1	7	Mainland China
Liu, Yan	Northeastern University - China	21	2.09	2	4	Mainland China
Courtney, Ronan	University of Limerick	21	1.10	0	3	Ireland
Liang, Sha	Huazhong University of Science & Technology	20	2.36	1	9	Mainland China
Lv, Guozhi	Northeastern University - China	20	0.45	0	1	Mainland China
Panias, Dimitrios	National Technical University of Athens	20	1.34	1	3	Greece

4.1.3.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC) with 1,957 publications, followed by Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPQ) with 356 publications, and the European Union (EU) with 331 publications as shown in Figure 48.

The highest citation impact measured by the CNCI is observed in publications funded by Australian Research Council followed by Fundamental Research Funds for the Central Universities and UK Research & Innovation (UKRI) with 2.07, 1.69 and 1.64 respectively.

Among the top 20 global funding organizations, 5 are also among the top 20 funding organizations of Saudi publications in this research topic.

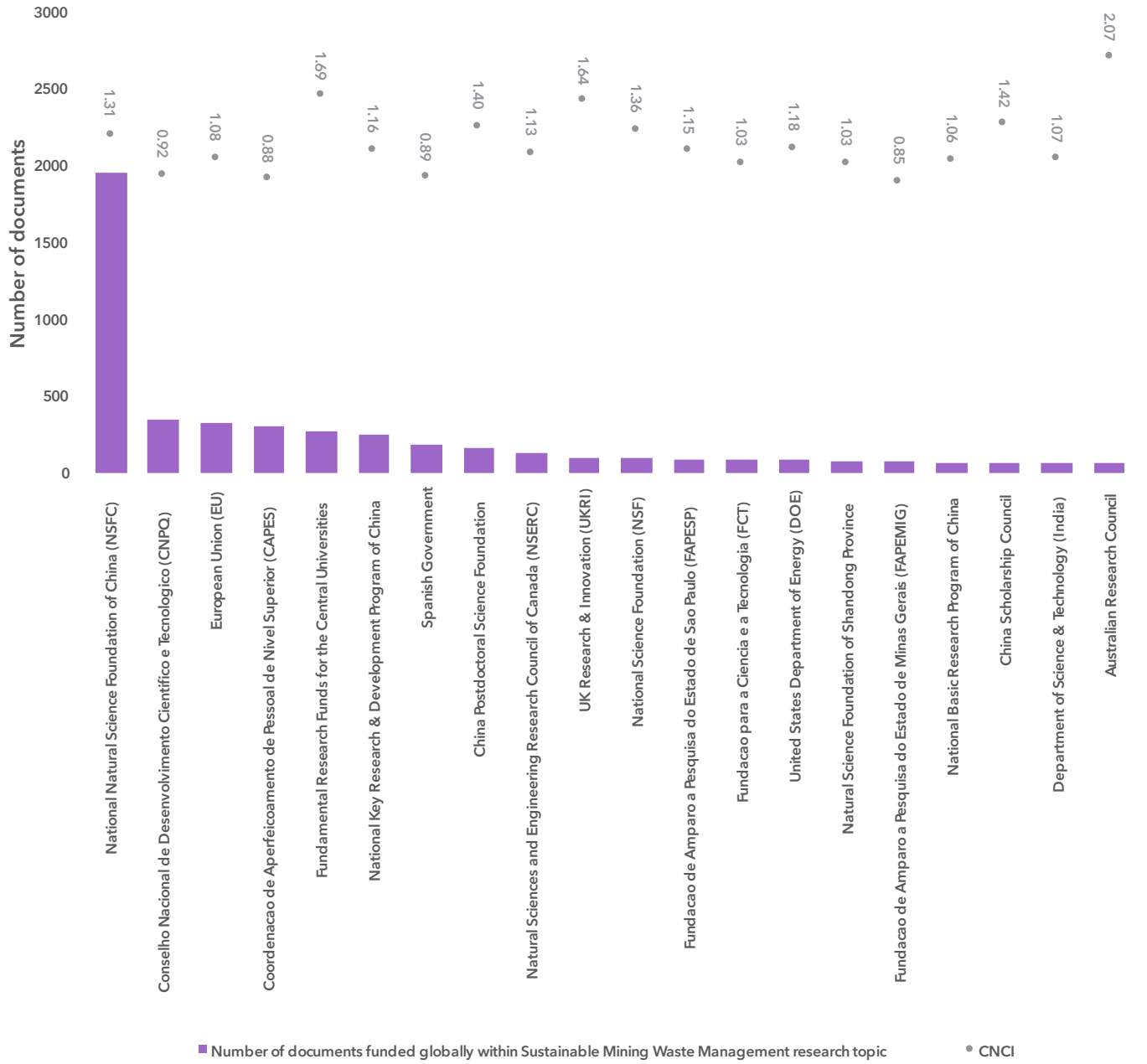


Figure 48: Top 20 funding organizations globally publications in the research topic Sustainable Mining Waste Management in terms of number of publications in the period 2014-2023

4.1.3.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section we investigate the emerging trends globally and in Saudi Arabia in the research topic Sustainable Mining Waste Management. For more information on the methodology used to identify emerging trends, please see the definitions section for Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Mineral & Metal Processing: Red Mud followed by Nanoparticles: Silver Nanoparticles and Photocatalysts: Photocatalysis as shown in Figure 49.

Table 15 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic. Among the identified global top 20 emerging micro-topics Saudi Arabia has publications in Nanoparticles: Silver Nanoparticles, Mineral & Metal Processing: Red Mud, Photocatalysts: Photocatalysis and Ionic, Molecular & Complex Liquids: Ionic Liquids.

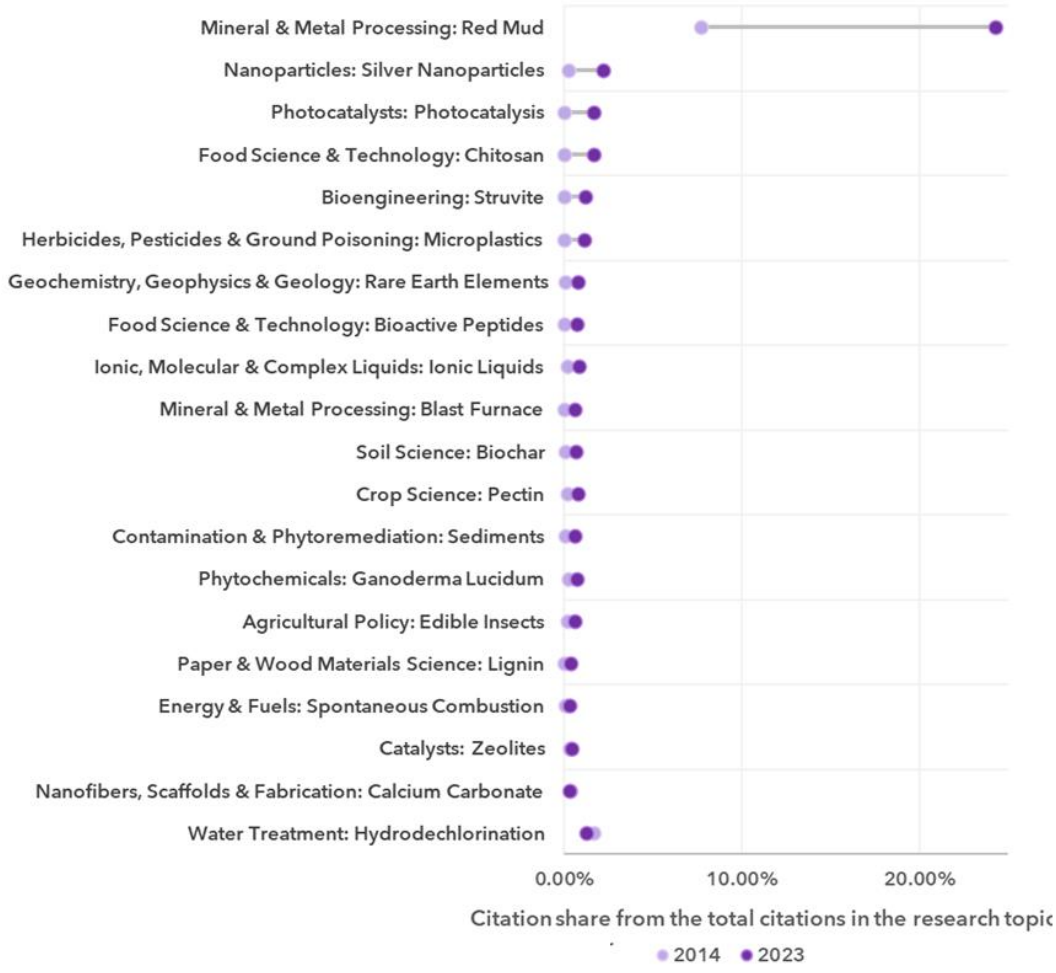


Figure 49: Top 20 emerging micro-topics globally in the research topic Sustainable Mining Waste Management in the period 2014-2023

Table 15: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic Sustainable Mining Waste Management in the period 2014-2023

Topic	Number of Saudi Arabian publications in the period 2014-2023
Sustainable Mining Waste Management	158
Concrete Science: Compressive Strength	16
Water Treatment: Adsorption	15
Nanoparticles: Silver Nanoparticles	12
Mineral & Metal Processing: Red Mud	7
Contamination & Phytoremediation: Heavy Metals	6
Phytochemicals: Antioxidant Activity	5
Combustion: Biodiesel	4
Energy & Fuels: Gasification	4
Catalysts: Fischer-Tropsch Synthesis	3
Thermodynamics: Bubble Column	3

4.1.4 Digital Twins

4.1.4.1 Evolution of Saudi publication share of global publications in the research topic

In 2014 and 2017, Saudi Arabia did not have any publications on the research topic. Since 2018, the share of Saudi Arabian publications from global publications on the research topic increased almost continuously till 2023, as shown in Figure 50.

This shows that Saudi Arabia was able to increase the number of publications on this research topic with a growth rate higher than the global growth rate. This is evident as the share of Saudi Arabian publications in the research topic is growing.

The CNCI of Saudi Arabian publications in this research topic were in all years higher than 1, indicating a citation impact performance higher than the global average.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic between 2018 and 2023 and had a relatively good citation impact as measured by the CNCI.

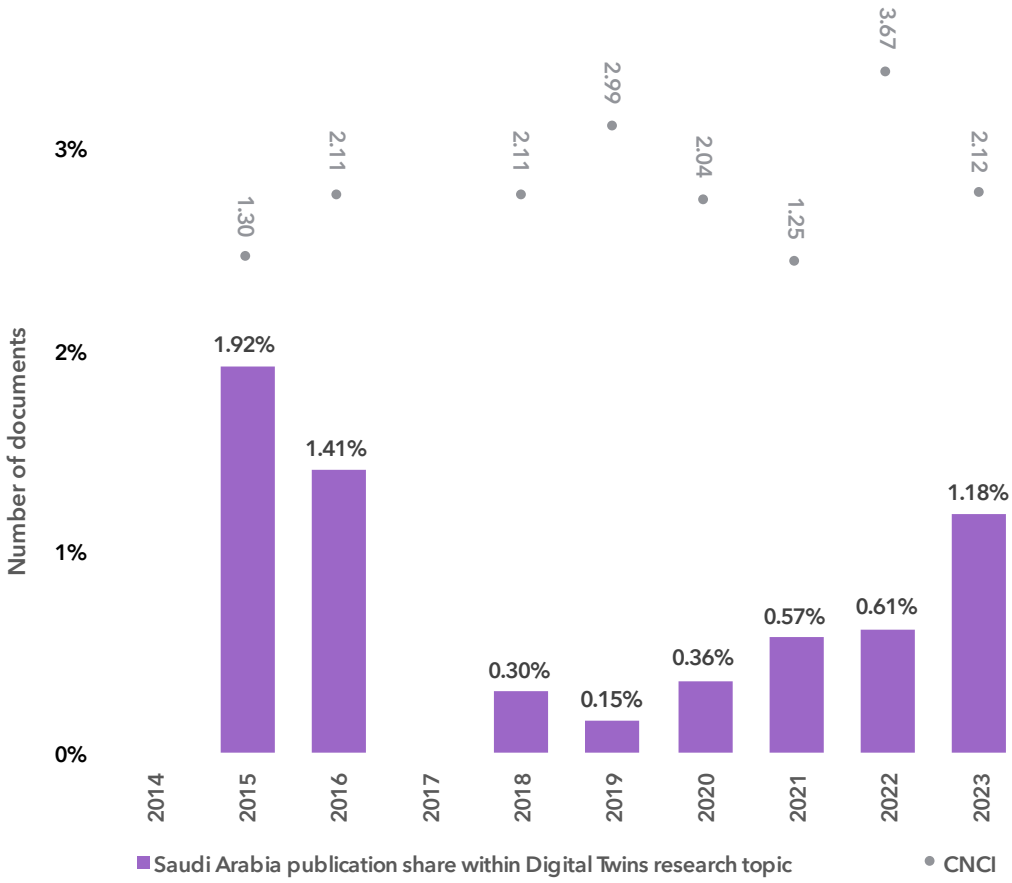


Figure 50: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.4.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is India, followed by Mainland China and Egypt, sharing the same number of publications with the United Kingdom with 18, 15 and 12 publications, respectively, as shown in Figure 51.

In terms of citation impact measured by the CNCI publications published in collaboration with Australia followed by Pakistan and Malaysia had the highest CNCI with 7.34, 3.97 and 3.81 respectively.

Nevertheless, all publications with the top 10 collaborating countries had a CNCI higher than 1, reflecting a performance higher than the global average.

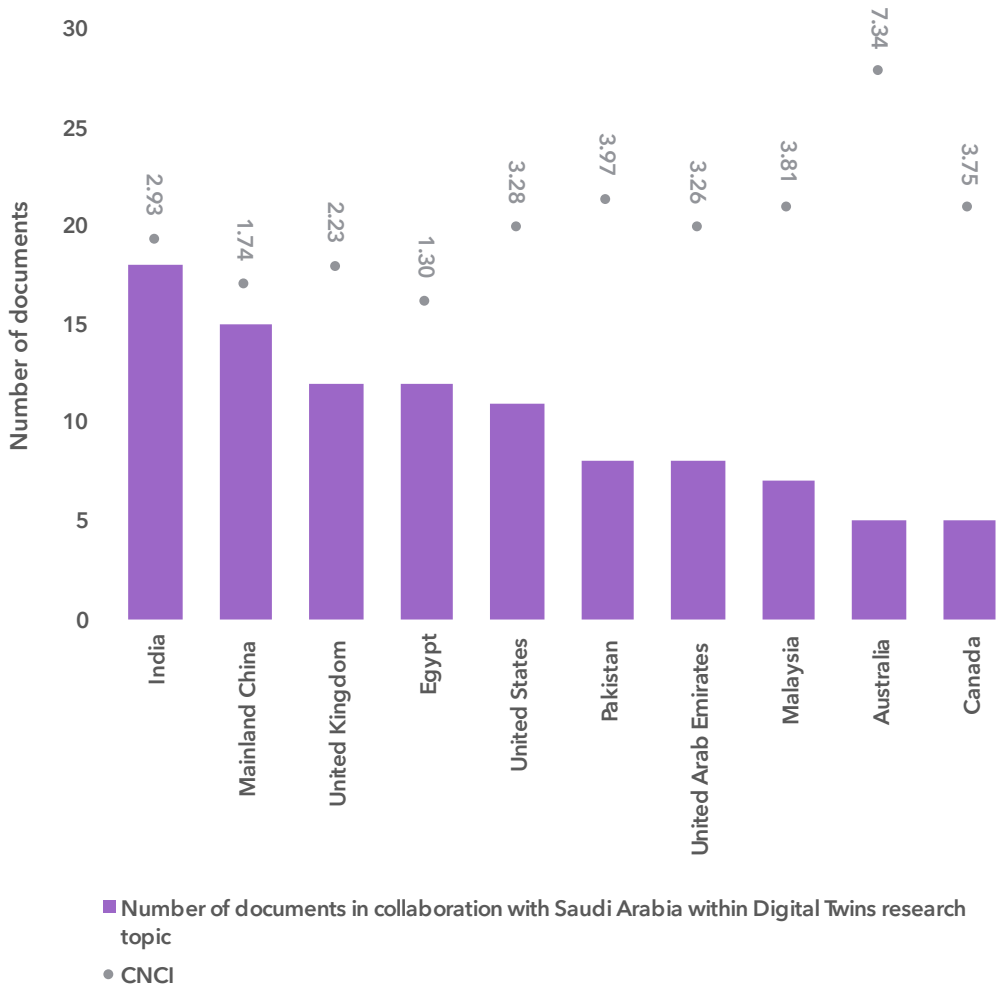


Figure 51: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic Digital Twins in the period 2014-2023

4.1.4.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by the National Natural Science Foundation of China (NSFC) and Princess Nourah bint Abdulrahman University with 12, 7 and 5 publications respectively as shown in Figure 52.

Documents funded European Union (EU) and Science Foundation Ireland with the same CNCI, followed by King Saud University followed by Ministry of Education (MOE), Republic of Korea had the highest citation impact measured by the CNCI with 6.11, 2.18 and 1.96 respectively.

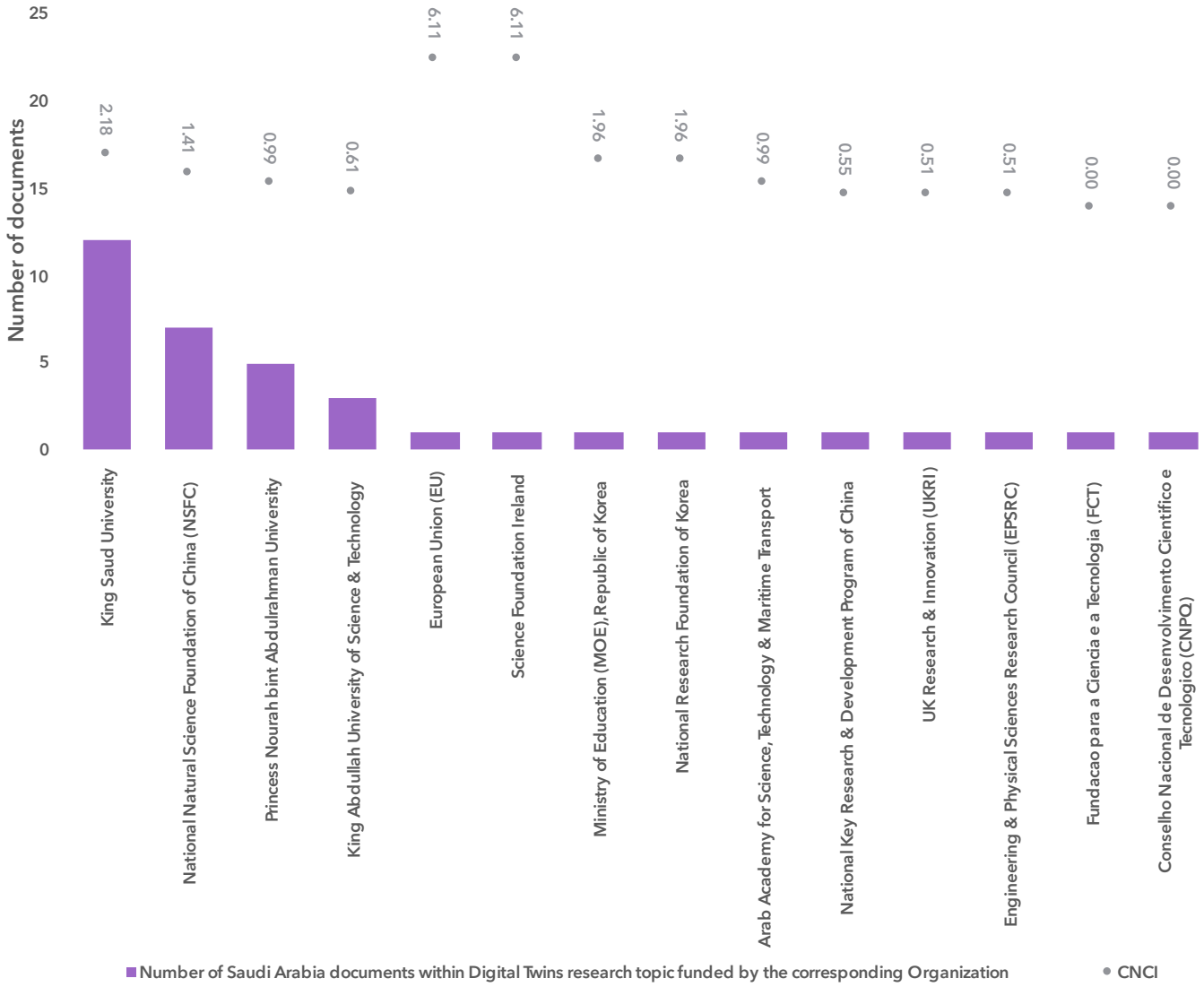


Figure 52: Top 20 funding organizations of Saudi Arabian publications in the research topic Digital Twins in terms of number of publications in the period 2014-2023

4.1.4.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published on this research topic in the period 2014-2023 are King Saud University, followed by Prince Sattam Bin Abdulaziz University and King Abdulaziz University, with the same number of publications as King Abdullah University of Science & Technology with 19, 10 and 9 publications respectively as shown in Figure 53.

In terms of citation impact as measured by the CNCI, Taif University, followed by Najran University and Al Baha University, had the highest CNCI with 9.01, 7.73 and 7.59, respectively.

Except Al Jouf University, Umm Al Qura University, Saudi Electronic University and University of Jeddah, all top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

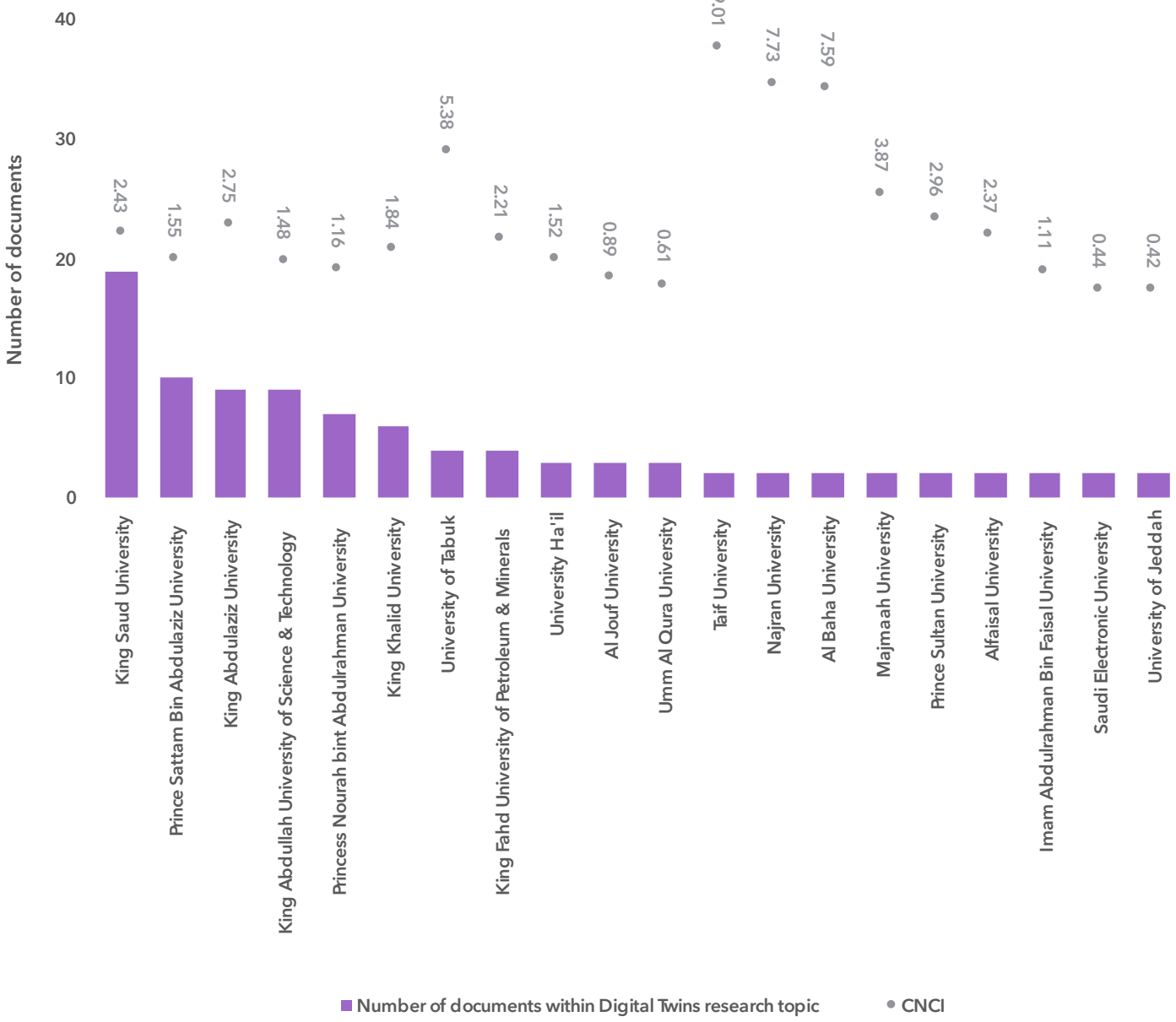


Figure 53: Top 20 Saudi organizations in terms of publications published in the research topic Digital Twins in the period 2014-2023 and their corresponding CNCI

4.1.4.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Abdulrahman M. Al-Ahmari and Bashir Salah, both affiliated with King Saud University, with 3 publications, as shown in Table 16.

The highest CNCI is achieved by publications published by Ahamed Aljuhani affiliated with University of Tabuk with a CNCI of 9.02.

The latter researcher has also the only Top 1% among the top 20 researchers in terms of number of publications. Also, Ahamed Aljuhani has the highest number of Top 10% publications amounting to 2 publications.

Three other researchers also have two Top 10% publications on the research topic.

Table 16: Top 20 researchers affiliated with Saudi organizations in terms of the number of publications published on the research topic Digital Twins in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Al-Ahmari, Abdulrahman M.	King Saud University	3	1.40	0	0
Salah, Bashir	King Saud University	3	1.15	0	0
Alouini, Mohamed-Slim	King Abdullah University of Science & Technology	2	3.81	0	2
Abidi, Mustufa Haider	King Saud University	2	1.49	0	1
Imran, Muhammad	King Saud University	2	4.91	0	2
Abbas, Mohamed	King Khalid University	2	3.03	0	1
Ahmed, Shehab	King Abdullah University of Science & Technology	2	0.49	0	0
El-Shafai, Walid	Prince Sultan University	2	2.96	0	2
Darmoul, Saber	King Saud University	2	1.05	0	0
Zhang, Tao	King Abdullah University of Science & Technology	2	0.74	0	0
Sun, Shuyu	King Abdullah University of Science & Technology	2	0.74	0	0
Aljuhani, Ahamed	University of Tabuk	2	9.02	1	2
Ghoniem, Rania M.	Princess Nourah bint Abdulrahman University	2	1.27	0	0
Alkhalefah, Hisham	King Saud University	2	2.55	0	1
Alzahmi, Ahmed	University of Tabuk	1	1.22	0	0
Abdelhafez, Mohamed H. H.	University Ha'il	1	0.28	0	0
Hossain, M. Shamim	King Saud University	1	2.87	0	0
Zuo, Shouwei	King Abdullah University of Science & Technology	1	0.55	0	0
Al-Mutiri, Fuad	King Khalid University	1	1.68	0	0
Alkahtani, Manal E.	Prince Sattam Bin Abdulaziz University	1	0.51	0	0

4.1.4.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (2,528 publications), followed by the United States (1,520 publications) and Germany (1,472 publications), as shown in Figure 54.

The highest citation impact measured by the CNCI is achieved by publications published by Sweden, United States and United Kingdom with a CNCI of 2.52, 2.49 and 2.40 respectively.

Three of the top 10 countries in terms of number of publications published in the research topic are also among the top 10 collaborators with Saudi Arabia. These are United States, Mainland China and United Kingdom.

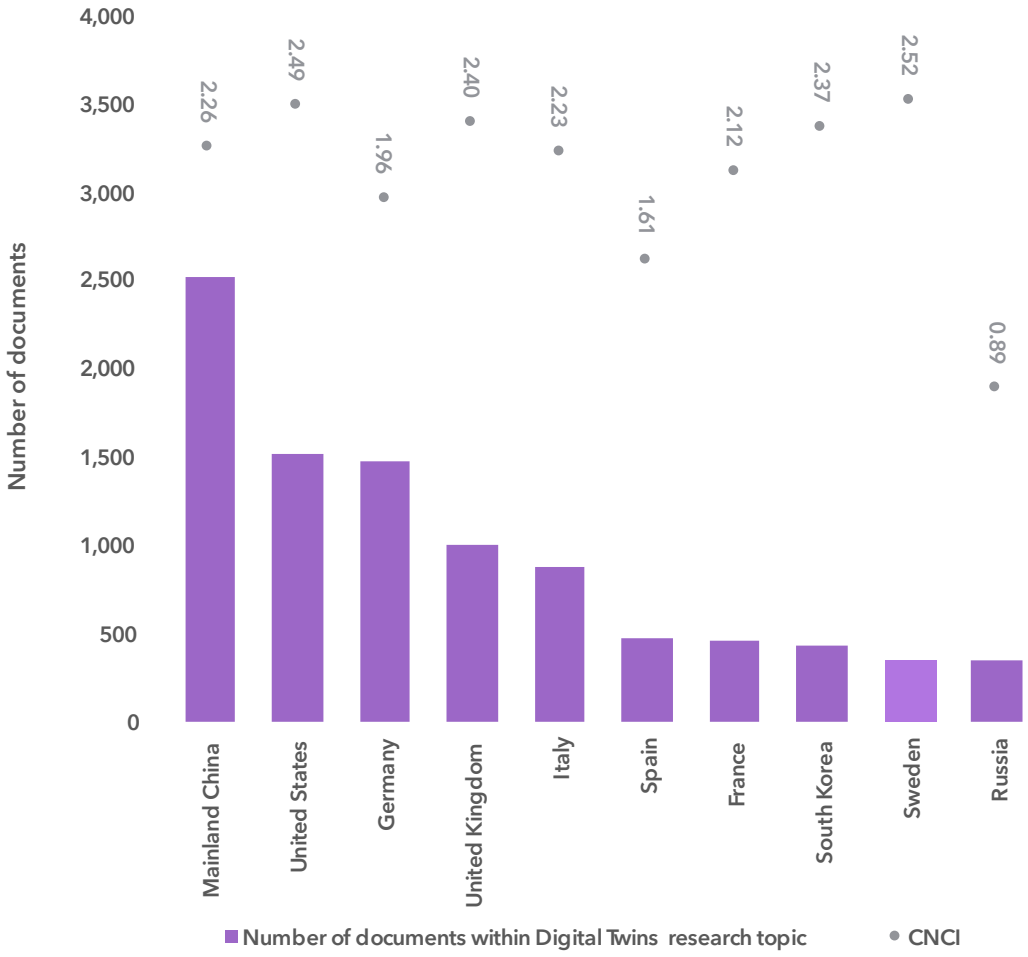


Figure 54: Top 10 countries in terms of number of publications in the research topic Digital Twins in the period 2014-2023 and their corresponding CNCI

4.1.4.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are RWTH Aachen University (162 publications), followed by Centre National de la Recherche Scientifique (CNRS) (160 publications) and Polytechnic University of Milan (143 publications) respectively as shown in Figure 55.

In terms of citation impact measured by the CNCI, Beihang University, followed by Siemens AG and Hong Kong Polytechnic University, had the highest CNCI with 5.10, 4.14 and 4.02, respectively.

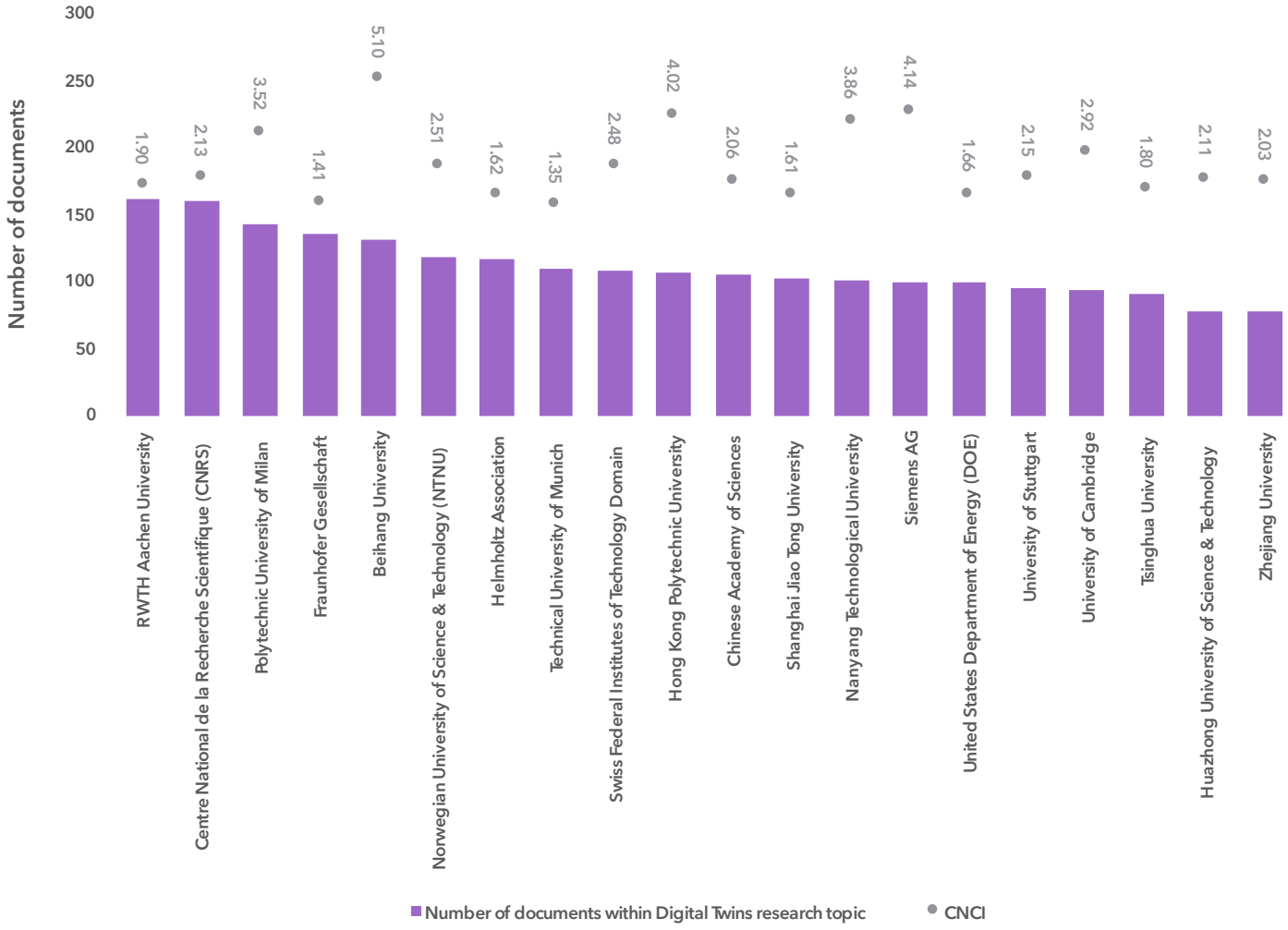


Figure 55: Top 20 organizations globally in terms of number of publications published in the research topic Digital Twins in the period 2014-2023 and their corresponding CNCI

4.1.4.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications in this research topic are Fei Tao affiliated with Beihang University, with 46 publications, followed by Zhihan Lv, affiliated with Uppsala University, with 45 publications, and Jochen Strube, affiliated with TU Clausthal, with 31 publications, as shown in Table 17.

The highest CNCI among the top 20 researchers globally is achieved by Tao Fei, affiliated with Beihang University, with a CNCI of 10.73.

The latter has also the highest Top 1% publications amounting to 17 publications and Top 10% publications amounting to 28 publications.

Table 17: Top 20 researchers globally in terms of the number of publications published on the research topic Digital Twins in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Tao, Fei	Beihang University	46	10.73	17	28	Mainland China
Lv, Zhihan	Uppsala University	45	3.49	7	14	Sweden
Strube, Jochen	TU Clausthal	31	0.93	0	0	Germany
Weyrich, Michael	University of Stuttgart	30	2.48	3	10	Germany
Rossmann, Juergen	RWTH Aachen University	29	2.19	2	7	Germany
Zhang, Yan	University of Oslo	28	8.39	13	20	Norway
Soderberg, Rikard	Chalmers University of Technology	27	1.58	1	5	Sweden
Zheng, Pai	Hong Kong Polytechnic University	26	3.40	3	15	Hong Kong
Leng, Jiewu	Guangdong University of Technology	25	4.90	8	15	Mainland China
Bao, Jinsong	Donghua University	25	3.04	3	12	Mainland China
Liu, Qiang	Guangdong University of Technology	24	5.02	8	14	Mainland China
Tan, Jianrong	Zhejiang University	23	1.46	0	4	Mainland China
Zhong, Ray Y.	University of Hong Kong	23	4.35	2	16	Hong Kong
Warmefjord, Kristina	Chalmers University of Technology	23	1.51	1	3	Sweden
Kuts, Vladimir	Tallinn University of Technology	22	1.52	0	8	Estonia
Liu, Zhansheng	Beijing University of Technology	21	1.41	0	5	Mainland China
Noh, Sang Do	Sungkyunkwan University (SKKU)	21	2.51	0	10	South Korea
Liu, Xiaojun	Southeast University - China	21	3.15	3	11	Mainland China
Wang, Lihui	Royal Institute of Technology	20	6.79	4	12	Sweden
Schmidt, Axel	TU Clausthal	20	1.06	0	0	Germany

4.1.4.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC) with 1,229 publications, followed by the European Union (EU) with 670 publications, and UK Research & Innovation (UKRI) with 280 publications, as shown in Figure 56.

The highest citation impact measured by the CNCI is observed in publications funded by H2020 Societal Challenges Programme followed by Horizon 2020 and National Key Research & Development Program of China with 5.60, 4.30 and 3.73 respectively.

Among the top 20 global funding organizations, 6 are also among the top 20 funding organizations of Saudi publications in this research topic.

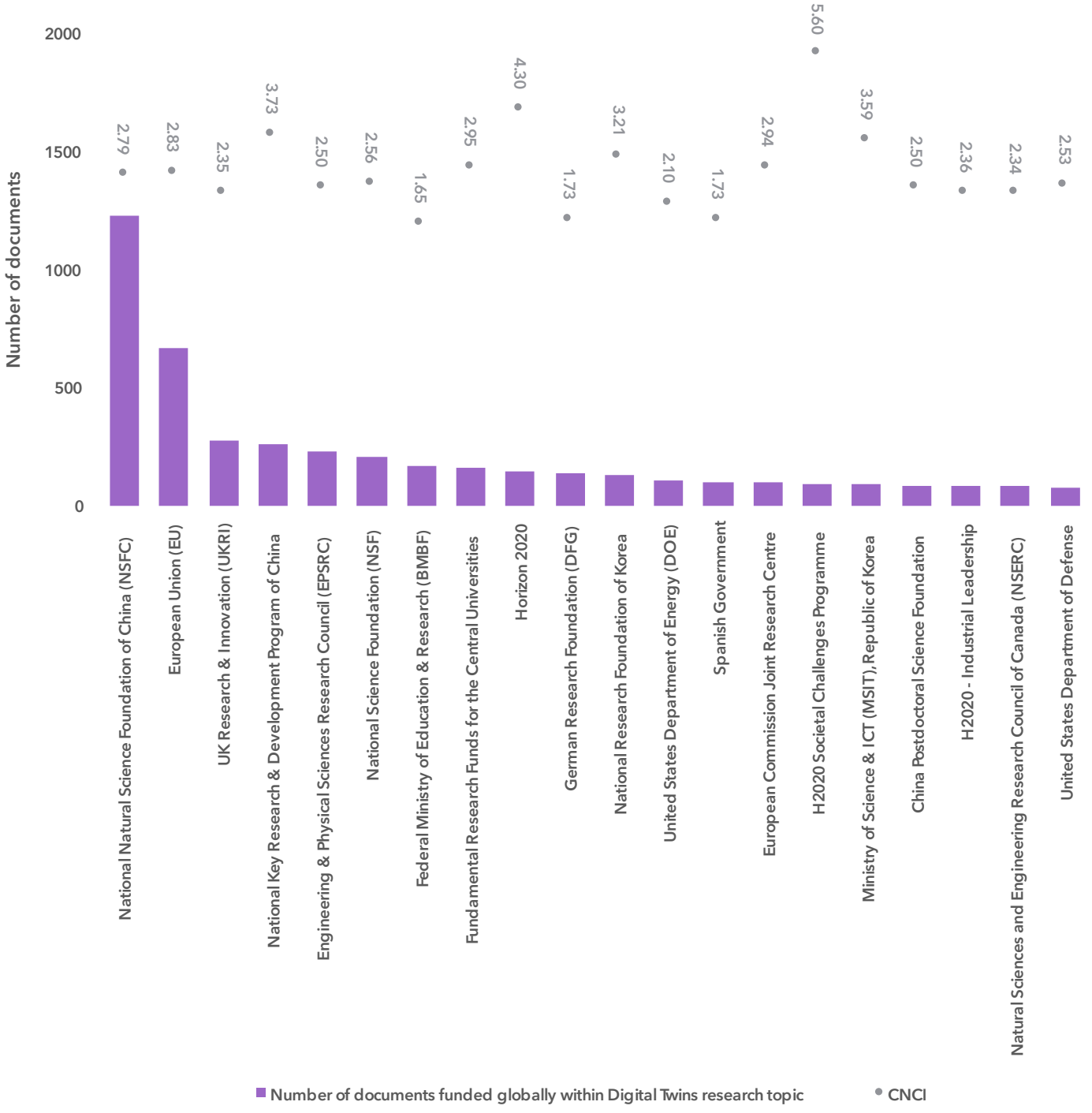


Figure 56: Top 20 funding organizations globally publications in the research topic Digital Twins in terms of number of publications in the period 2014-2023

4.1.4.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section, we investigate the emerging trends globally and in Saudi Arabia on the research topic of Digital Twins. For more information on the methodology used to identify emerging trends, please see the definitions section for Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Security Systems: Blockchain followed by Friction & Vibration, Fault Diagnosis and Design & Manufacturing Project Scheduling, as shown in Figure 57.

It is worth noting that the micro-topics Human Computer Interaction: Augmented Reality and Nanofibers, Scaffolds & Fabrication: Additive Manufacturing are growing in terms of number of publications but shrinking in terms of citation share from the research topic.

Table 18 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic. From Saudi Arabia top 10 micro-topics, five are also among the identified global emerging micro-topics. Namely in Telecommunications: Internet of Things, Security Systems: Blockchain, Power Systems & Electric Vehicles: Distributed Generation, Security Systems: Differential Privacy and Human Computer Interaction: Augmented Reality.

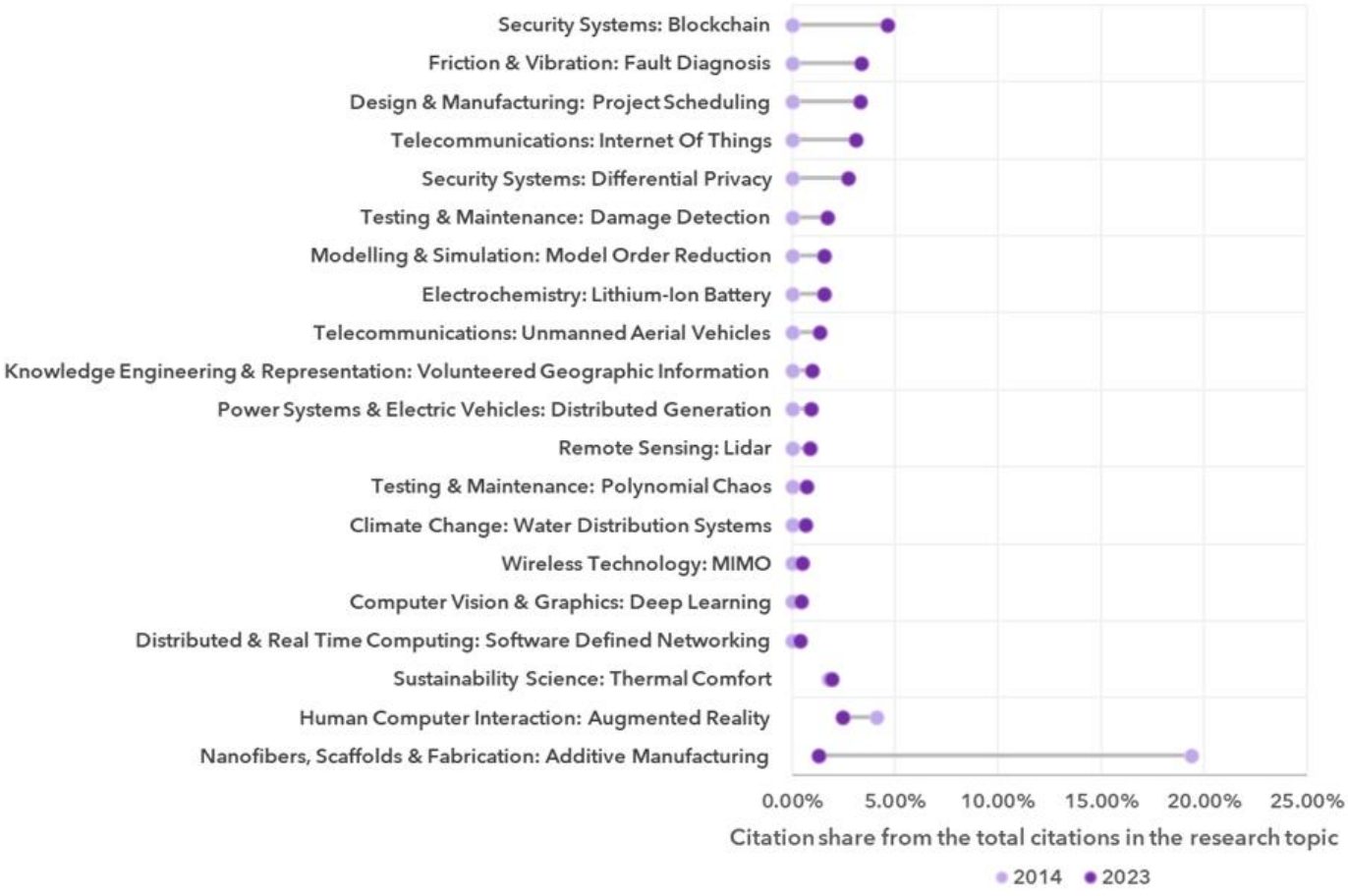


Figure 57: Top 20 emerging micro-topics globally in the research topic Digital Twins in the period 2014-2023

Table 18: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic Digital Twins in the period 2014-2023

Topic	Number of Saudi Arabian publications in the period 2014-2023
Digital Twins research topic	81
Design & Manufacturing: Industry 4.0	30
Telecommunications: Internet Of Things	5
Security Systems: Blockchain	3
Wireless Technology: MIMO	2
Design & Manufacturing: Process Planning	2
Computer Vision & Graphics: OCR	2
Power Systems & Electric Vehicles: Distributed Generation	2
Security Systems: Differential Privacy	2
Electrochemistry: Proton Conductivity	2
Human Computer Interaction: Augmented Reality	2

4.1.5 Net Zero - Industrial Emissions

4.1.5.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications on the research topic increased almost continuously from 2014 till 2023, as shown in Figure 58. This shows that Saudi Arabia was not only able to increase the number of publications in this research topic but also having a growth higher than the global growth rate.

This is evident as the share of Saudi Arabian publications in the research topic is growing. Although the CNCI fluctuated in the last 10 years between 1.14 and 4.60 in the period 2014-2023, the CNCI of Saudi Arabian publications in this research topic was in all years higher than 1, indicating a citation impact performance higher than the global average.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic and had a relatively good citation impact as measured by the CNCI.

Figure 58: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.5.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is Pakistan, followed by Mainland China and the United Kingdom, India and Malaysia, sharing the same number of publications with 28, 25 and 12 publications, respectively as shown in Figure 59.

In terms of citation impact measured by the CNCI publications published in collaboration with Malaysia, Egypt and Finland had the highest CNCI with 4.20, 3.57, and 2.55, respectively. Except for Vietnam, all publications with the top 10 collaborating countries had a CNCI higher than 1, reflecting a performance higher than the global average.

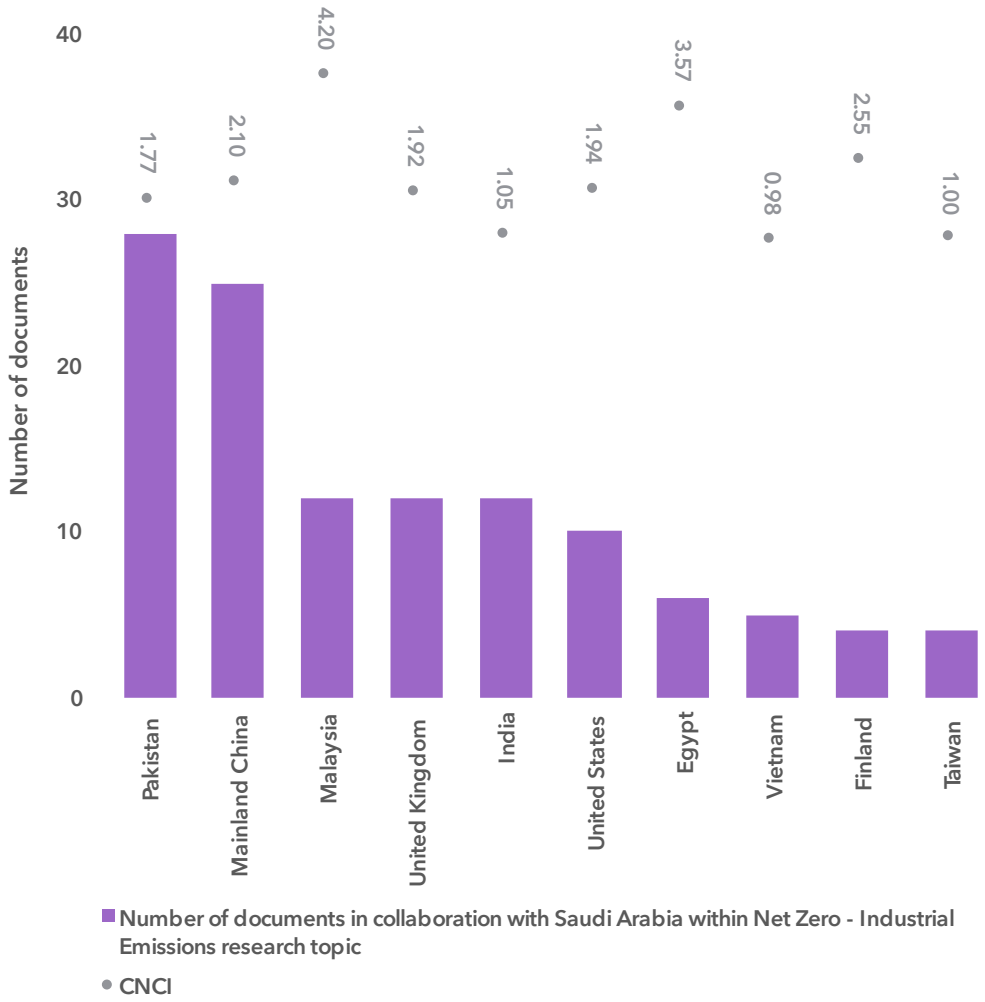


Figure 59: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic Net Zero - Industrial Emissions in the period 2014-2023

4.1.5.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by the National Natural Science Foundation of China (NSFC) and Princess Nourah bint Abdulrahman University with 19, 4 and 2 publications respectively as shown in Figure 60.

All other funding organizations had only one document. Documents funded by Princess Nourah bint Abdulrahman University, followed by the National Natural Science Foundation of China (NSFC), followed by Ministry of Science and Technology, Government of India, and the University Grants Commission, India, with the same CNCI had the highest citation impact measured by the CNCI with 4.42, 3.39 and 2.27 respectively.

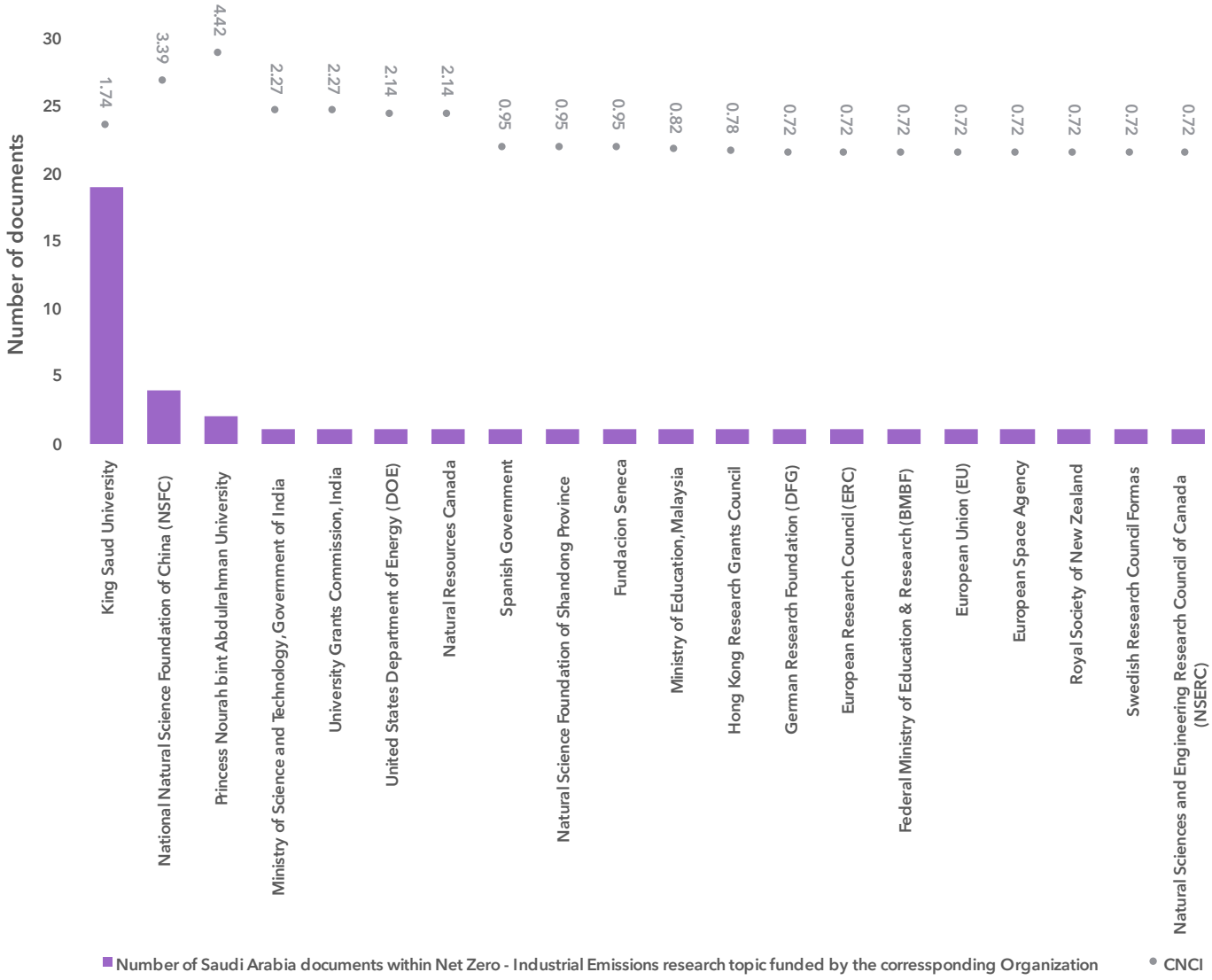


Figure 60: Top 20 funding organizations of Saudi Arabian publications in the research topic Net Zero - Industrial Emissions in terms of number of publications in the period 2014-2023

4.1.5.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published in this research topic and in the period 2014-2023 are King Saud University, followed by King Fahd University of Petroleum & Minerals and King Abdulaziz University, with 26, 13 and 9 publications, respectively, as shown in Figure 61.

In terms of citation impact as measured by the CNCI, Prince Sattam Bin Abdulaziz University, followed by Princess Nourah bint Abdulrahman University and King Fahd University of Petroleum & Minerals had the highest CNCI with 5.05, 4.42 and 3.43, respectively.

Twelve of the top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

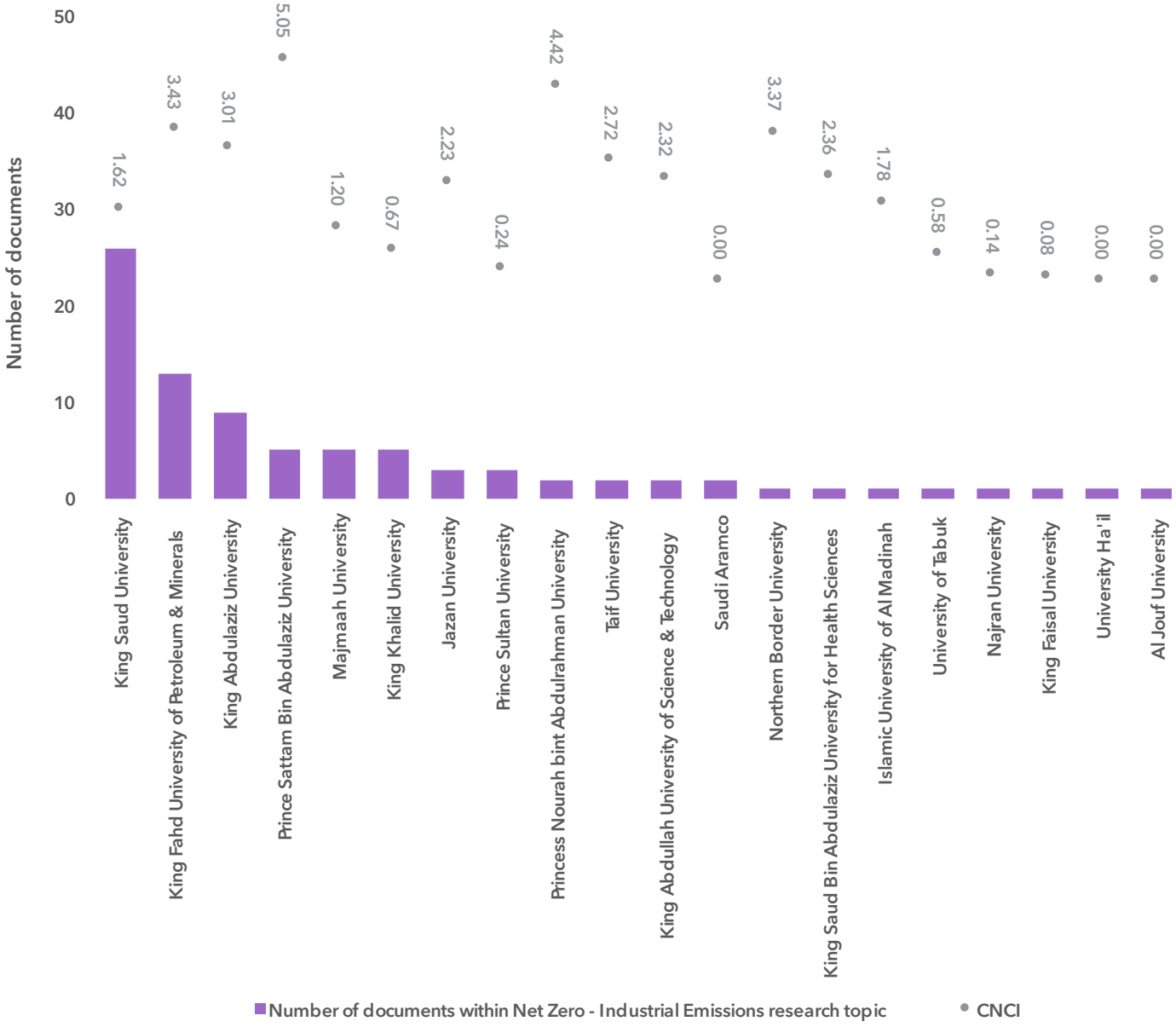


Figure 61: Top 20 Saudi organizations in terms of publications published in the research topic Net Zero - Industrial Emissions in the period 2014-2023 and their corresponding CNCI

4.1.5.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Abdelmohsen A. Nassani, Muhammad Moinuddin Qazi Abro, and Abdullah Mohammed Aldakhil, all affiliated with King Saud University, with 16, 10 and 4 publications, respectively, as shown in Table 19. The highest CNCI is achieved by publications published by Samia Elattar, affiliated with Princess Nourah bint Abdulrahman University with a CNCI of 8.12.

Though the latter has only one document published in this research topic, which is also a Top 1% document.

Two other researchers among the top 20 also have a Top 1% document. Abdelmohsen A. Nassani has the highest number of Top 10% publications, with a total of 6 publications on this research topic.

Table 19: Top 20 researchers affiliated with Saudi organizations in terms of the number of publications published in the research topic Net Zero - Industrial Emissions in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Nassani, Abdelmohsen A.	King Saud University	16	1.87	0	6
Abro, Muhammad Moinuddin Qazi	King Saud University	10	1.18	0	2
Aldakhil, Abdullah Mohammed	King Saud University	4	2.46	0	3
Selim, Shokri Z.	King Fahd University of Petroleum & Minerals	3	2.76	0	1
Askar, Sameh E.	King Saud University	3	1.02	0	1
Alkahtani, Mohammed	King Saud University	2	0.86	0	0
Alamri, Adel A.	Majmaah University	2	0.21	0	0
Alsenani, Theyab R.	Prince Sattam Bin Abdulaziz University	2	4.90	1	1
Hashem, Abeer	King Saud University	2	0.38	0	0
Selim, S. Z.	King Fahd University of Petroleum & Minerals	2	6.73	1	1
Abd Allah, Elsayed Fathi	King Saud University	2	0.38	0	0
Masoud, Mahmoud	King Fahd University of Petroleum & Minerals	1	2.21	0	0
Elattar, Samia	Princess Nourah bint Abdulrahman University	1	8.59	1	1
Elkatatny, Salaheldin	King Fahd University of Petroleum & Minerals	1	0.47	0	0
Ramli, Makbul A. M.	King Abdulaziz University	1	0.56	0	0
Qazi Abro, Muhammad Moinuddin	King Saud University	1	0.30	0	0
Hossain, Fahim	Imam Abdulrahman Bin Faisal University	1	1.83	0	0
Ghramh, Hamed A.	King Khalid University	1	0.58	0	0
Gascon, Jorge	King Abdullah University of Science & Technology	1	3.93	0	1
Sarathy, S. Mani	King Abdullah University of Science & Technology	1	3.93	0	1

4.1.5.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (2,755 publications), followed by the United States (1,501 publications) and the United Kingdom (615 publications), as shown in Figure 62.

The highest citation impact measured by the CNCI is achieved by publications published by United Kingdom, India and United States with a CNCI of 1.93, 1.87 and 1.73 respectively.

Four of the top 10 countries in terms of number of publications published in the research topic are also among the top 10 collaborators with Saudi Arabia. These are United States, Mainland China, United Kingdom and India.

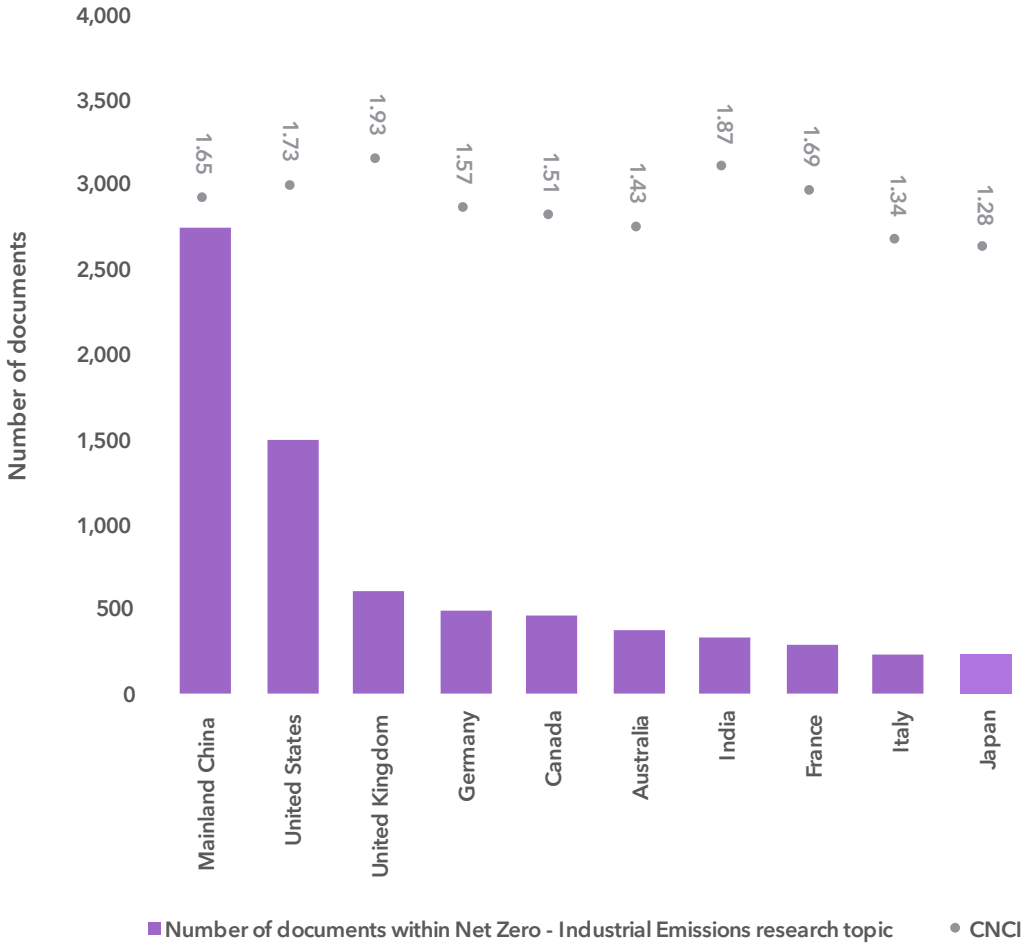


Figure 62: Top 10 countries in terms of the number of publications in the research topic Net Zero - Industrial Emissions in the period 2014-2023 and their corresponding CNCI

4.1.5.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are the Chinese Academy of Sciences (244 publications) followed by Tsinghua University (148 publications) and Centre National de la Recherche Scientifique (CNRS) (86 publications) respectively as shown in Figure 63.

In terms of citation impact measured by the CNCI, Beijing Institute of Technology followed by National Bureau of Economic Research and Technical University of Berlin had the highest CNCI with 2.65, 2.64 and 2.58 respectively.

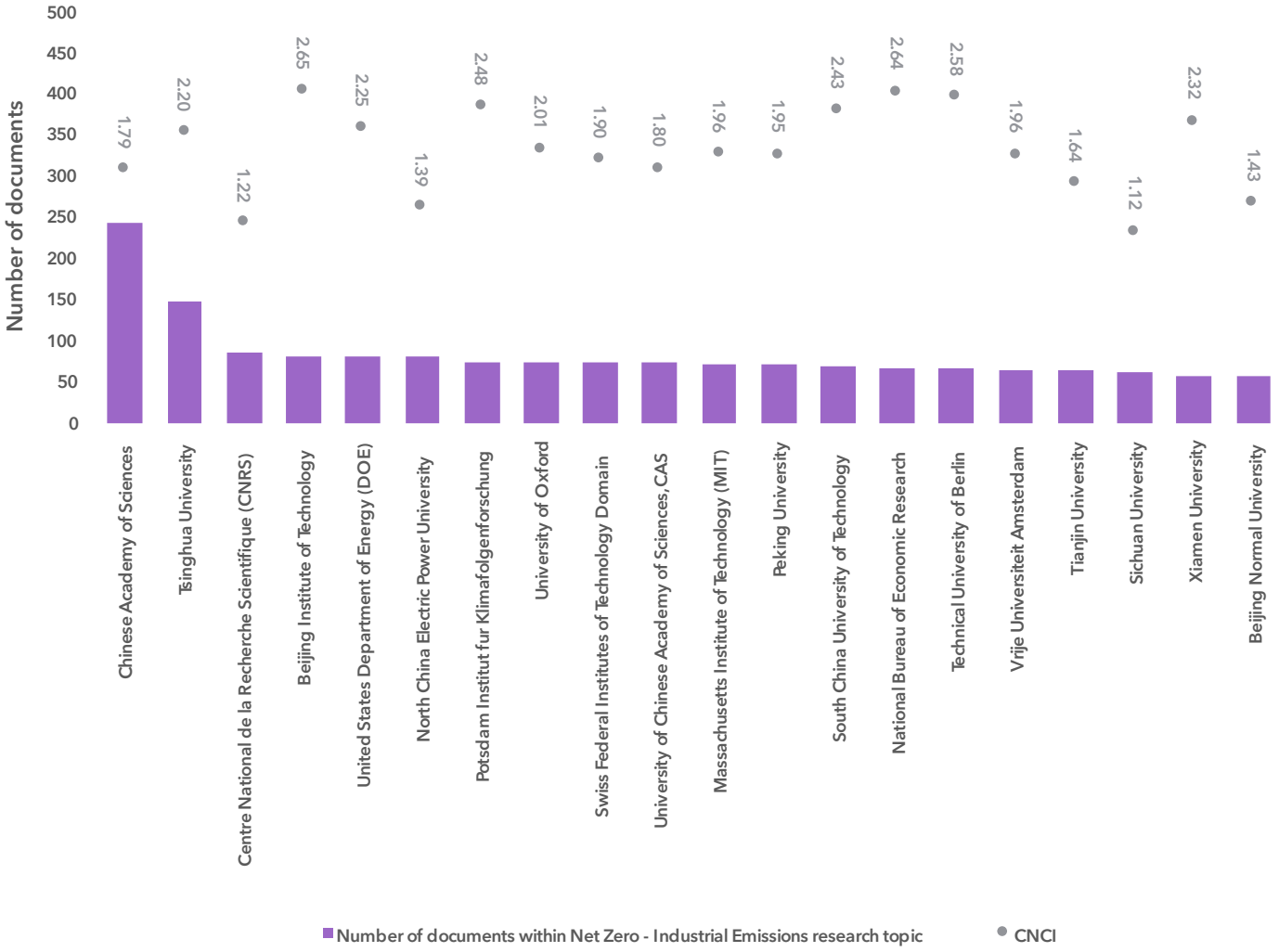


Figure 63: Top 20 organizations globally in terms of the number of publications published in the research topic Net Zero - Industrial Emissions in the period 2014-2023 and their corresponding CNCI

4.1.5.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications in this research topic are Boqiang Lin, affiliated to Xiamen University, with 34 publications, followed by Frederick van der Ploeg, affiliated to the University of Oxford, with 28 publications, and Ottmar Edenhofer, affiliated to Potsdam Institut fur Klimafolgenforschung with 35 publications as shown in Table 20.

The highest CNCI among the top 20 researchers globally is achieved by Biswajit Sarkar affiliated to Yonsei University with a CNCI of 6.10. The latter also has the highest Top 1% publications, amounting to 7 publications.

Boqiang Lin also has the highest number of publications in the Top 10%, amounting to 15 publications.

Table 20: Top 20 researchers globally in terms of the number of publications published in the research topic Net Zero - Industrial Emissions in the period 2014-2023

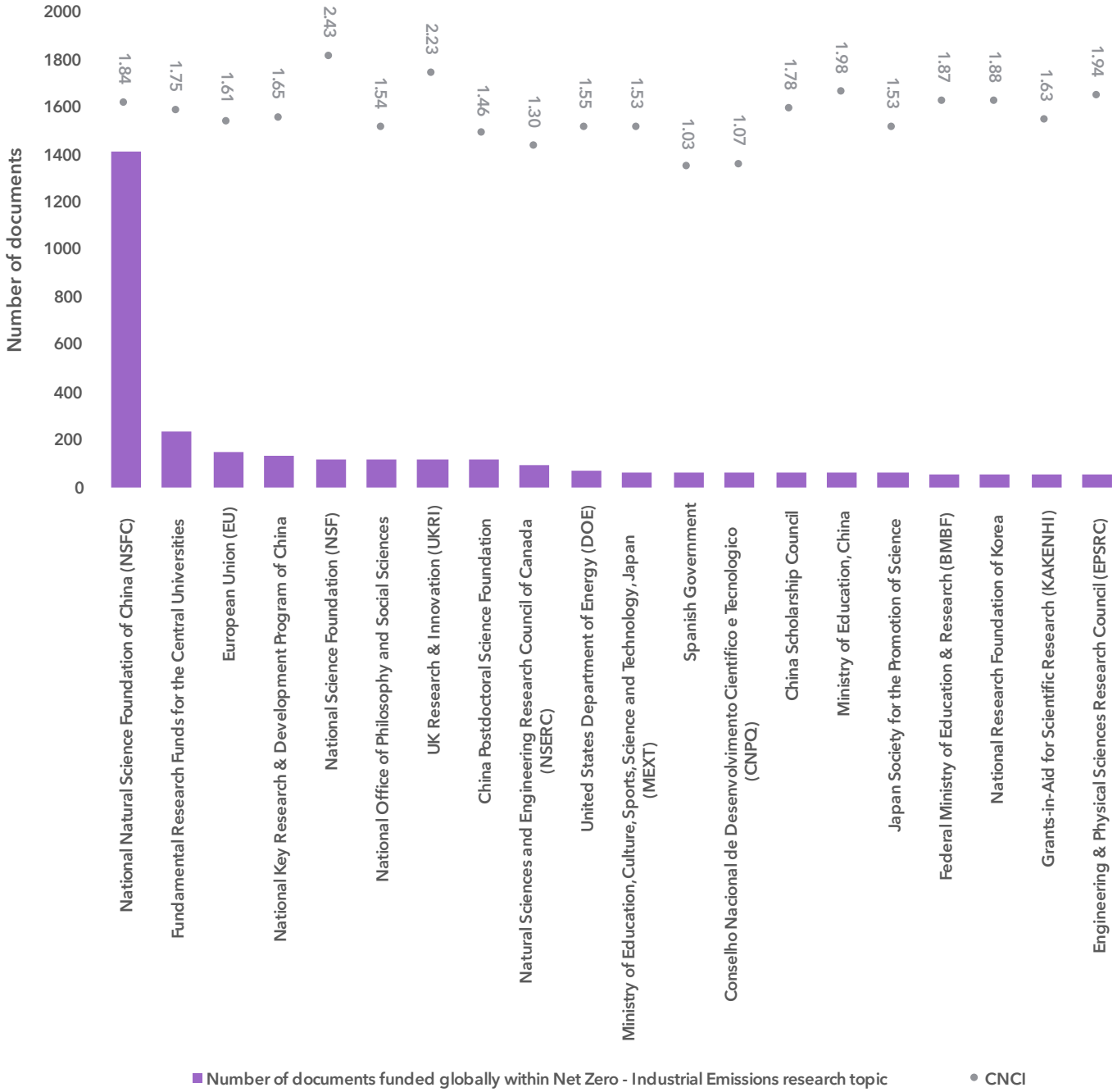
Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Lin, Boqiang	Xiamen University	34	2.70	4	15	Mainland China
van der Ploeg, Frederick	University of Oxford	28	0.98	0	1	England
Edenhofer, Ottmar	Potsdam Institut fur Klimafolgenforschung	25	2.10	1	9	Germany
Yang, Lei	South China University of Technology	24	2.80	6	8	Mainland China
Bai, Qingguo	Qufu Normal University	21	2.83	2	10	Mainland China
Wang, Chuanxu	Shanghai Maritime University	18	2.79	1	9	Mainland China
Fan, Ying	Beihang University	18	2.44	2	6	Mainland China
Xu, Jianteng	Qufu Normal University	17	2.08	0	7	Mainland China
Sarkar, Biswajit	Yonsei University	16	6.10	7	12	South Korea
Tsai, Wen-Hsien	National Central University	16	0.53	0	0	Taiwan
Liang, Qiao-Mei	Beijing Institute of Technology	16	1.38	0	3	Mainland China
Pan, Yanchun	Shenzhen University	15	2.33	1	5	Mainland China
Kriegler, Elmar	Potsdam Institut fur Klimafolgenforschung	14	3.77	2	7	Germany
Mardones, Cristian	Universidad de Concepcion	14	1.28	0	3	Chile
Axsen, Jonn	Simon Fraser University	13	2.48	1	5	Canada
Luderer, Gunnar	Potsdam Institut fur Klimafolgenforschung	13	3.60	2	6	Germany
Xu, Jiuping	Sichuan University	13	1.15	0	1	Mainland China
Wang, Can	Tsinghua University	13	2.24	1	4	Mainland China
Rausch, Sebastian	Massachusetts Institute of Technology (MIT)	12	1.76	0	3	United States
Xu, Xiaoping	Anhui University	12	4.60	3	8	Mainland China

4.1.5.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC), with 1,414 publications, followed by Fundamental Research Funds for the Central Universities, with 236 publications, and European Union (EU) with 147 publications, as shown in Figure 64.

The highest citation impact measured by the CNCI is observed in publications funded by National Science Foundation (NSF) followed by UK Research & Innovation (UKRI) and Ministry of Education, China with 2.43, 2.23 and 1.98 respectively.

Among the top 20 global funding organizations, 6 are also among the top 20 funding organizations of Saudi publications in this research topic.



4.1.5.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section, we investigate the emerging trends globally and in Saudi Arabia on the research topic of net zero industrial emissions. For more information on the methodology used to identify emerging trends, please see the definition section for Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Supply Chain & Logistics: Supply Chain followed by Power Systems & Electric Vehicles: Unit Commitment and Power Systems & Electric Vehicles: Distributed Generation as shown in Figure 65.

It is worth noting that the micro-topic Forestry: Forest Management is growing in terms of the number of publications but shrinking in terms of citation share from the research topic.

Table 21 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic. From Saudi Arabia's top 10 micro-topics, three are also among the identified global emerging micro-topics. Namely in Supply Chain & Logistics: Supply Chain, Sustainability Science: Life Cycle Assessment and Power Systems & Electric Vehicles: Unit Commitment.

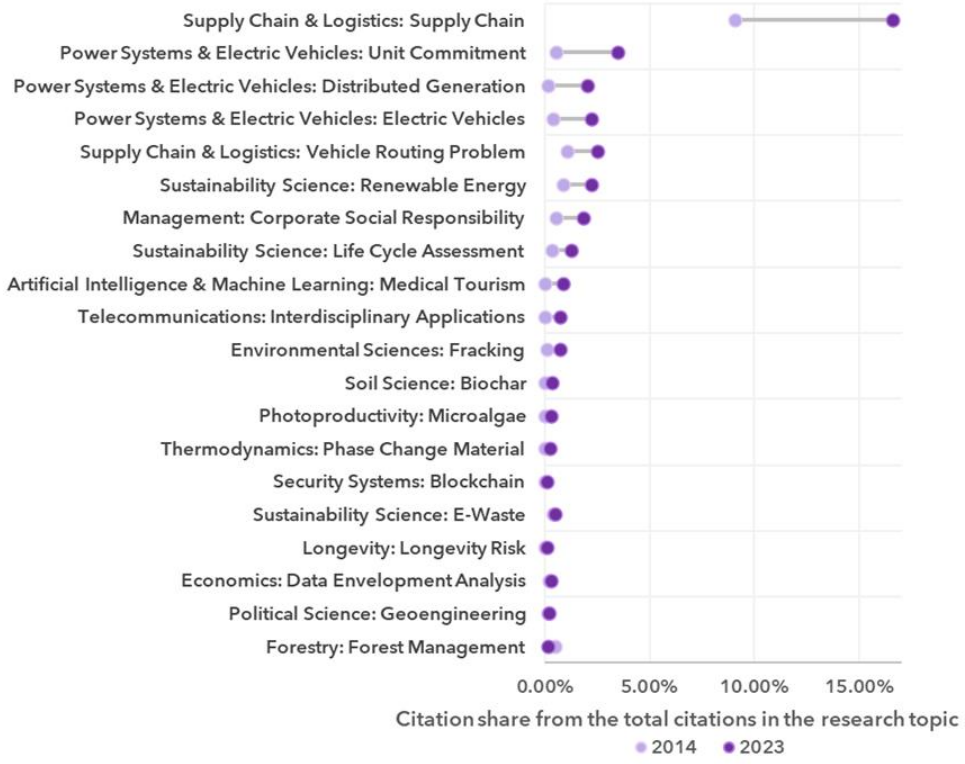


Figure 65: Top 20 emerging micro-topics globally in the research topic Net Zero - Industrial Emissions in the period 2014-2023

Table 21: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic Net Zero - Industrial Emissions in the period 2014-2023

Topic	Number of Saudi Arabian publications in the period 2014-2023
Net Zero - Industrial Emissions research topic	90
Sustainability Science: Environmental Kuznets Curve	24
Supply Chain & Logistics: Supply Chain	17
Environmental Sciences: Aerosols	4
Power Systems & Electric Vehicles: Voltage Stability	4
Concrete Science: Compressive Strength	4
Water Treatment: Adsorption	2
Sustainability Science: Life Cycle Assessment	2
Power Systems & Electric Vehicles: Unit Commitment	2
Energy & Fuels: CO2 Capture	2
Thermodynamics: Organic Rankine Cycle	1

4.1.6 Smart Grids

4.1.6.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications in the research topic increased almost continuously from 2014 till 2023 with a massive increase in the share in 2020-2023, as shown in Figure 66.

This shows that Saudi Arabia was not only able to increase the number of publications on this research topic but also had a growth higher than the global growth rate.

This is evident as the share of Saudi Arabian publications in the research topic are growing. Although the CNCI fluctuated between 1.40 and 2.02 in the period 2014-2023, the CNCI of Saudi Arabian publications in this research topic were in all years higher than 1, indicating a citation impact performance higher than the global average.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic and had a relatively good citation impact as measured by the CNCI.

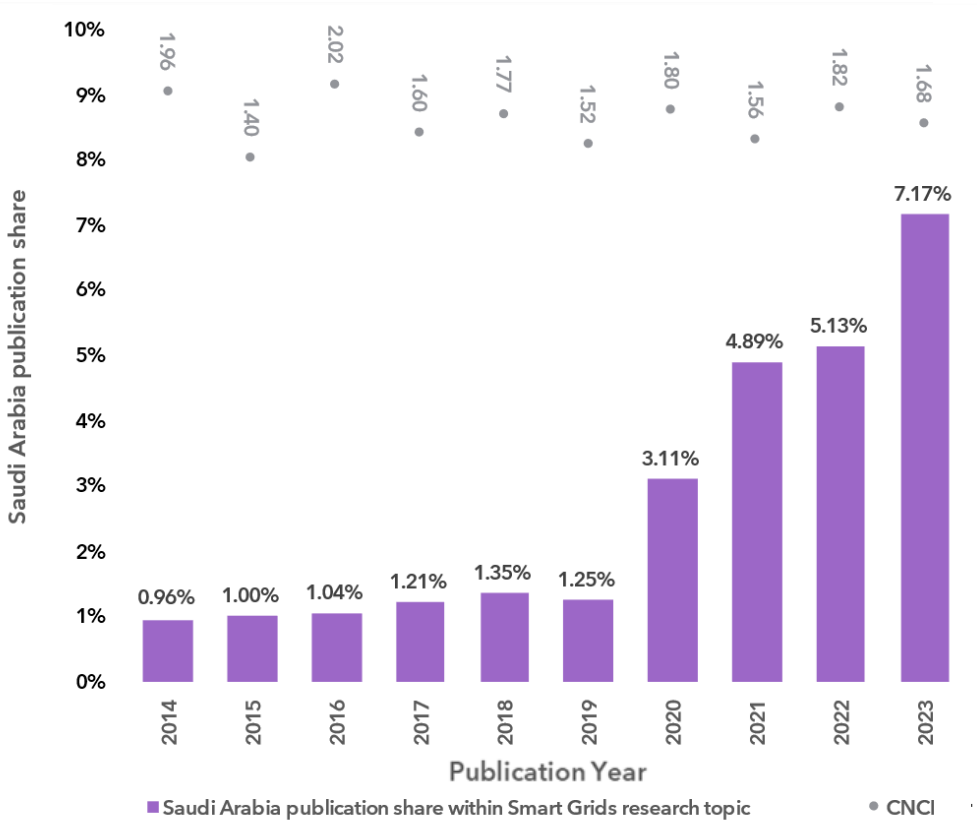


Figure 66: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.6.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is Pakistan, followed by the United States and Egypt with 223, 127 and 121 publications, respectively, as shown in Figure 67.

In terms of citation impact measured by the CNCI publications published in collaboration with the United States, Canada and Malaysia had the highest CNCI with 2.51, 2.16, and 2.15, respectively. Nevertheless, all publications with the top 10 collaborating countries had a CNCI higher than 1, reflecting a performance higher than the global average.

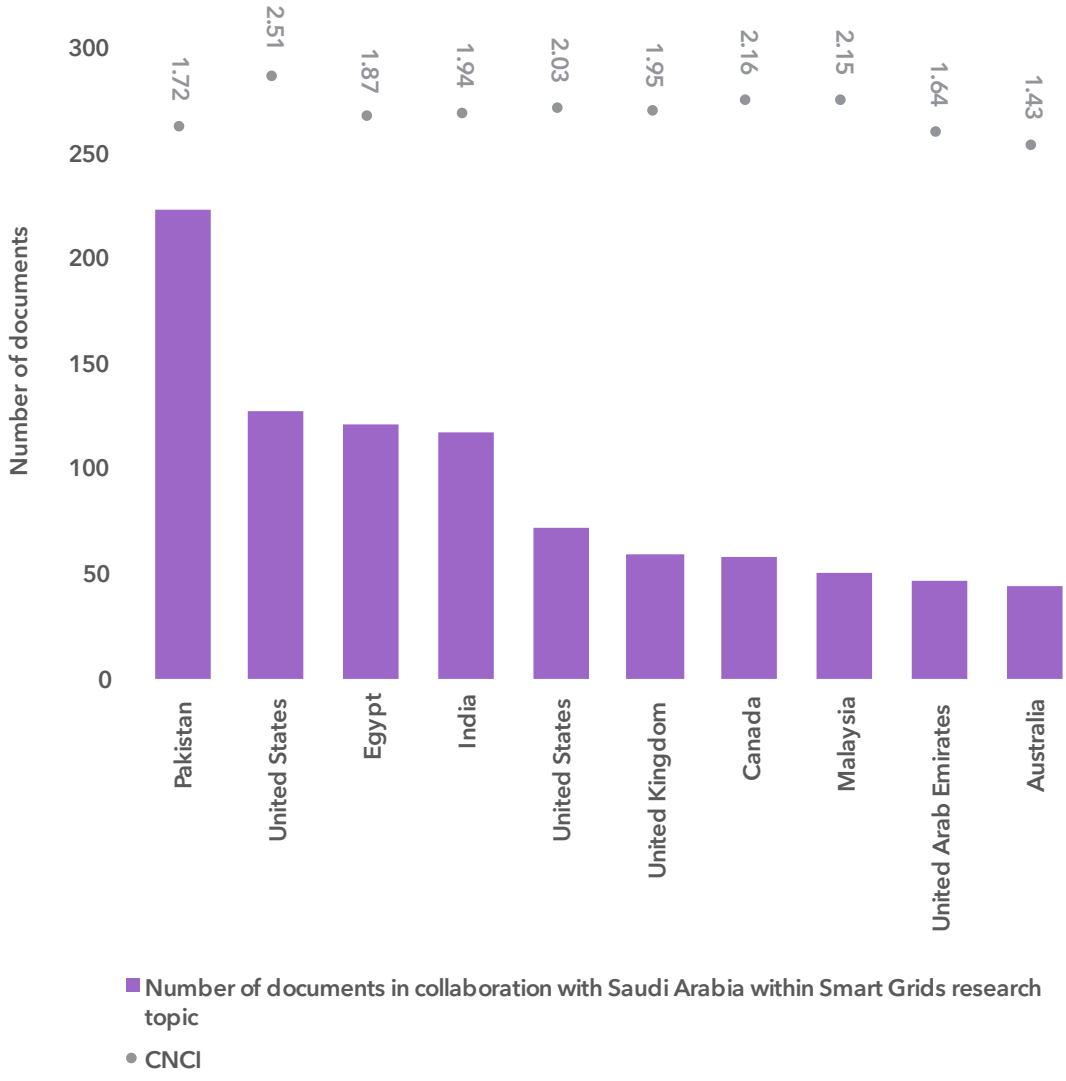


Figure 67: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic Smart Grids in the period 2014-2023

4.1.6.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by the National Natural Science Foundation of China (NSFC) and Princess Nourah bint Abdulrahman University with 106, 23 and 18 publications respectively as shown in Figure 68.

Documents funded by European Consiliul National al Cercetarii Stiintifice (CNCS) and Unitatea Executiva pentru Finantarea Invatamantului Superior, a Cercetarii, Dezvoltarii si Inovarii (UEFISCDI), followed by United States Department of Energy (DOE) and NSF - Directorate for Computer & Information Science & Engineering (CISE) had the highest citation impact measured by the CNCI with 6.35, 5.04 and 4.19 respectively.

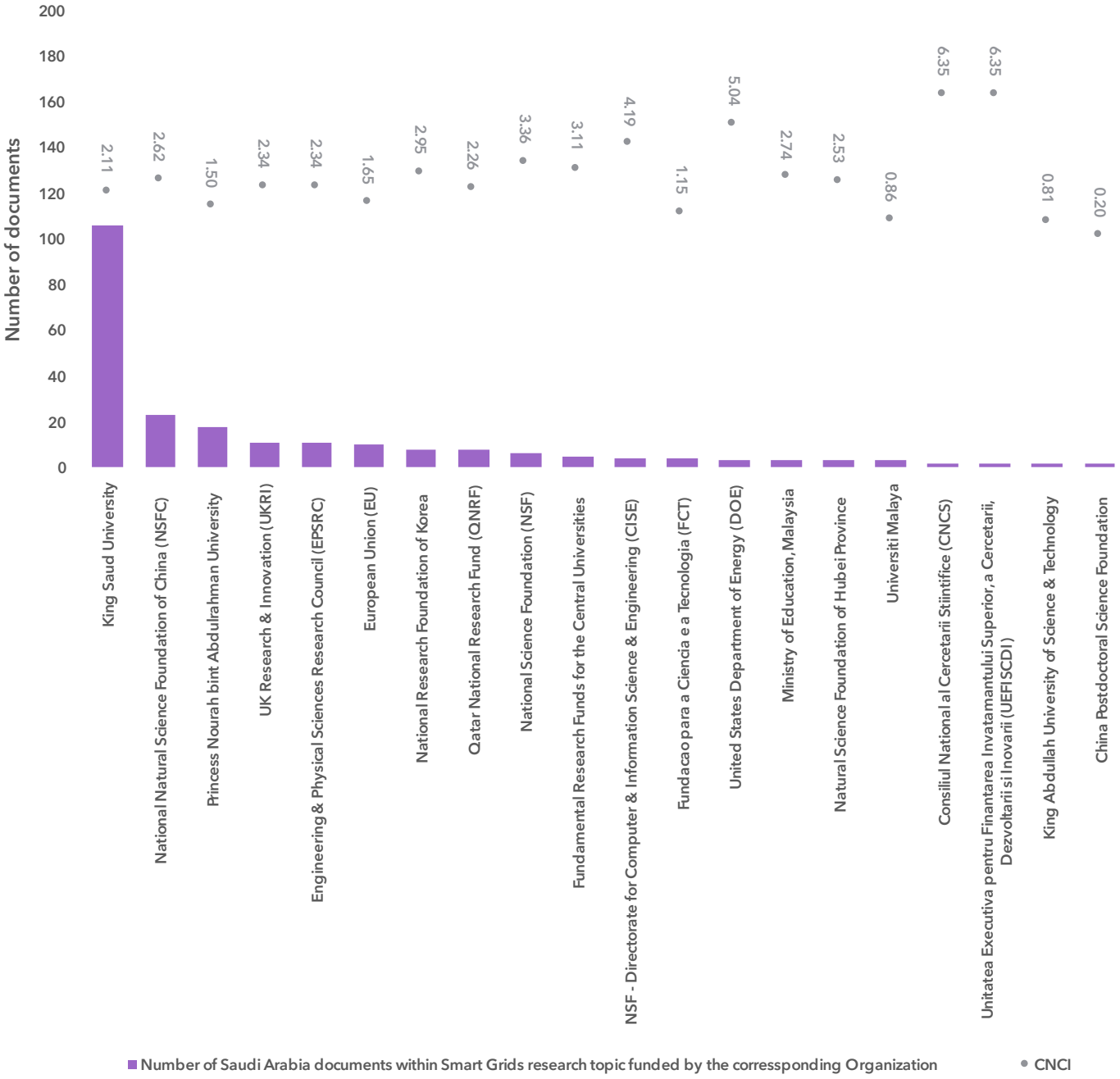


Figure 68: Top 20 funding organizations of Saudi Arabian publications in the research topic Smart Grids in terms of number of publications in the period 2014-2023

4.1.6.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published in this research topic and in the period 2014-2023 are King Saud University, followed by King Abdulaziz University and King Fahd University of Petroleum & Minerals, with 201, 150 and 76 publications, respectively, as shown in Figure 69.

In terms of citation impact, as measured by the CNCI, Effat University followed University Ha'il and King Saud University, which had the highest CNCI with 2.83, 2.31, and 2.22, respectively. Except for Majmaah University, all top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

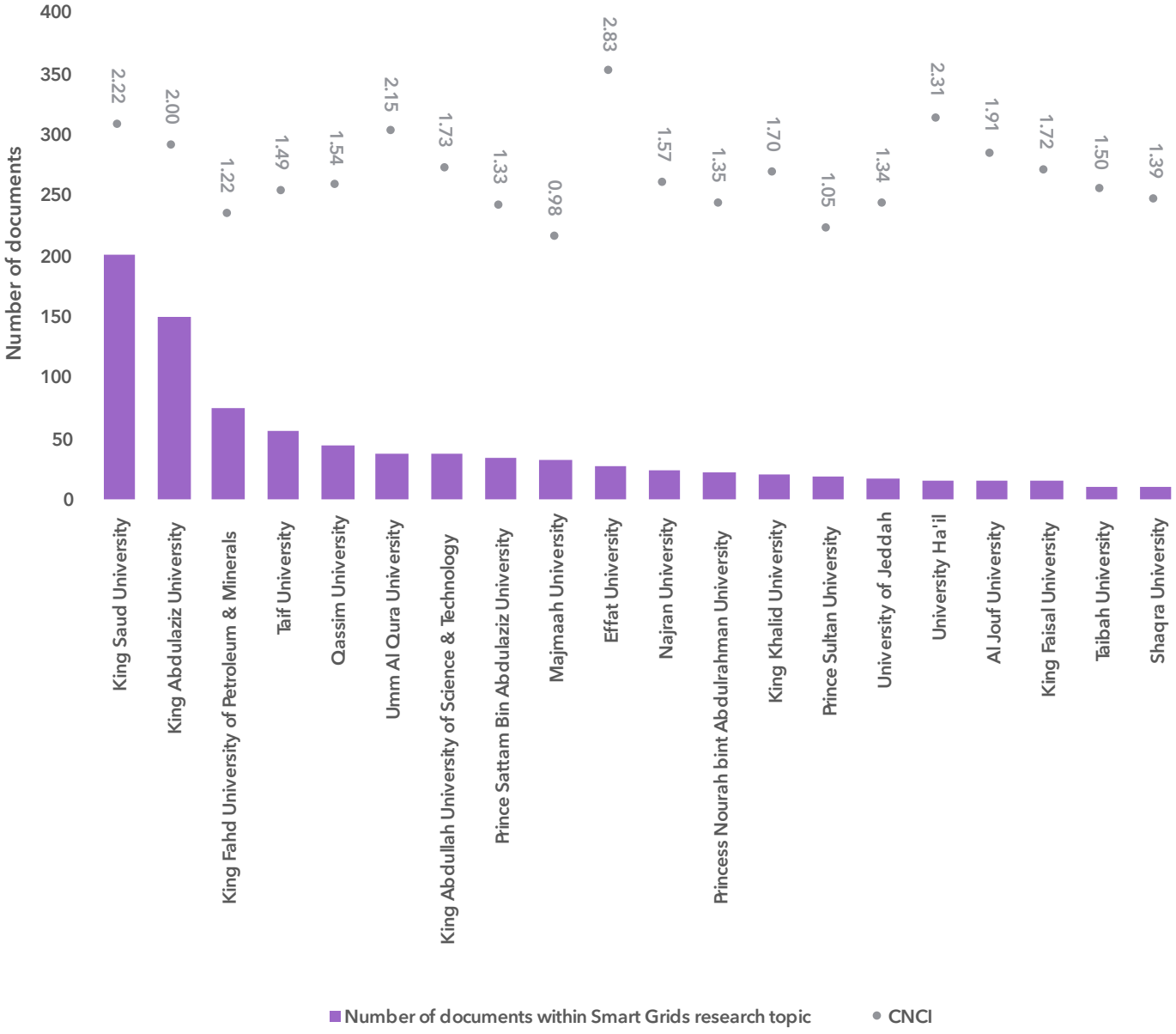


Figure 69: Top 20 Saudi organizations in terms of publications published in the research topic Smart Grids in the period 2014-2023 and their corresponding CNCI

4.1.6.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Khursheed Aurangzeb, followed by Ahmad Almogren and Nabil Alrajeh, all affiliated with King Saud University, with 20, 18 and 17 publications, respectively, as shown in Table 22.

The highest CNCI is achieved by publications published by Waleed Alasmary, affiliated with Umm Al Qura University, with a CNCI of 4.46.

The latter researcher has also the highest number of Top 1% amounting to one document, with also seven other researchers having one Top 1% document and Top 10% publications amounting to 10 publications. Waleed Alasmary and Nabil Alrajeh affiliated to King Saud University also had the highest the number of Top 10% publications amounting to 9 publications.

Table 22: Top 20 researchers affiliated with Saudi organizations in terms of the number of publications published on the research topic Smart Grids in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Aurangzeb, Khursheed	King Saud University	20	1.97	1	7
Almogren, Ahmad	King Saud University	18	1.83	0	5
Alrajeh, Nabil	King Saud University	17	2.64	1	9
Albogamy, Fahad R.	Taif University	15	1.77	0	4
Eltamaly, Ali M.	King Saud University	13	2.23	0	7
Alasmary, Waleed	Umm Al Qura University	12	4.46	1	9
Alhussein, Musaed	King Saud University	12	2.32	1	4
Haider, Syed Irtaza	King Saud University	12	3.05	1	6
Qaisar, Saeed Mian	Effat University	12	1.92	1	1
Al-Awami, Ali T.	King Fahd University of Petroleum & Minerals	11	1.03	0	2
Alquthami, Thamer	King Abdulaziz University	10	1.09	0	2
Khan, Farrukh Aslam	King Saud University	10	2.89	1	3
Khalid, Muhammad	King Fahd University of Petroleum & Minerals	10	1.08	0	2
Konstantinou, Charalambos	King Abdullah University of Science & Technology	9	1.59	0	0
Alsabaan, Maazen	King Saud University	9	1.18	0	1
Baroudi, Uthman	King Fahd University of Petroleum & Minerals	9	0.92	0	0
Irfan, Muhammad	Najran University	8	0.75	0	0
Alouini, Mohamed-Slim	King Abdullah University of Science & Technology	8	1.42	0	3
Alamri, Atif	King Saud University	8	2.37	0	4
Tolba, Amr	King Saud University	8	3.27	1	3

4.1.6.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (6,858 publications), followed by the United States (5,964 publications) and India (2,879 publications), as shown in Figure 70.

The highest citation impact measured by the CNCI is achieved by publications published by Australia, Canada and United States with a CNCI of 1.93, 1.87 and 1.67 respectively.

Five of the top 10 countries in terms of number of publications published in the research topic are also among the top 10 collaborators with Saudi Arabia. These are United States, United Kingdom, India, Australia and Canada.

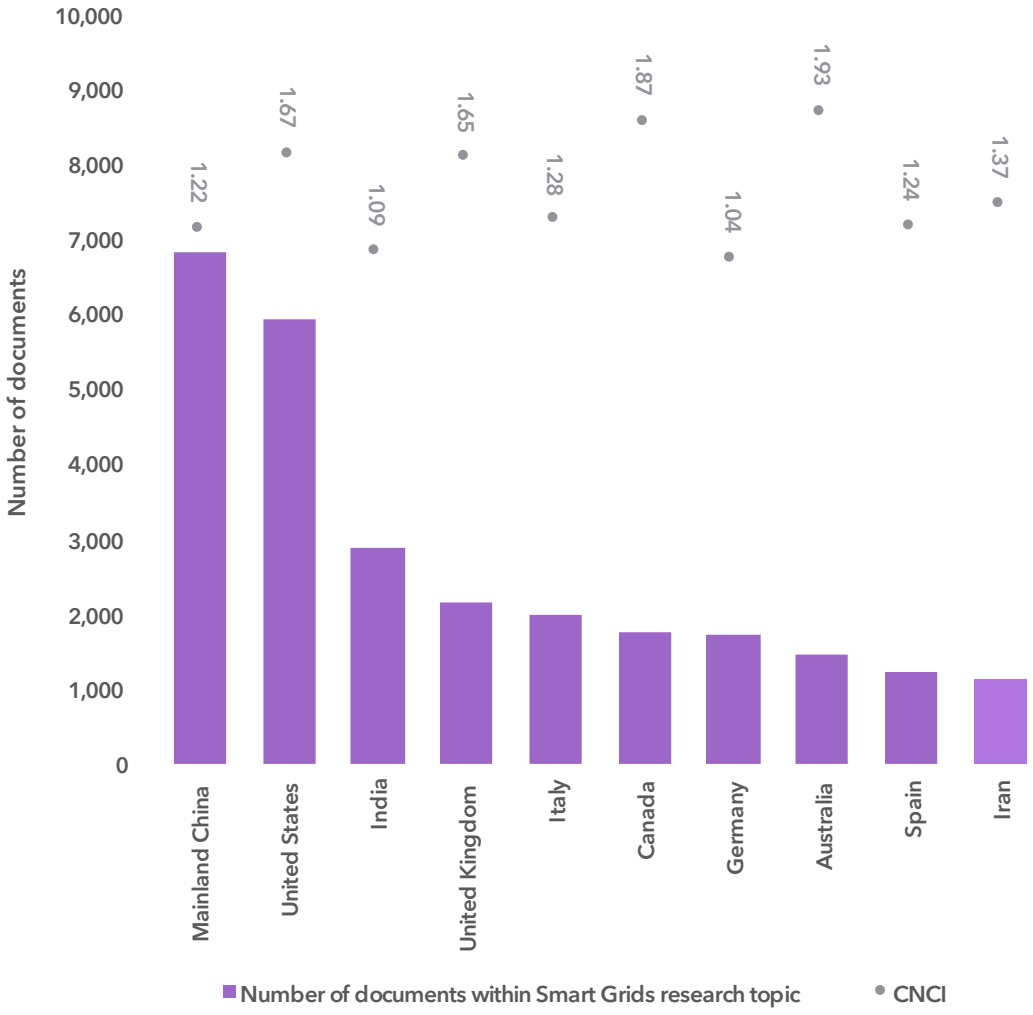


Figure 70: Top 10 countries in terms of the number of publications in the research topic Smart Grids in the period 2014-2023 and their corresponding CNCI

4.1.6.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published in this research topic in the period 2014-2023 are State Grid Corporation of China (809 publications) followed by the United States Department of Energy (DOE) (539 publications) and COMSATS University Islamabad (CUI) (492 publications) respectively as shown in Figure 71.

In terms of citation impact measured by the CNCI, the Swiss Federal Institutes of Technology Domain, followed by Nanyang Technological University and Xi'an Jiaotong University, had the highest CNCI with 2.49, 2.48 and 2.27, respectively.

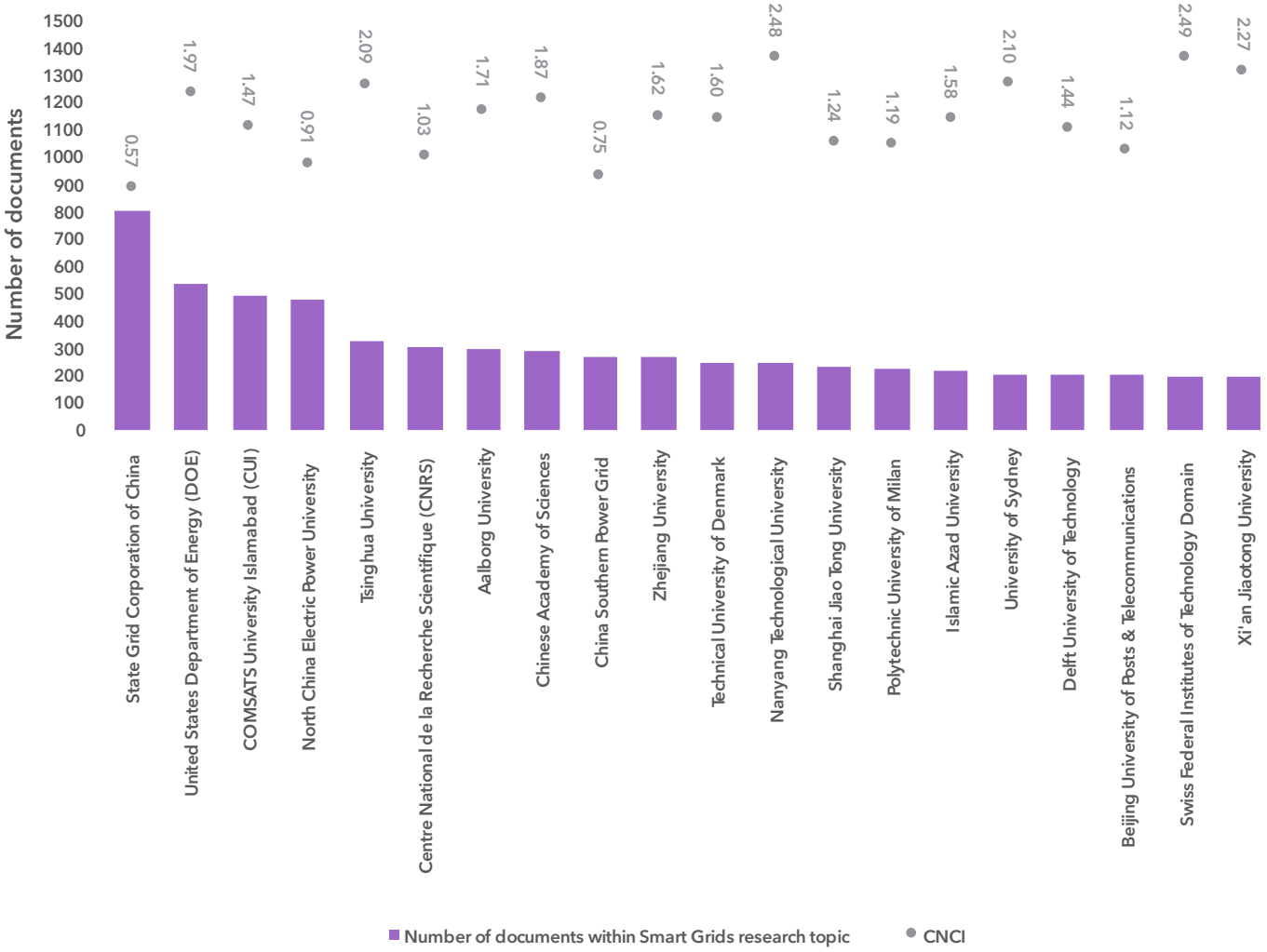


Figure 71: Top 20 organizations globally in terms of number of publications published in the research topic Smart Grids in the period 2014-2023 and their corresponding CNCI

4.1.6.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications in this research topic are Nadeem Javaid, affiliated to COMSATS University Islamabad (CUI), with 293 publications, followed by Zita Vale, affiliated to Instituto Politecnico do Porto, with 143 publications; and Neeraj Kumar, affiliated to Thapar Institute of Engineering & Technology with 77 publications as shown in Table 23.

The highest CNCI among the top 20 researchers globally is achieved by Wei Yu affiliated to University System of Maryland with a CNCI of 4.03. H. Vincent Poor affiliated to Princeton University and Neeraj Kumar affiliated to Thapar Institute of Engineering & Technology have the highest number of Top 1% publications amounting to 6 publications.

Nadeem Javaid affiliated to COMSATS University Islamabad (CUI) has the highest number of Top 10% publications amounting to 57 publications.

Table 23: Top 20 researchers globally in terms of the number of publications published on the research topic Smart Grids in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Javaid, Nadeem	COMSATS University Islamabad (CUI)	293	1.34	5	57	Pakistan
Vale, Zita	Instituto Politecnico do Porto	143	0.90	1	20	Portugal
Kumar, Neeraj	Thapar Institute of Engineering & Technology	77	2.82	6	36	India
Siano, Pierluigi	University of Salerno	72	2.38	2	26	Italy
Catalao, Joao P. S.	Universidade do Porto	72	1.89	4	22	Portugal
Poor, H. Vincent	Princeton University	65	2.98	6	30	United States
Monti, Antonello	RWTH Aachen University	60	1.05	0	9	Germany
Faria, Pedro	Instituto Politecnico do Porto	58	0.74	0	5	Portugal
Kundur, Deepa	University of Toronto	55	0.87	0	8	Canada
Guerrero, Josep M.	Aalborg University	52	2.61	2	16	Denmark
Lehtonen, Matti	Aalto University	49	1.59	0	13	Finland
Han, Zhu	University of Houston	48	2.54	2	15	United States
Mouftah, Hussein T.	University of Ottawa	47	1.51	1	11	Canada
Yu, Wei	University System of Maryland	45	4.03	3	17	United States
Afonso, Joao L.	Universidade do Minho	44	0.43	0	1	Portugal
Yu, Xinghuo	Royal Melbourne Institute of Technology (RMIT)	43	3.06	5	14	Australia
Soares, Joao	Instituto Politecnico do Porto	43	1.20	1	9	Portugal
Li, Li	University of Technology Sydney	42	1.58	0	12	Australia
Monteiro, Vitor	Universidade do Minho	42	0.61	0	3	Portugal
Patti, Edoardo	Polytechnic University of Turin	41	1.41	0	8	Italy

4.1.6.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC), with 2,747 publications, followed by the European Union (EU), with 1,293 publications; and National Science Foundation (NSF), with 1,242 publications, as shown in Figure 72.

The highest citation impact measured by the CNCI is observed in publications funded by Australian Research Council followed by NSF - Directorate for Computer & Information Science & Engineering (CISE) and Natural Sciences and Engineering Research Council of Canada (NSERC) with 2.51, 2.25 and 2.15 respectively.

Among the top 20 global funding organizations, 10 are also among the top 20 funding organizations of Saudi publications in this research topic.

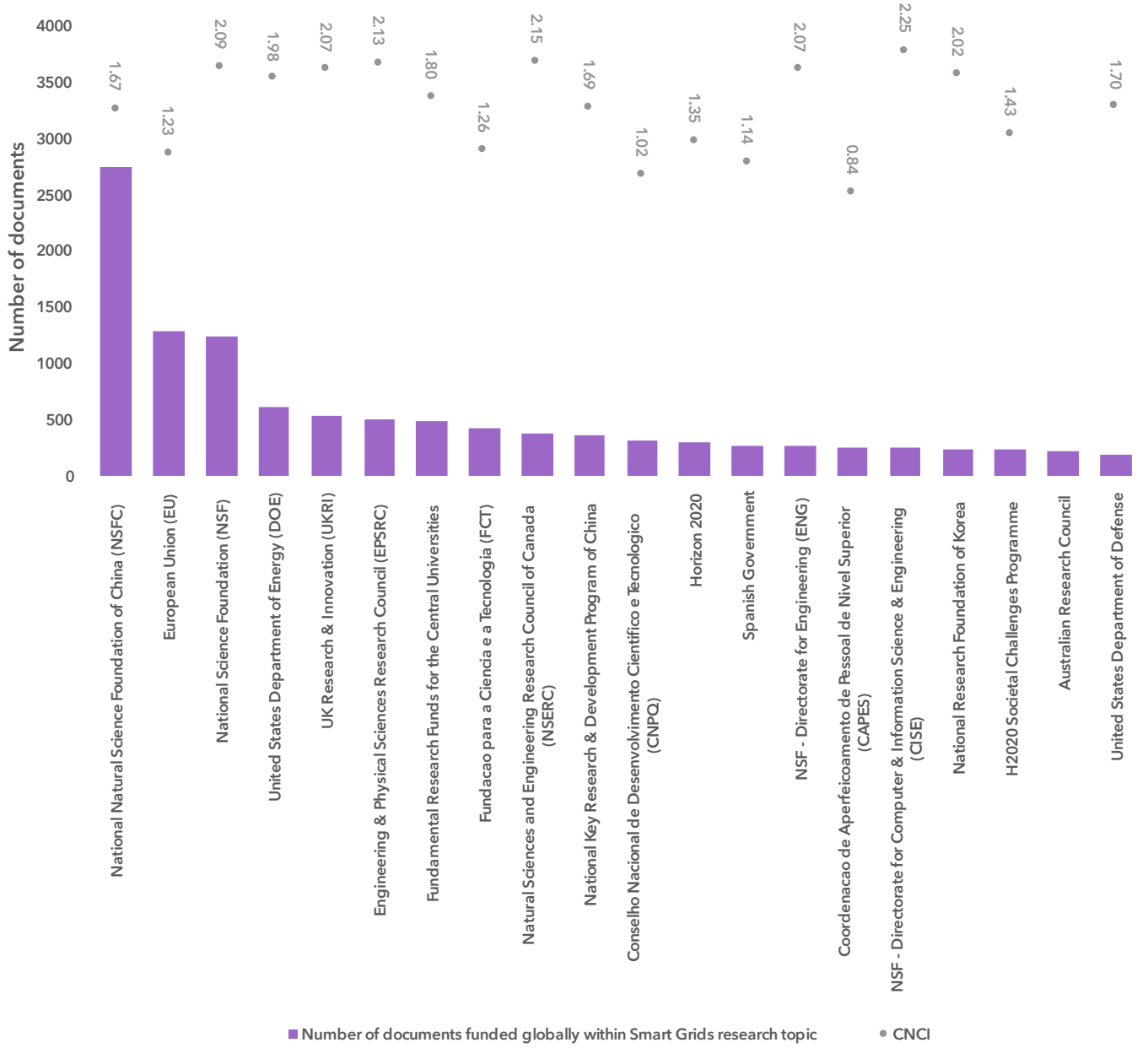


Figure 72: Top 20 funding organizations globally publications in the research topic Smart Grids in terms of number of publications in the period 2014-2023

4.1.6.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section we investigate the emerging trends globally and in Saudi Arabia in the research topic Smart Grids. For more information on the methodology used to identify emerging trends, please see the definitions section for Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Security Systems: Blockchain, followed by Telecommunications: Unmanned Aerial Vehicles and Security Systems: Differential Privacy, as shown in Figure 73.

Table 24 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic.

From Saudi Arabia's top 10 micro-topics, Security Systems: Blockchain is also among the identified global emerging micro-topics.

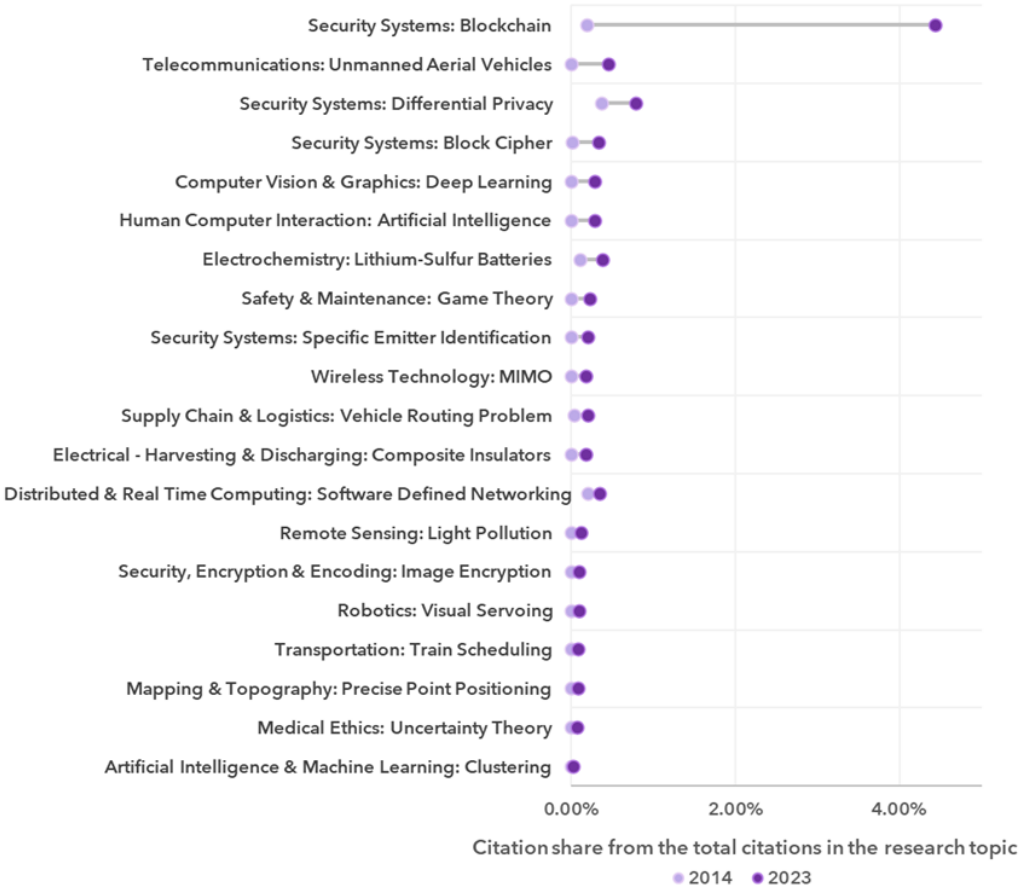


Figure 73: Top 20 emerging micro-topics globally in the research topic Smart Grids in the period 2014-2023

Table 24: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic Smart Grids in the period 2014-2023

Topic	Number of Saudi Arabian publications in the period 2014-2023
Smart Grids research topic	871
Power Systems & Electric Vehicles: Distributed Generation	312
Power Systems & Electric Vehicles: Non-Intrusive Load Monitoring	83
Power Systems & Electric Vehicles: Unit Commitment	73
Security Systems: Blockchain	49
Telecommunications: Internet Of Things	49
Power Systems & Electric Vehicles: Voltage Stability	47
Artificial Intelligence & Machine Learning: Intrusion Detection	37
Security Systems: Random Oracle Model	29
Telecommunications: Wireless Sensor Networks	20
Power Systems & Electric Vehicles: Power Quality	20

4.1.7 Hydrogen Production

4.1.7.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications on the research topic increased almost continuously from 2014 till 2023, as shown in Figure 74. This shows that Saudi Arabia was not only able to increase the number of publications in this research topic but also having a growth higher than the global growth rate. This is evident as the share of Saudi Arabian publications in the research topic are growing.

Although the CNCI fluctuated between 1.61 and 2.95 between 2014-2023, the CNCI of Saudi Arabian publications in this research topic were in all years higher than 1, indicating a citation impact performance higher than the global average.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic and had a relatively good citation impact as measured by the CNCI.

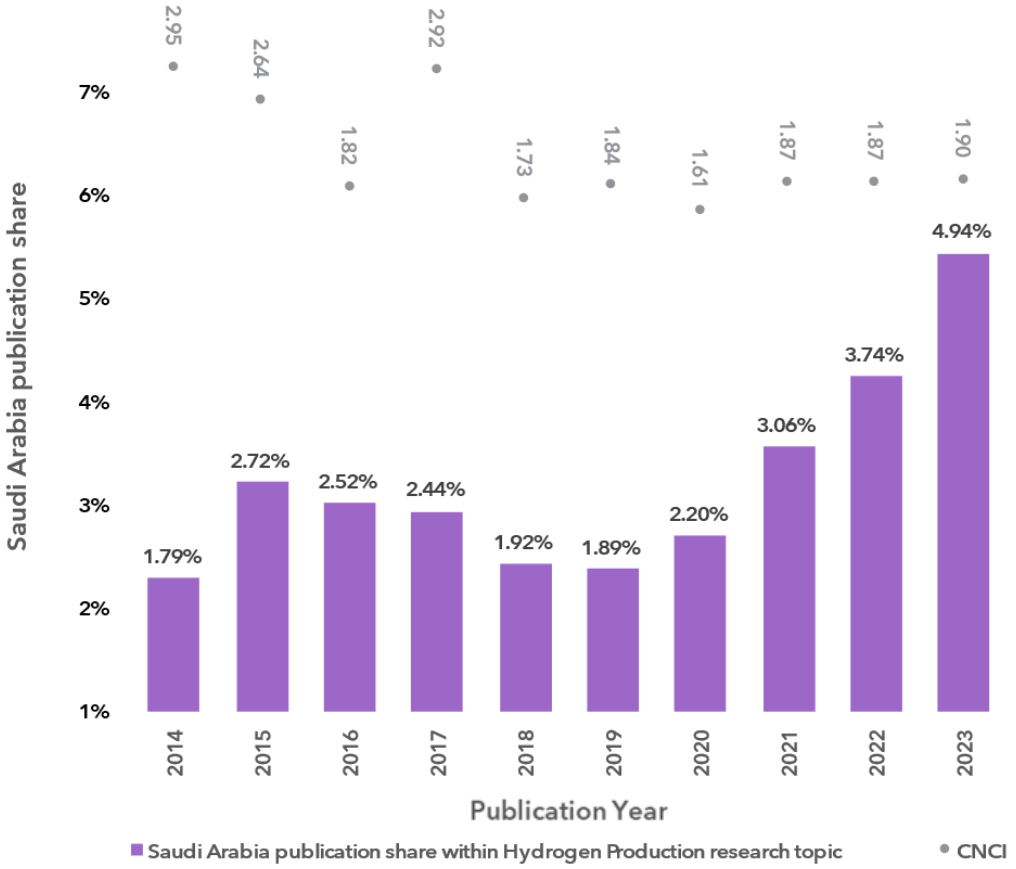


Figure 74: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.7.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is Mainland China, followed by India and Egypt with 543, 391 and 376 publications, respectively, as shown in Figure 75.

In terms of citation impact measured by the CNCI publications published in collaboration with Mainland China followed by United States and South Korea had the highest CNCI with 3.79, 2.26 and 1.86 respectively.

All publications with the top 10 collaborating countries had a CNCI higher than 1, reflecting a performance higher than the global average.

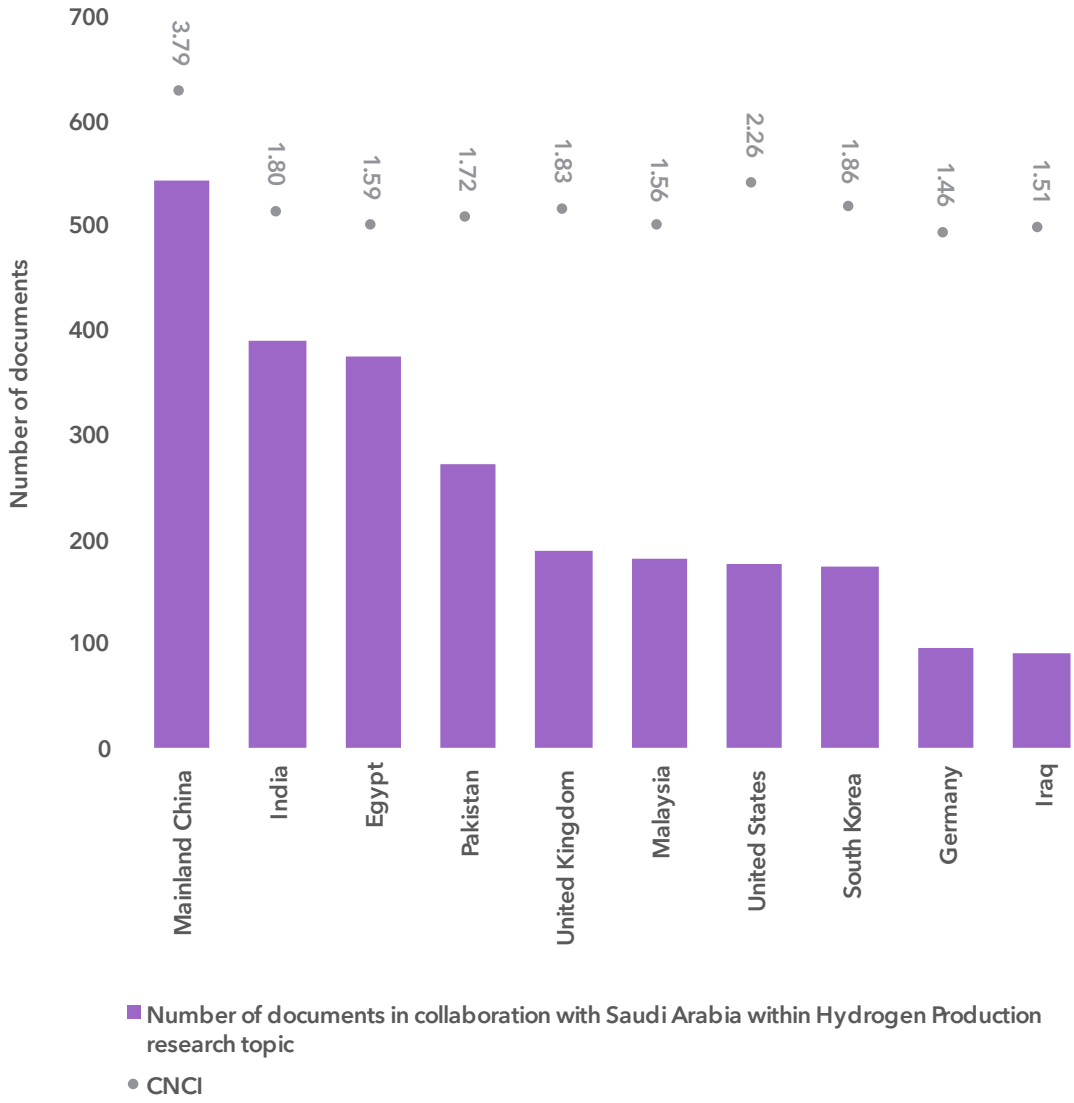


Figure 75: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic Hydrogen Production in the period 2014-2023

4.1.7.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Saud University followed by the National Natural Science Foundation of China (NSFC) and King Abdullah University of Science & Technology with 297, 263 and 107 publications respectively as shown in Figure 76.

Documents funded by National Basic Research Program of China, followed by Natural Science Foundation of Hubei Province and China Postdoctoral Science Foundation had the highest citation impact measured by the CNCI with 8.08, 6.79 and 6.67 respectively.

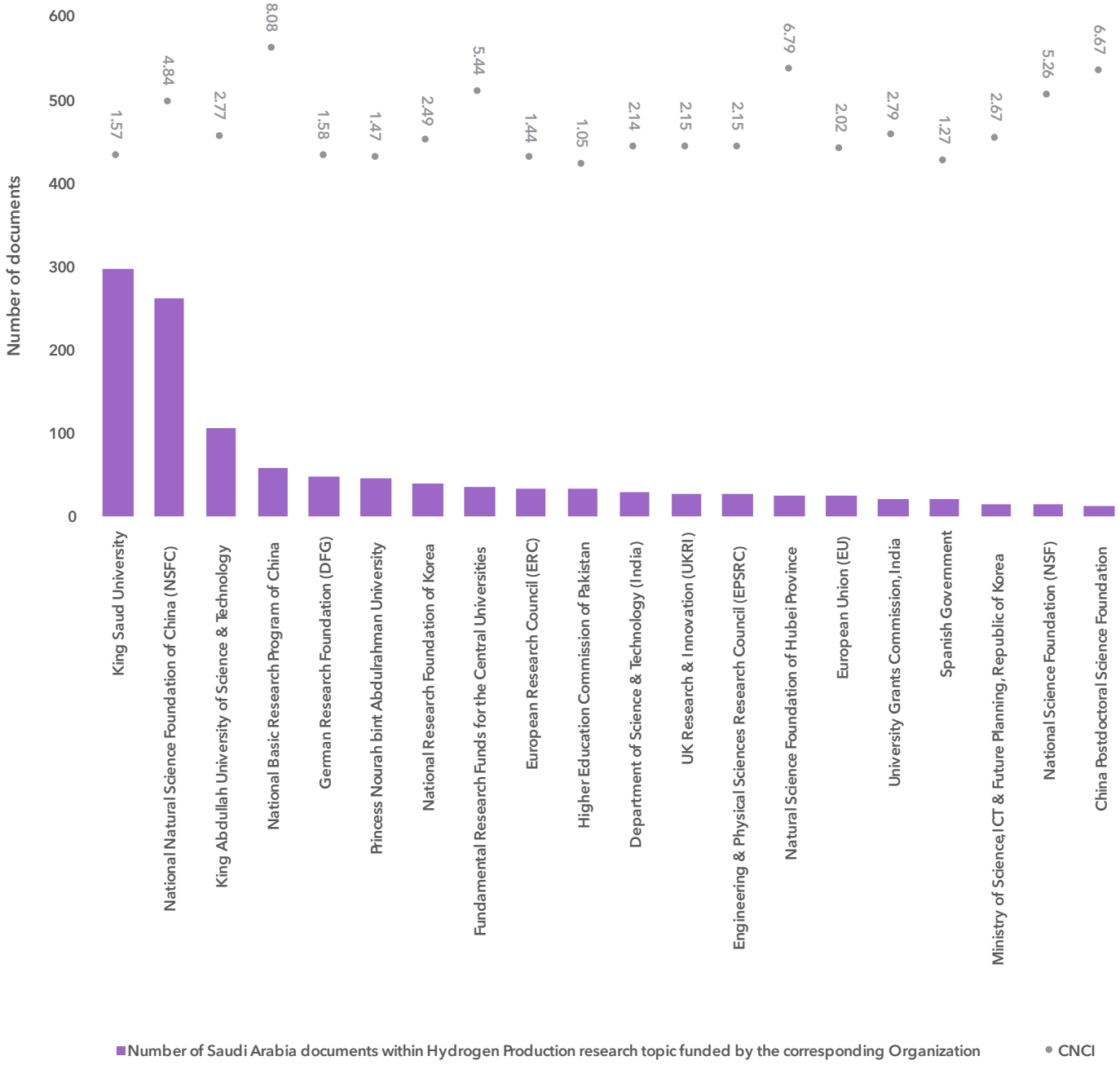


Figure 76: Top 20 funding organizations of Saudi Arabian publications in the research topic Hydrogen Production in terms of number of publications in the period 2014-2023

4.1.7.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published in this research topic and in the period 2014-2023 are King Abdulaziz University, followed by King Saud University and King Abdullah University of Science & Technology, with 511, 477 and 316 publications, respectively, as shown in Figure 77.

In terms of citation impact as measured by the CNCI, King Abdulaziz University followed by King Abdullah University of Science & Technology and University of Jeddah had the highest CNCI with 3.29, 2.15 and 2.06 respectively.

Except for Jazan University all top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

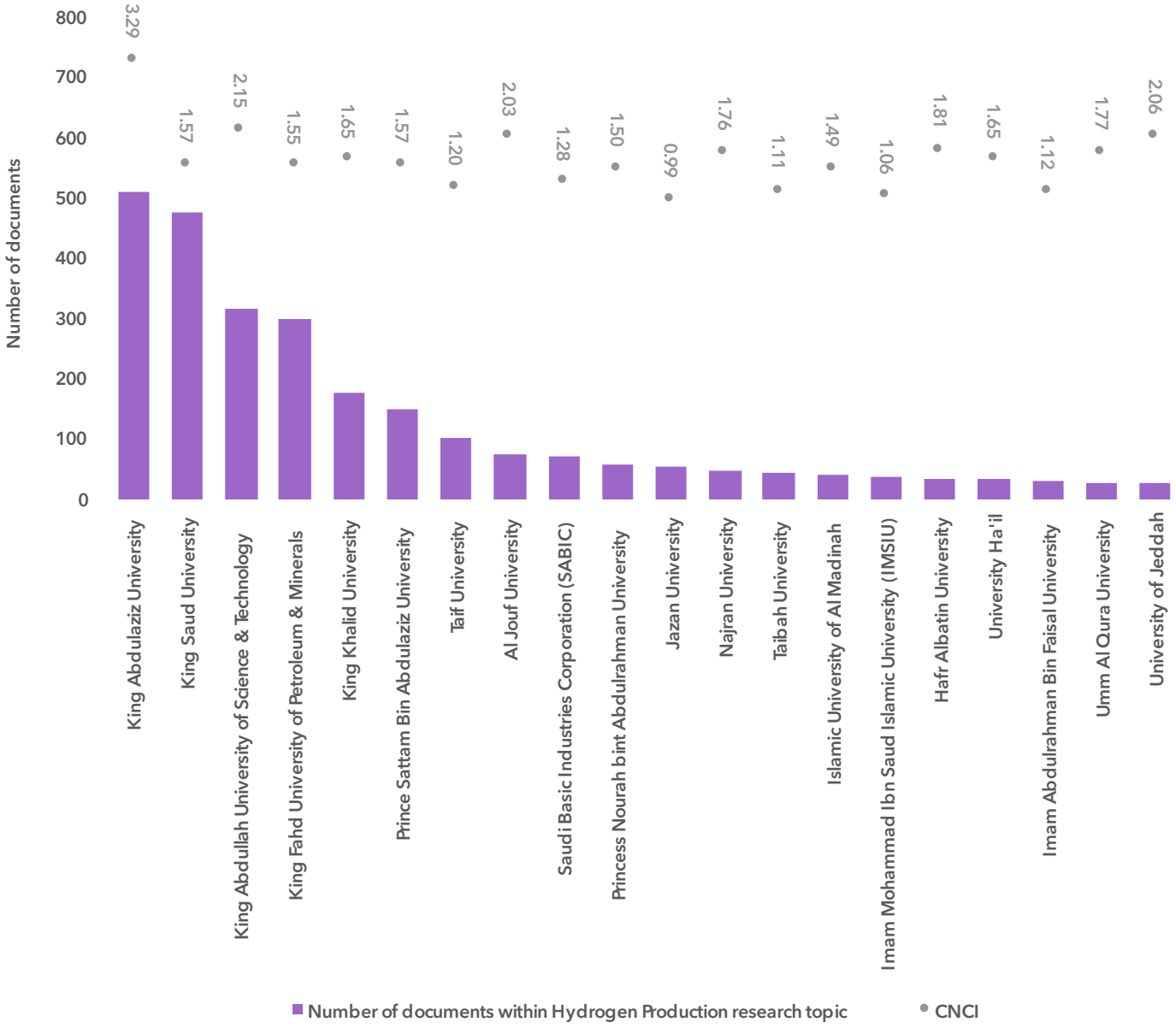


Figure 77: Top 20 Saudi organizations in terms of publications published in Hydrogen Production in the period 2014-2023 and their corresponding CNCI

4.1.7.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Abdullah M. Asiri, affiliated with King Abdulaziz University, followed by Anis H. Fakeeha and Ahmed S. Al-Fatesh, both affiliated with King Saud University with the same number of publications followed by Ahmed A. Ibrahim also affiliated to King Saud University with 124, 39 and 35 publications respectively as shown in Table 25.

The highest CNCI is achieved by publications published by Abdullah M. Asiri with a CNCI of 4.75. The latter researcher has also the highest number of Top 1% amounting to 23 publications and Top 10% publications amounting to 68 publications.

Table 25: Top 20 researchers affiliated with Saudi organizations in terms of the number of publications published on the research topic Hydrogen Production in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Asiri, Abdullah M.	King Abdulaziz University	124	4.75	23	68
Fakeeha, Anis H.	King Saud University	39	1.25	0	7
Al-Fatesh, Ahmed S.	King Saud University	39	1.34	0	8
Ibrahim, Ahmed A.	King Saud University	35	1.27	0	6
Hossain, Mohammad M.	King Fahd University of Petroleum & Minerals	30	0.68	0	1
Abasaeed, Ahmed E.	King Saud University	28	1.31	0	6
Idriss, Hicham	King Abdullah University of Science & Technology	28	1.51	1	6
Amin, Mohammed A.	Taif University	28	1.62	1	7
Al-Fatesh, Ahmed Sadeq	King Saud University	26	1.29	0	5
Idriss, H.	King Abdullah University of Science & Technology	25	1.00	0	3
Almohana, Abdulaziz Ibrahim	King Saud University	24	1.27	0	4
Almojil, Sattam Fahad	King Saud University	24	1.27	0	4
Fakeeha, Anis Hamza	King Saud University	24	1.23	0	4
Alali, Abdulrhman Fahmi	King Saud University	23	1.28	0	4
Huang, Kuo-Wei	King Abdullah University of Science & Technology	23	4.62	4	8
Mohamed, Reda M.	King Abdulaziz University	22	1.18	0	5
Abasaeed, Ahmed Elhag	King Saud University	21	1.24	0	3
Takanabe, Kazuhiro	King Abdullah University of Science & Technology	20	1.05	0	2
Ibrahim, Ahmed Aidid	King Saud University	20	1.25	0	4
Khan, Sher Bahadar	King Abdulaziz University	19	1.09	0	2

4.1.7.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (32,207 publications), followed by the United States (7,697 publications) and India (5,792 publications), as shown in Figure 78.

The highest citation impact measured by the CNCI is achieved by publications published by Mainland China, United States and United Kingdom with a CNCI of 1.77, 1.72 and 1.69 respectively.

Six of the top 10 countries in terms of number of publications published in the research topic are also among the top 10 collaborators with Saudi Arabia. These are United States, Mainland China, United Kingdom, India, South Korea and Germany.

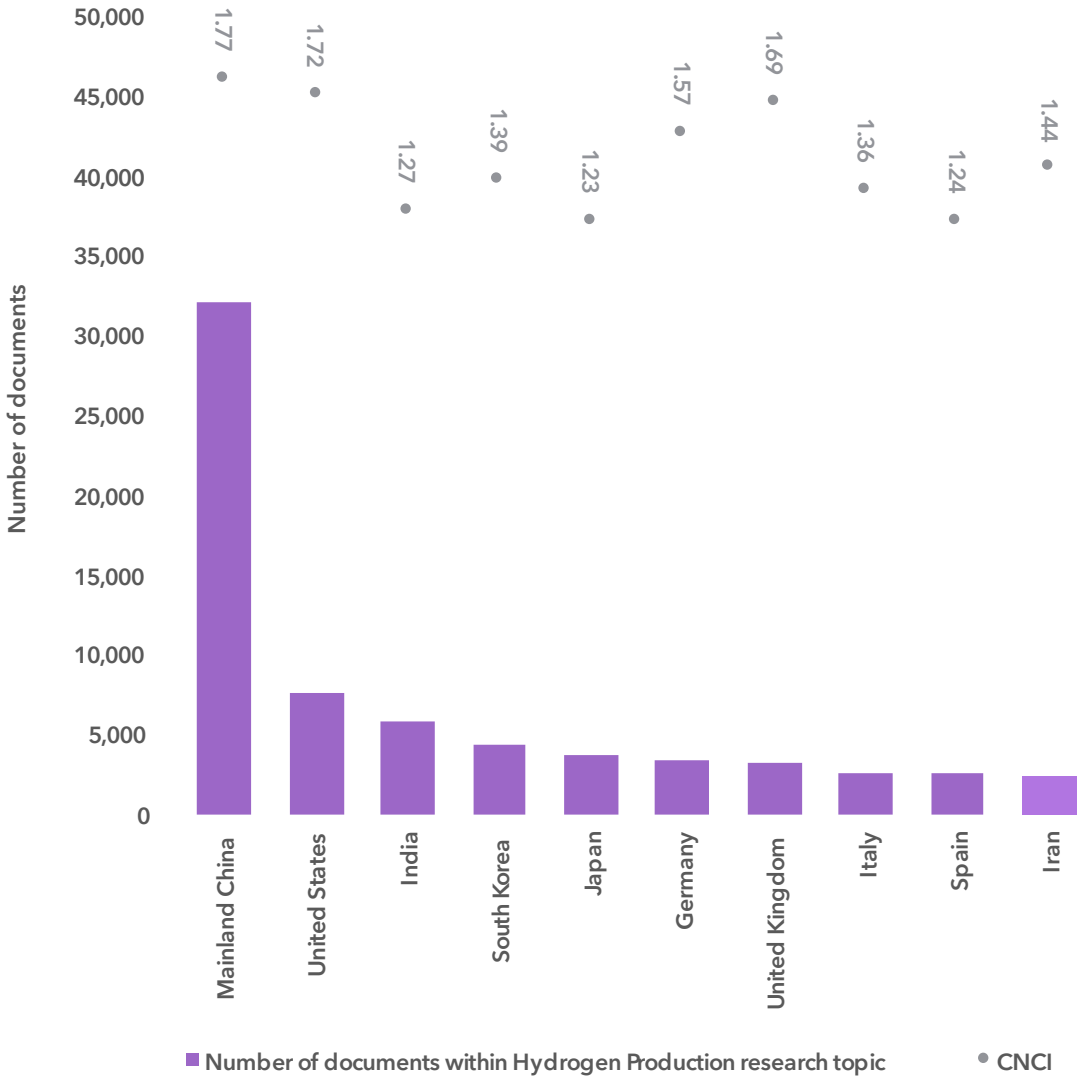


Figure 78: Top 10 countries in terms of number of publications in the research topic Hydrogen Production in the period 2014-2023 and their corresponding CNCI

4.1.7.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are the Chinese Academy of Sciences (4,662 publications), followed by the Centre National de la Recherche Scientifique (CNRS) (1,397 publications) and the University of Chinese Academy of Sciences, CAS (1,379 publications) respectively as shown in Figure 79.

In terms of citation impact measured by the CNCI, Zhengzhou University, followed by the University of Science & Technology of China, CAS, and Fuzhou University had the highest CNCI with 2.96, 2.69 and 2.48, respectively.

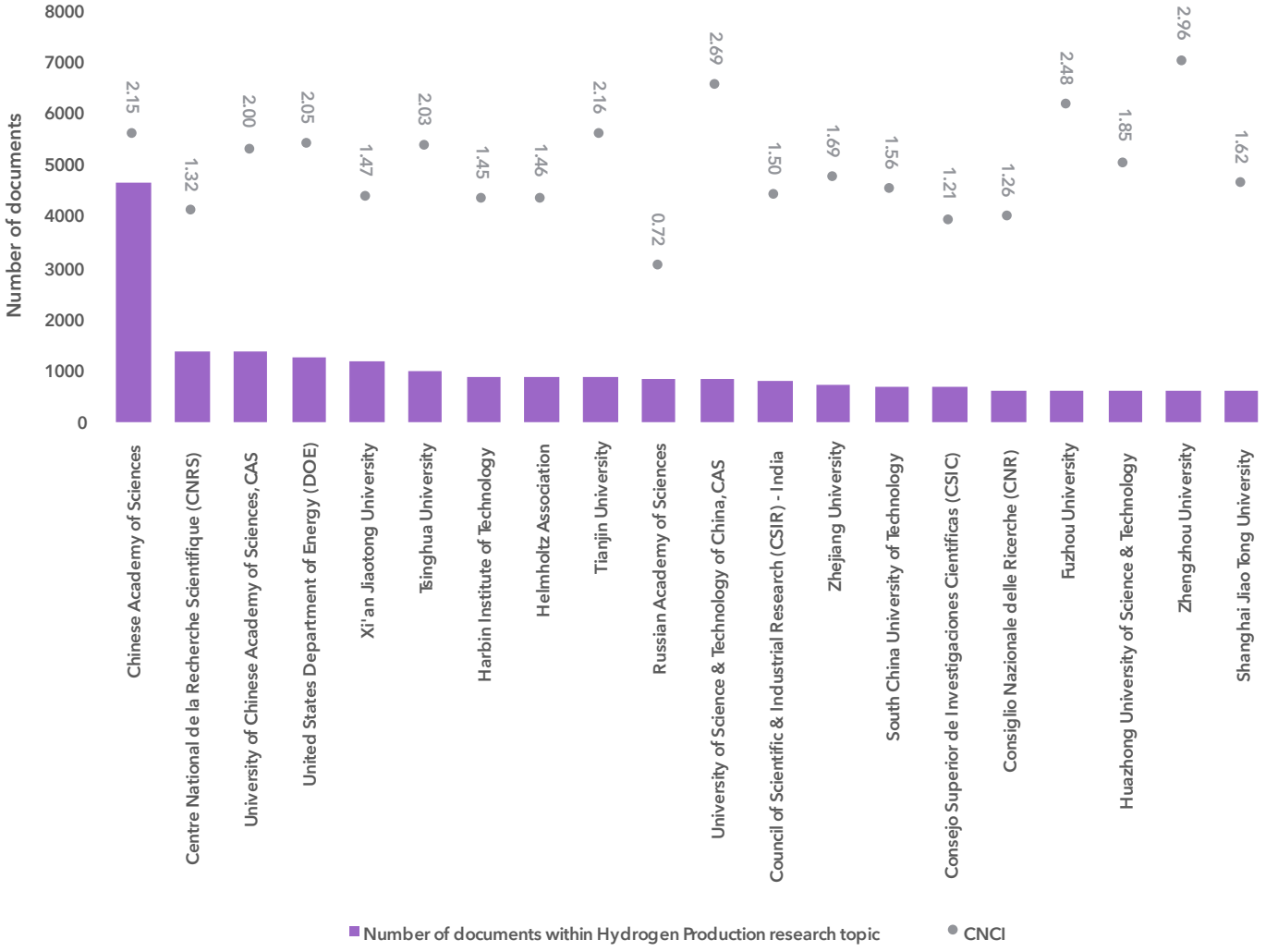


Figure 79: Top 20 organizations globally in terms of number of publications published in the research topic Hydrogen Production in the period 2014-2023 and their corresponding CNCI

4.1.7.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications on this research topic are Liejin Guo, affiliated with Xi'an Jiaotong University, with 268 publications, followed by Zhiliang Jin, affiliated with North Minzu University, with 210 publications, and Hui Jin, affiliated to Xi'an Jiaotong University with 185 publications as shown in Table 26.

The highest CNCI, number of Top 1% publications and number of Top 10% publications is achieved by Jiaguo Yu affiliated to Wuhan University of Technology with 8.38, 49 publications and 97 publications respectively.

Table 26: Top 20 researchers globally in terms of number of publications published in the research topic Hydrogen Production in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Guo, Liejin	Xi'an Jiaotong University	268	1.36	6	43
Jin, Zhiliang	North Minzu University	210	2.84	19	88
Jin, Hui	Xi'an Jiaotong University	185	1.37	1	28
Dincer, Ibrahim	Ontario Tech University	184	1.42	7	42
Wang, Lei	Qingdao University of Science & Technology	125	2.22	9	37
Zhang, Quanguo	Henan Agricultural University	119	1.31	0	30
Domen, Kazunari	University of Tokyo	115	4.02	16	41
Yu, Jiaguo	Wuhan University of Technology	108	8.38	49	97
Haghighi, Mohammad	Sahand University of Technology	107	1.35	0	24
Li, Can	Dalian Institute of Chemical Physics, CAS	105	2.94	10	40
Park, Young-Kwon	University of Seoul	93	1.30	2	18
Kang, Misook	Yeungnam University	90	1.13	0	11
Bilbao, Javier	University of Basque Country	88	1.81	0	31
Wang, Xinchen	Fuzhou University	86	5.28	23	54
Zhan, Shu-Zhong	South China University of Technology	85	0.57	0	1
Zou, Zhigang	Nanjing University	82	2.21	7	25
Hu, Xun	University of Jinan	81	1.25	1	11
Shi, Weidong	Jiangsu University	79	2.02	2	29
Zhang, Zhiping	Henan Agricultural University	78	1.31	0	20
Abanades, Stephane	Centre National de la Recherche Scientifique (CNRS)	78	1.09	0	7

4.1.7.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC) with 22,837 publications, followed by Fundamental Research Funds for the Central Universities with 3506 publications, and European Union (EU) with 2006 publications, as shown in Figure 80.

The highest citation impact measured by the CNCI is observed in publications funded by National Basic Research Program of China followed by China Postdoctoral Science Foundation and Fundamental Research Funds for the Central Universities with 2.70, 2.16 and 2.09 respectively.

Among the top 20 global funding organizations, 11 are also among the top 20 funding organizations of Saudi publications in this research topic.

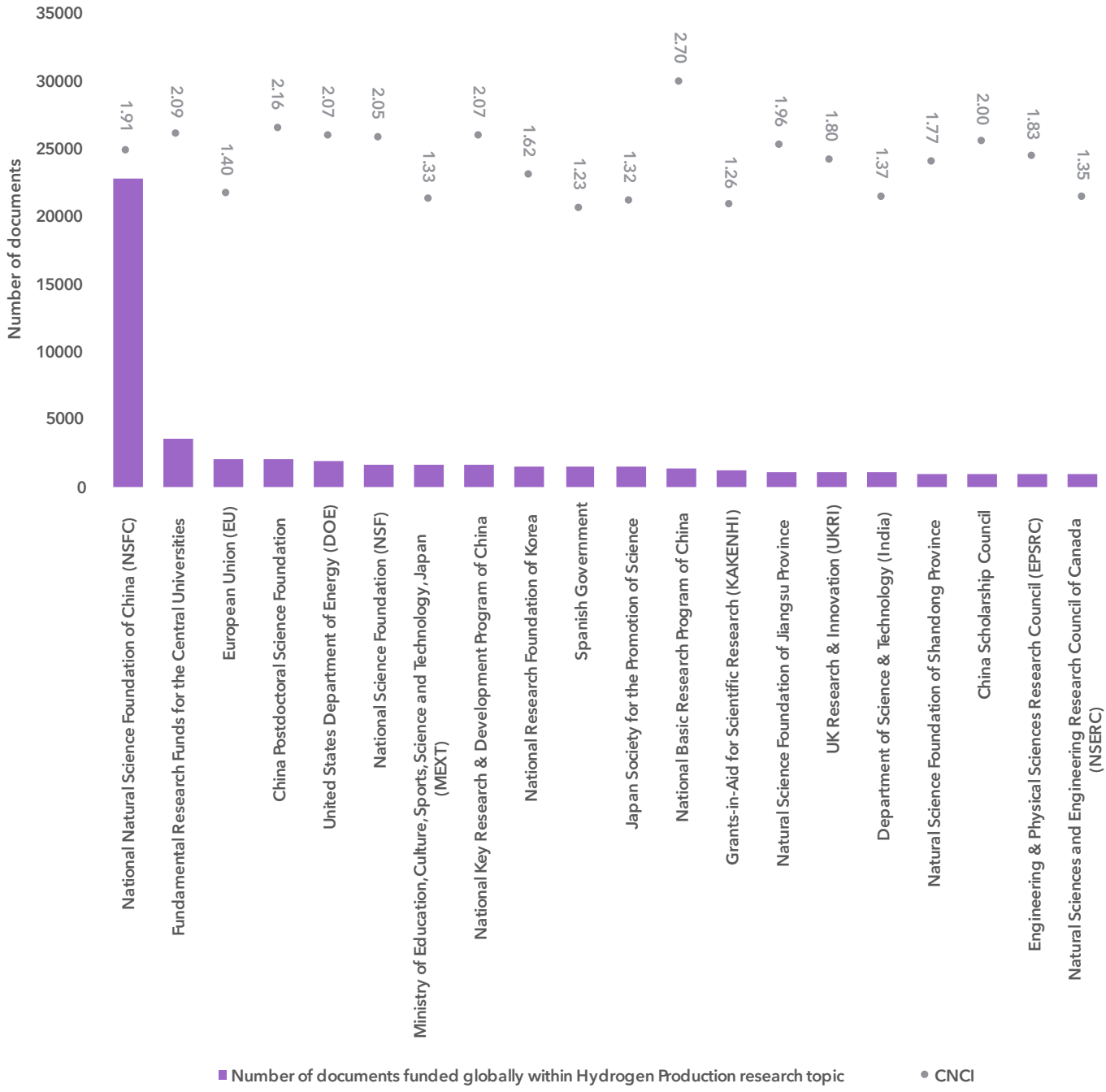


Figure 80: Top 20 funding organizations globally publications in the research topic Hydrogen Production in terms of number of publications in the period 2014-2023

4.1.7.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section, we investigate the emerging trends globally and in Saudi Arabia in the research topic of Hydrogen Production. For more information on the methodology used to identify emerging trends, please see the definitions sections for Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Electrochemistry: CO2 Reduction followed by Water Resources: Enhanced Oil Recovery and Thermodynamics: Solar Still as shown in Figure 81.

For Saudi Arabia, we were able to identify ten micro-topics that are shown in Figure 82. The top 3 emerging micro-topics in Saudi Arabia are Thermodynamics: Organic Rankine Cycle followed by Hydrogen Chemistry & Storage: Hydrogen Storage and Bioengineering: Anaerobic Digestion. Among the identified 10 emerging micro-topics in Saudi Arabia, two of them are also emerging micro-topics globally. These are Water Resources: Enhanced Oil Recovery and Perovskite Solar Cells: Perovskite Solar Cells.

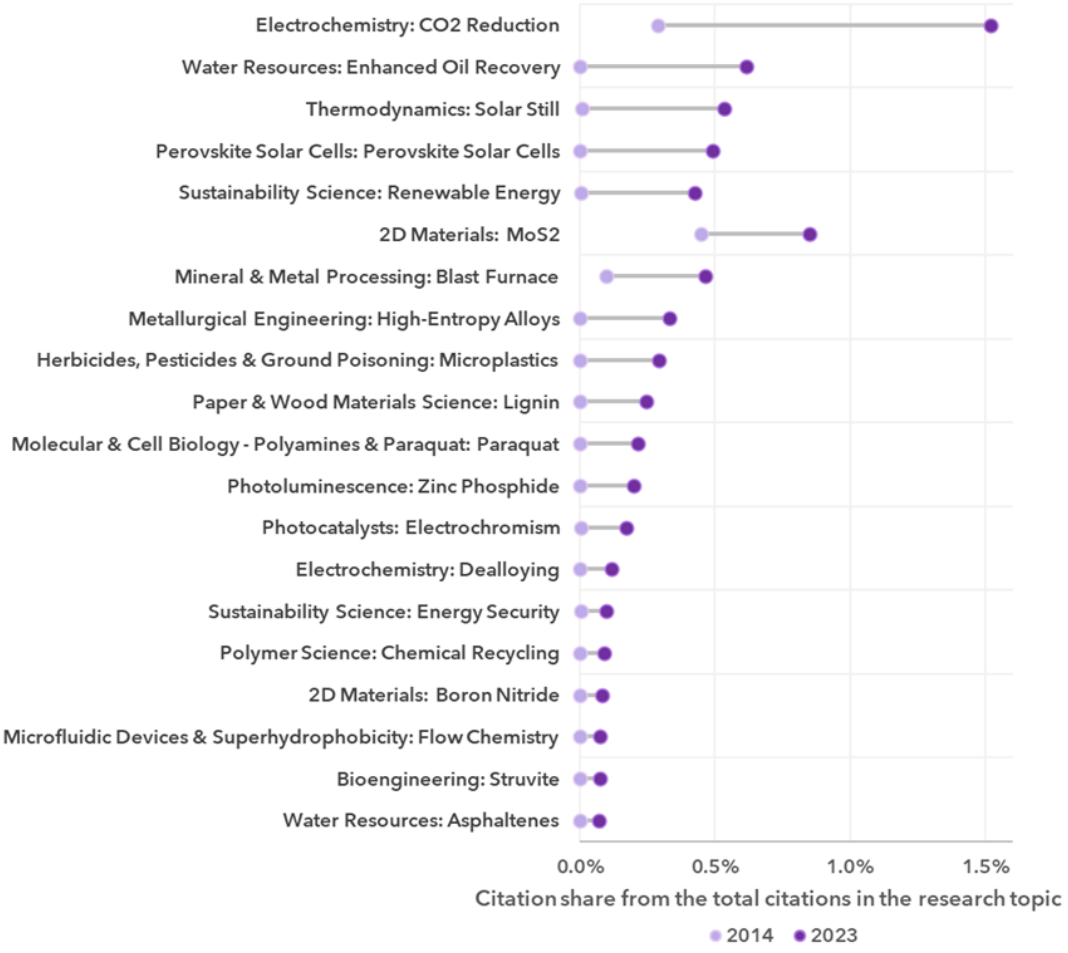


Figure 81: Top 20 emerging micro-topics globally in the research topic Hydrogen Production in the period 2014-2023

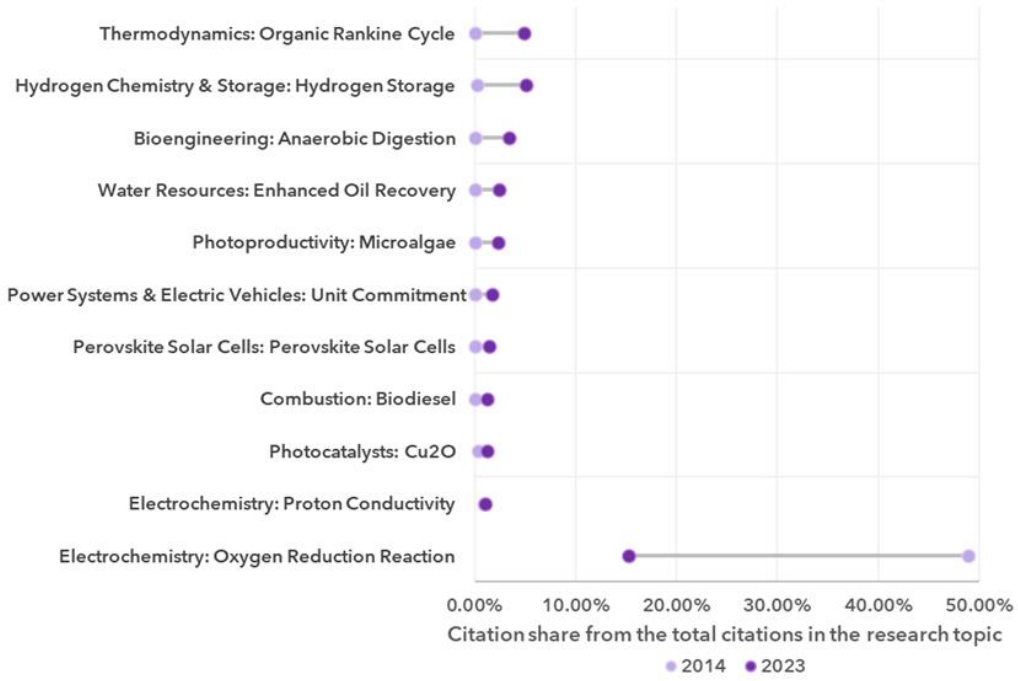


Figure 82: Top 10 emerging micro-topics identified in Saudi Arabia research output in the research topic Hydrogen Production in the period 2014-2023

4.1.8 Hydrogen Storage and Transportation

4.1.8.1 Evolution of Saudi publication share of global publications in the research topic

The share of Saudi Arabian publications from global publications on the research topic increased almost continuously from 2014 till 2023, reaching 4.26% in 2023, as shown in Figure 83.

This shows that Saudi Arabia was not only able to increase the number of publications on this research topic but also had a growth higher than the global growth rate. This is evident as the share of Saudi Arabian publications in the research topic is growing.

The CNCI of Saudi Arabian publications in this research topic was almost in all years higher than 1, indicating a citation impact performance higher than the global average. Although the CNCI decreased from 1.74 in 2014 to 0.96 in 2019 it then increased almost continuously to 2.22 in 2023, indicating a 122% higher citation impact performance than the global average.

Overall, Saudi Arabian publications increased with a higher growth rate than the global average in this research topic and had a relatively good citation impact as measured by the CNCI.

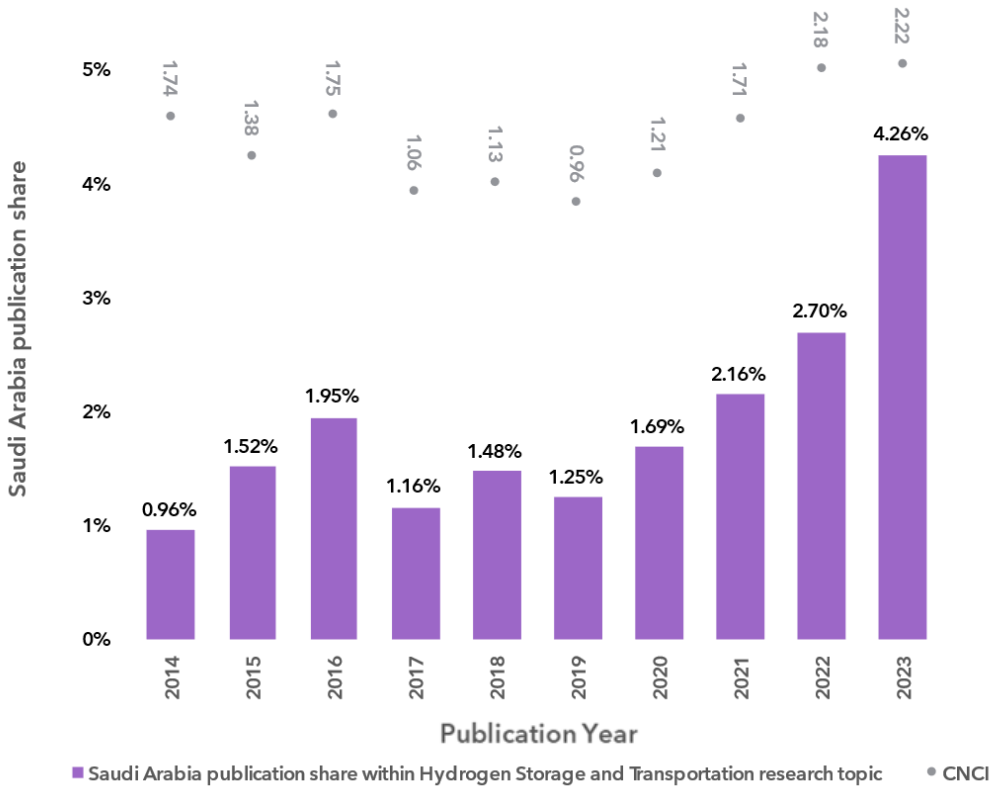


Figure 83: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabian publications in the research topic

4.1.8.2 Top 10 countries collaborating with Saudi Arabia

The top collaborating country with Saudi Arabia in this research topic in the period 2014-2023 is Egypt, followed by Mainland China and Tunisia with 103, 94 and 78 publications, respectively, as shown in Figure 84.

In terms of citation impact measured by the CNCI publications, published in collaboration with the United Kingdom followed by Australia and Pakistan, sharing the same CNCI with Malaysia had the highest CNCI with 4.02, 3.51 and 2.49, respectively. All publications with the top 10 collaborating countries had a CNCI higher than 1, reflecting a performance higher than the global average.

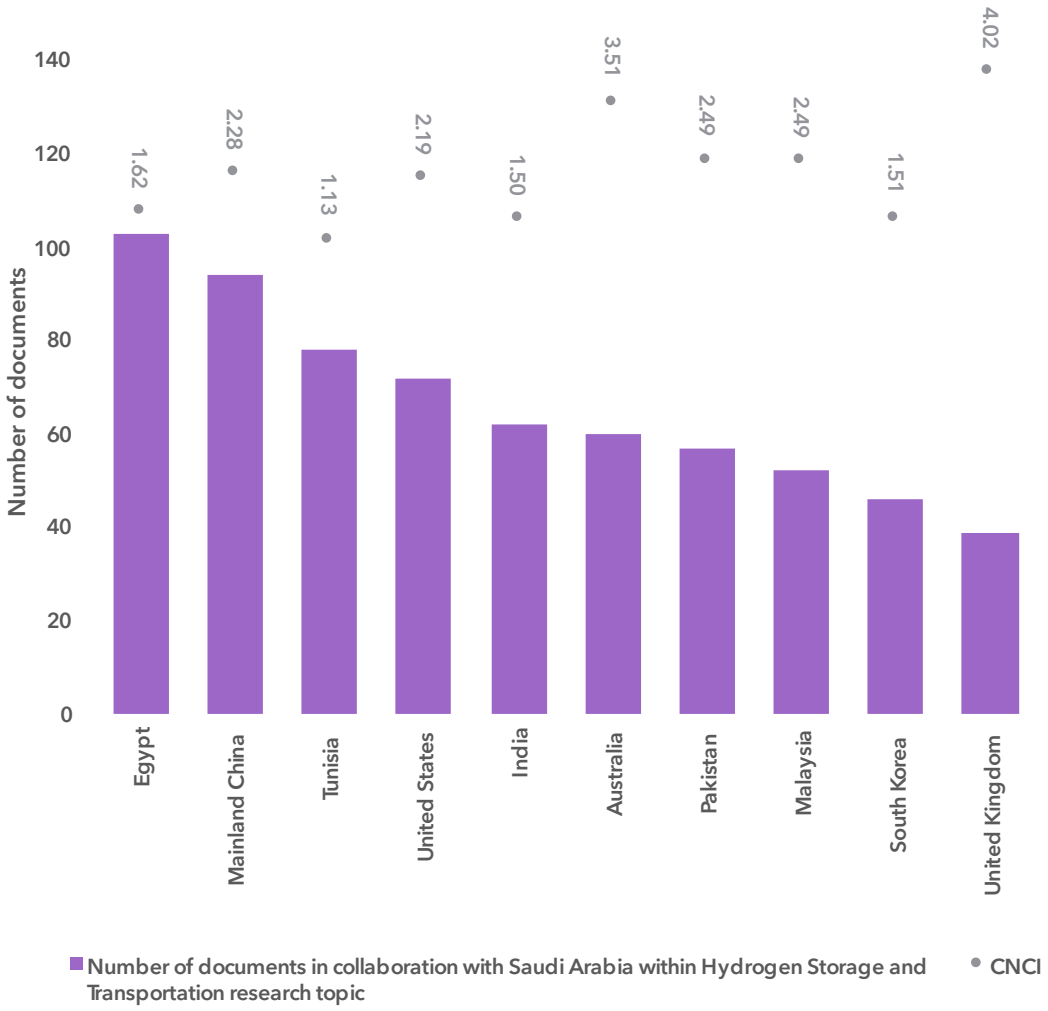


Figure 84: Top 10 collaborating countries with Saudi Arabia in terms of the number of publications in the research topic Hydrogen Storage and Transportation in the period 2014-2023

4.1.8.3 Top 20 funders of Saudi publications by number of publications

The top 3 funding organizations of Saudi Arabian publications in this research topic in terms of the number of publications mentioning the organization in the funding text in the period 2014-2023 are King Abdullah University of Science & Technology followed by King Saud University and National Natural Science Foundation of China (NSFC) with 46, 43 and 42 publications respectively as shown in Figure 85.

Documents funded by the Australian Research Council, followed by UK Research & Innovation (UKRI) and Engineering & Physical Sciences Research Council (EPSRC) with the same CNCI followed by the Australian Government had the highest citation impact measured by the CNCI with 5.65, 4.94 and 4.47 respectively.

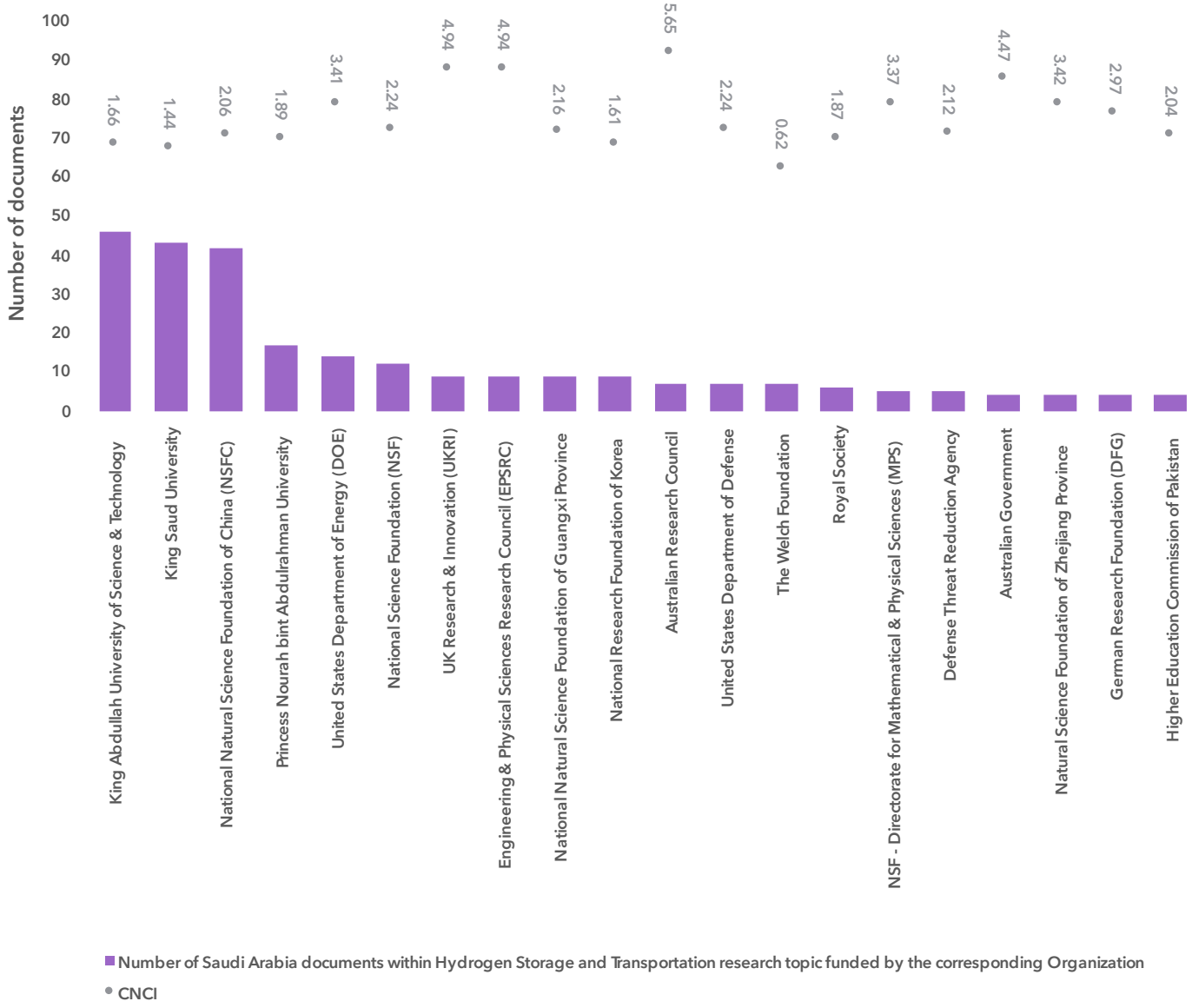


Figure 85: Top 20 funding organizations of Saudi Arabian publications in the research topic Hydrogen Storage and Transportation in terms of number of publications in the period 2014-2023

4.1.8.4 Top 20 Saudi Arabia organizations in terms of number of publications

The top 3 organizations in terms of publications published on this research topic and in the period 2014-2023 are King Abdulaziz University, followed by King Abdullah University of Science & Technology and King Fahd University of Petroleum & Minerals, with 125, 108 and 103 publications, respectively as shown in Figure 86.

In terms of citation impact as measured by the CNCI, Northern Border University, followed by Saudi Aramco and Al Jouf University, had the highest CNCI with 3.55, 2.69 and 2.62, respectively. Except for Jazan University, Qassim University and Taibah University, all top 20 organizations had a CNCI higher than 1, reflecting a citation impact performance higher than the global average.

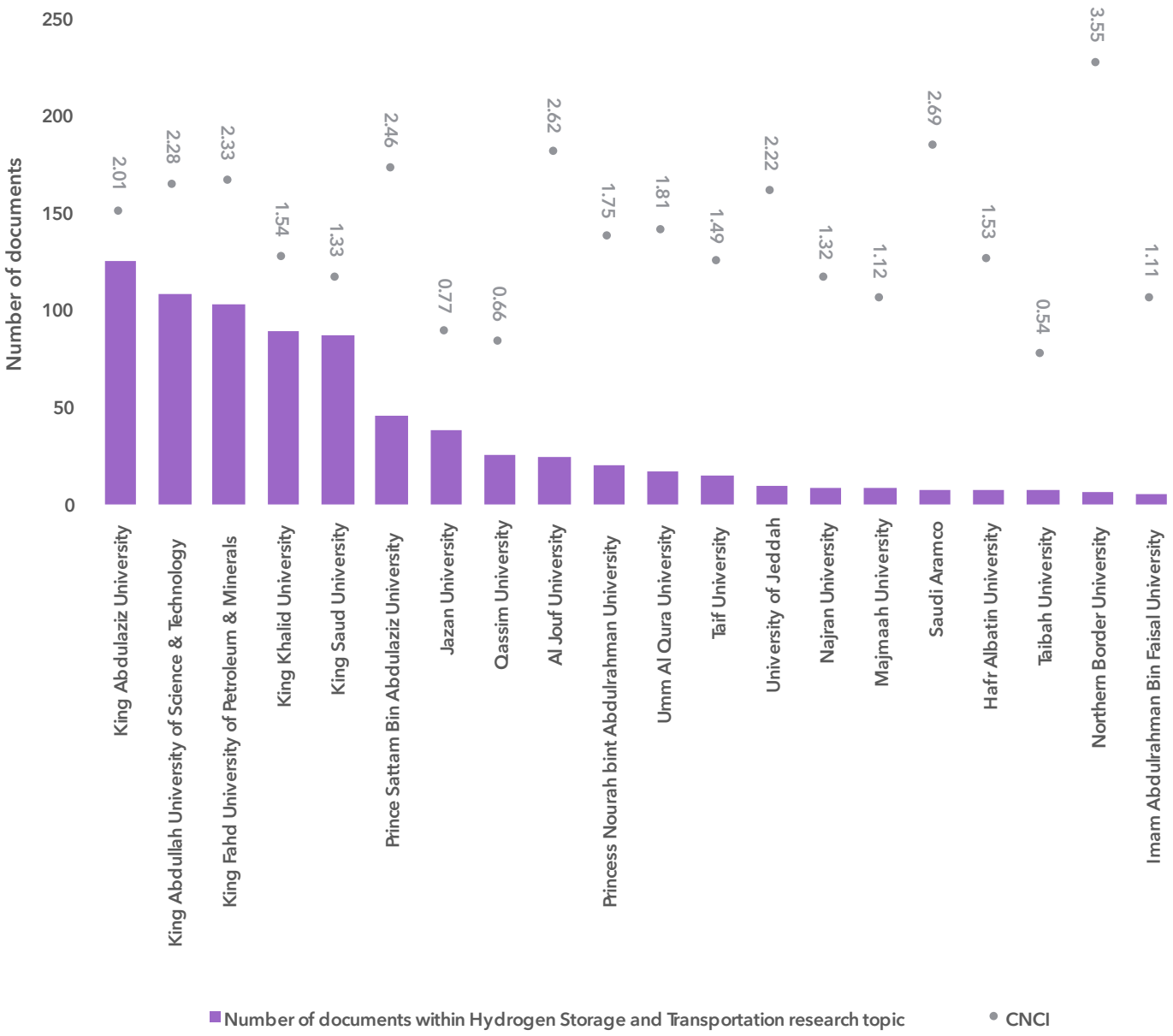


Figure 86: Top 20 Saudi organizations in terms of publications published in the research topic Hydrogen Storage and Transportation in the period 2014-2023 and their corresponding CNCI

4.1.8.5 The top 20 researchers are affiliated with Saudi organizations in terms of the number of publications they publish.

The highest number of publications are published by Ahmed Al-Yaseri, affiliated with King Fahd University of Petroleum & Minerals, followed by Ahmed Abutaleb, affiliated with Jazan University, and Abdullah M. Asiri, affiliated with King Abdulaziz University, with 24, 15 and 14 publications, respectively as shown in Table 27.

The highest CNCI is achieved by publications published by Hussein Hoteit affiliated with King Abdullah University of Science & Technology with a CNCI of 3.77. The latter researcher has also the highest number of Top 1% amounting to 2 publications.

Ahmed Al-Yaseri affiliated to King Fahd University of Petroleum & Minerals has the highest number of Top 10% publications amounting to 18 publications.

Table 27: Top 20 researchers affiliated with Saudi organizations in terms of the number of publications published in the research topic Hydrogen Storage and Transportation in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%
Al-Yaseri, Ahmed	King Fahd University of Petroleum & Minerals	24	3.11	1	18
Abutaleb, Ahmed	Jazan University	15	0.59	0	0
Asiri, Abdullah M.	King Abdulaziz University	14	1.42	0	3
Alqahtani, Talal	King Khalid University	13	1.26	0	3
Hoteit, Hussein	King Abdullah University of Science & Technology	13	3.77	2	7
Mansir, Ibrahim B.	Prince Sattam Bin Abdulaziz University	10	1.69	0	4
Mahmoud, Mohamed	King Fahd University of Petroleum & Minerals	10	1.96	0	4
Dhaou, Mohamed Houcine	Qassim University	10	0.61	0	0
Mellouli, Sofiene	Jazan University	9	1.26	0	2
Eddaoudi, Mohamed	King Abdullah University of Science & Technology	9	2.30	0	4
Isimjan, Tayirjan Taylor	King Abdullah University of Science & Technology	9	2.16	0	3
Rather, Sami Ullah	King Abdulaziz University	8	0.74	0	0
Algarni, Salem	King Khalid University	8	1.41	0	3
Maafa, Ibrahim M.	Jazan University	8	0.70	0	0
El-Newehy, Mohamed H.	King Saud University	8	0.80	0	0
Zouli, Nasser	Jazan University	7	0.65	0	0
Taha, Taha Abdel Mohaymen	Al Jouf University	7	1.81	0	3
Huang, Kuo-Wei	King Abdullah University of Science & Technology	7	1.23	0	1
Haq, Bashirul	King Fahd University of Petroleum & Minerals	7	3.75	1	5
Raza, Arshad	King Fahd University of Petroleum & Minerals	7	1.57	0	2

4.1.8.6 Top 10 countries in terms of publications

The highest number of publications published on this research topic is published by Mainland China (10,876 publications), followed by the United States (3,793 publications) and Japan (2,198 publications), as shown in Figure 87.

The highest citation impact measured by the CNCI is achieved by publications published by Australia, United Kingdom and United States with a CNCI of 1.92, 1.63 and 1.34 respectively. Six of the top 10 countries in terms of number of publications published in the research topic are also among the top 10 collaborators with Saudi Arabia.

These are the United States, Mainland China, the United Kingdom, India, Australia and South Korea.

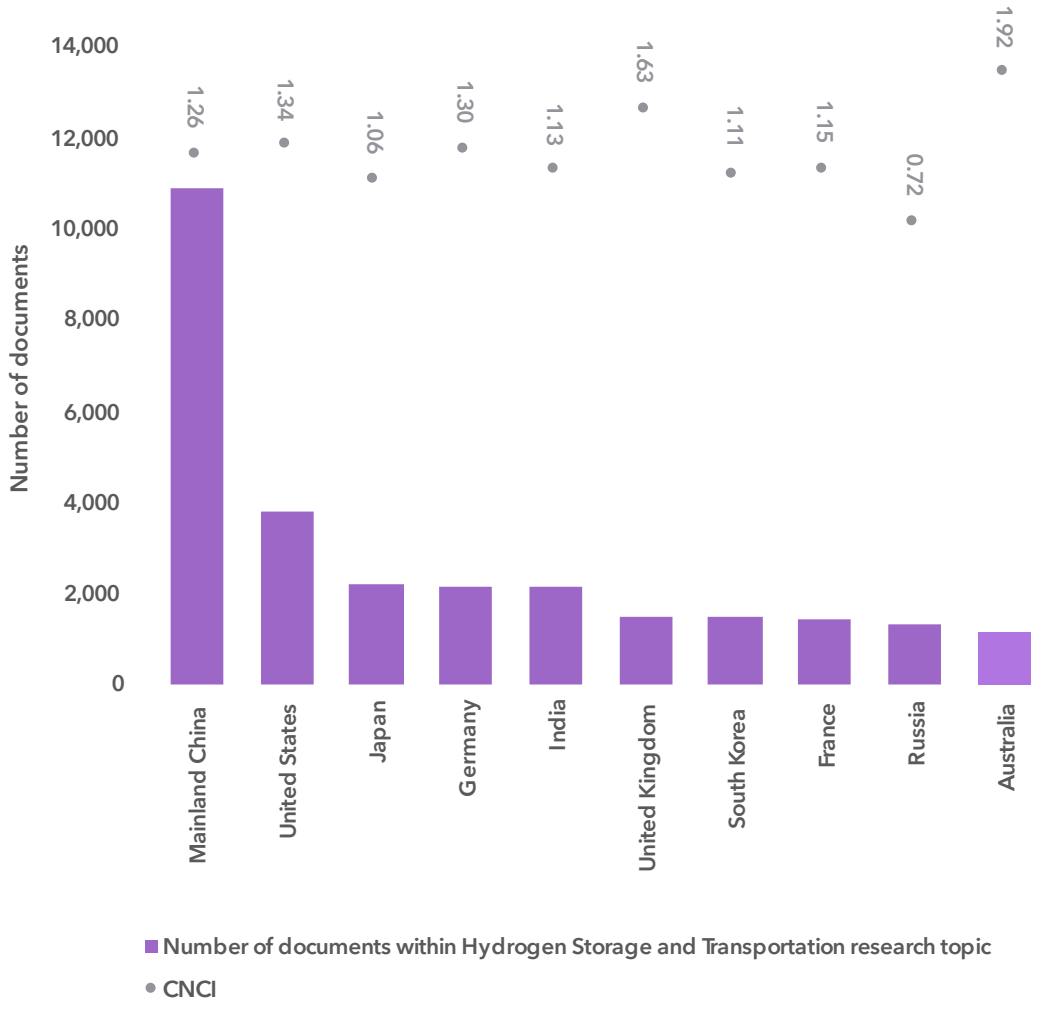


Figure 87: Top 10 countries in terms of number of publications in the research topic Hydrogen Storage and Transportation in the period 2014-2023 and their corresponding CNCI

4.1.8.7 Top 20 organizations globally in terms of number of publications

The top 3 organizations in terms of the number of publications published on this research topic in the period 2014-2023 are the Chinese Academy of Sciences (1,287 publications), followed by the Centre National de la Recherche Scientifique (CNRS) (946 publications) and the United States Department of Energy (DOE) (891 publications) respectively as shown in Figure 88.

In terms of citation impact measured by the CNCI, Tsinghua University, followed by the Swiss Federal Institutes of Technology Domain and the University of Chinese

Academy of Sciences, CAS had the highest CNCI with 1.77, 1.63 and 1.56, respectively.

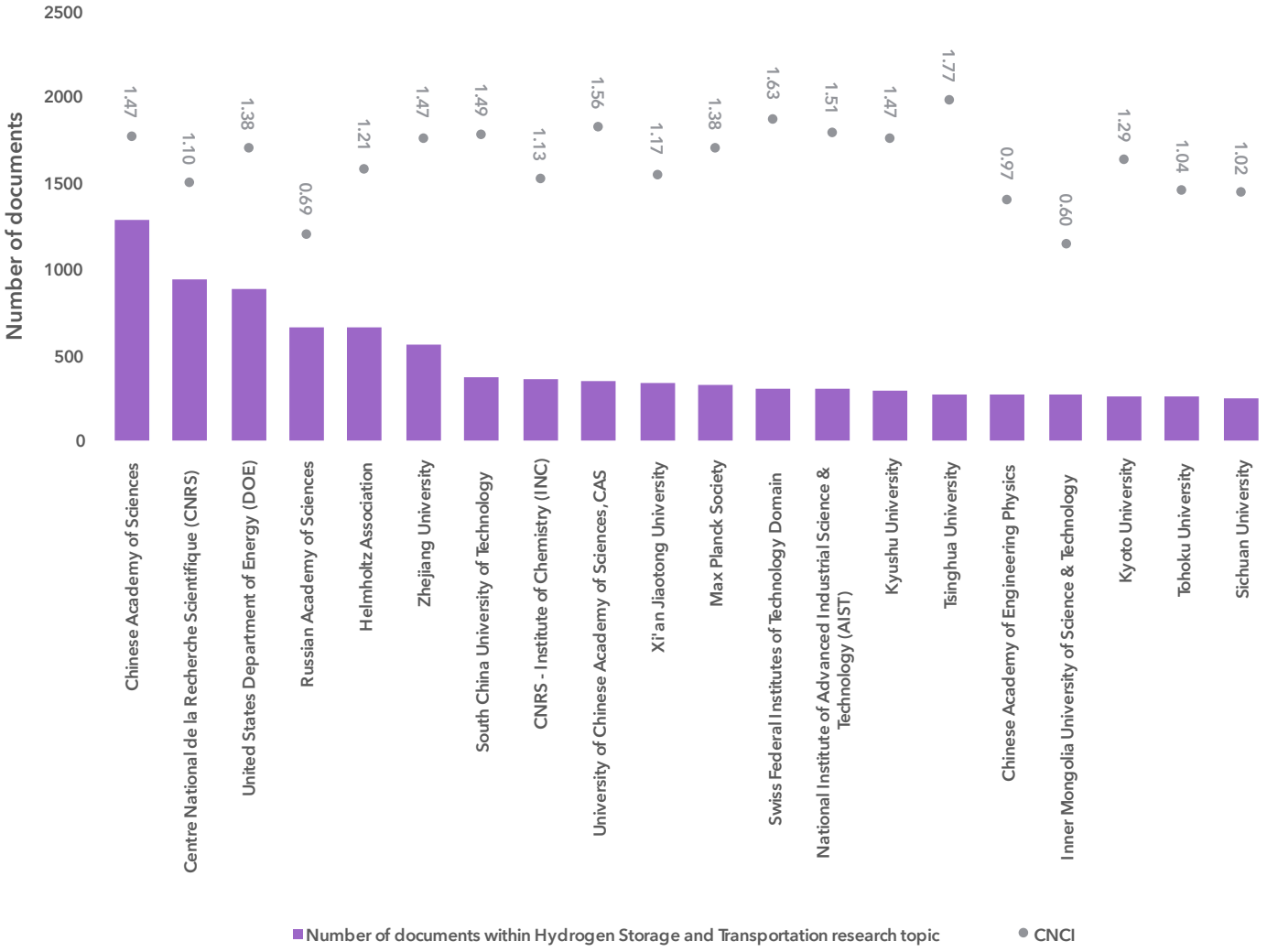


Figure 88: Top 20 organizations globally in terms of number of publications published in the research topic Hydrogen Storage and Transportation in the period 2014-2023 and their corresponding CNCI

4.1.8.8 Top 20 researchers globally in terms of number of publications

The top 3 researchers globally in terms of the number of publications on this research topic are Torben R. Jensen, affiliated to Aarhus University, with 147 publications, followed by Liuzhang Ouyang and Min Zhu, affiliated to South China University of Technology, with 144 publications, and Yanghuan Zhang, affiliated to Inner Mongolia University of Science & Technology with 141 publications as shown in Table 28.

The highest CNCI among the top 20 researchers globally is achieved by Masoud Salavati-Niasari affiliated to University Kashan with a CNCI of 1.80. The latter has also the highest Top 1% publications amounting to 6 publications.

Min Zhu affiliated to South China University of Technology had the highest number of Top 10% publications amounting to 38 publications.

Table 28: Top 20 researchers globally in terms of the number of publications published in the research topic Hydrogen Storage and Transportation in the period 2014-2023

Name	Affiliation	Web of Science Publications	CNCI	Documents in the top 1%	Documents in the top 10%	Country
Jensen, Torben R.	Aarhus University	147	1.35	3	21	Denmark
Ouyang, Liuzhang	South China University of Technology	144	1.53	3	33	Mainland China
Zhu, Min	South China University of Technology	144	1.68	4	38	Mainland China
Zhang, Yanghuan	Inner Mongolia University of Science & Technology	141	0.74	0	6	Mainland China
Wang, Hui	South China University of Technology	119	1.70	4	32	Mainland China
Han, Shumin	Yanshan University	116	1.00	2	8	Mainland China
Chen, Lixin	Zhejiang University	111	1.66	4	28	Mainland China
Xiao, Xuezhang	Zhejiang University	104	1.32	1	17	Mainland China
Li, Yuan	Yanshan University	101	1.02	2	8	Mainland China
Zhu, Yunfeng	Nanjing Tech University	97	1.43	3	25	Mainland China
Dornheim, Martin	Helmholtz-Zentrum Hereon	96	1.29	3	9	Germany
Orimo, Shin-ichi	Tohoku University	93	1.33	2	17	Japan
Sun, Lixian	Guilin University of Electronic Technology	92	1.25	1	16	Mainland China
Li, Liquan	Nanjing Tech University	91	1.26	2	20	Mainland China
Song, Myoung Youp	Jeonbuk National University	89	0.36	0	0	South Korea
Qi, Yan	China Iron & Steel Research Institute Group	86	0.62	0	4	Mainland China
Salavati-Niasari, Masoud	University Kashan	86	1.80	6	22	Iran
Ichikawa, Takayuki	Hiroshima University	85	0.60	0	4	Japan
Chen, Ping	Chinese Academy of Sciences	84	1.39	2	13	Mainland China
Liu, Jiangwen	South China University of Technology	83	1.74	3	23	Mainland China

4.1.8.9 Top 20 global funders globally in terms of number of publications

The top 3 organizations in terms of funded publications in this research topic are the National Natural Science Foundation of China (NSFC) with 7,255 publications, followed by the United States Department of Energy (DOE) with 1,065 publications, and Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT) with 1010 publications as shown in Figure 89.

The highest citation impact measured by the CNCI is observed in publications funded by Australian Research Council followed by Engineering & Physical Sciences Research Council (EPSRC) and UK Research & Innovation (UKRI) with 2.15, 1.93 and 1.84 respectively.

Among the top 20 global funding organizations, 8 are also among the top 20 funding organizations of Saudi publications in this research topic.

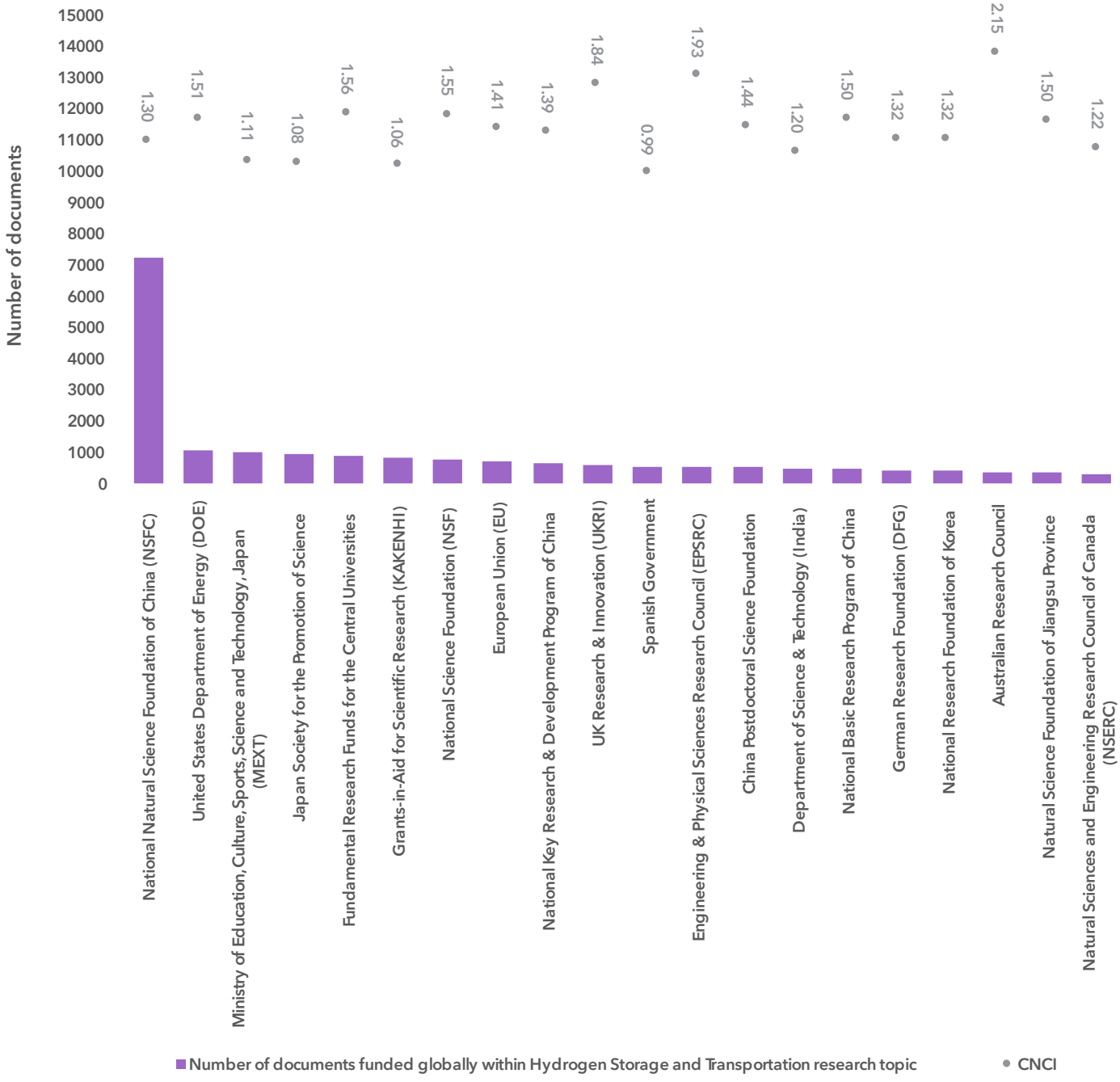


Figure 89: Top 20 funding organizations globally publications in the research topic Hydrogen Storage and Transportation in terms of number of publications in the period 2014-2023

4.1.8.10 Emerging trends in the research topic globally and in Saudi Arabia

In this section we investigate the emerging trends globally and in Saudi Arabia in the research topic Hydrogen Storage and Transportation. For more information on the methodology used to identify emerging trends, please see the definitions section for Emerging Trends.

The top 3 emerging micro-topics globally in this research topic are Water Resources, Enhanced Oil Recovery, followed by Thermodynamics: Organic Rankine Cycle and Metalloenzymes: Hydrogenase, as shown in Figure 90.

It is worth mentioning that the micro-topic Metallurgical Engineering: High-Entropy Alloys has grown in terms of number of publications, but its citation share shrank. Saudi Arabia has few publications in this research topic, such that it was not meaningful to identify emerging micro-topics.

Table 29 shows the identified top 10 micro-topics in Saudi Arabia research output in this research topic. From Saudi Arabia top 10 micro-topics, Water Resources: Enhanced Oil Recovery and Thermodynamics: Organic Rankine Cycle are also among the identified global emerging micro-topics.

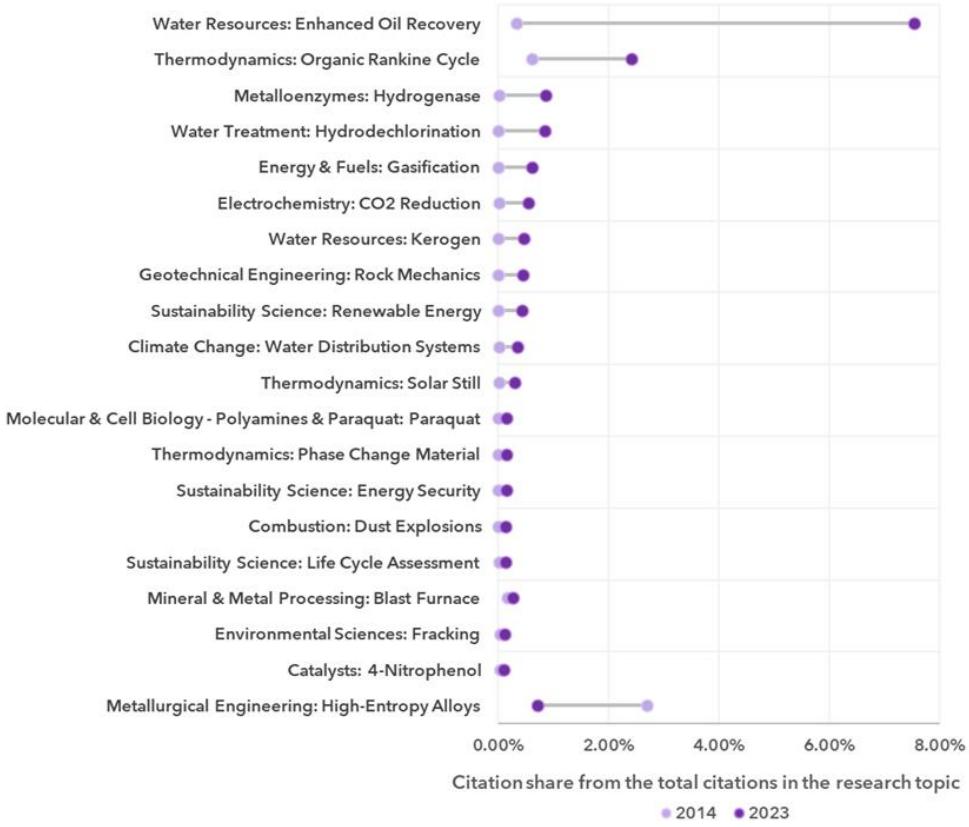


Figure 90: Top 20 emerging micro-topics globally in the research topic Hydrogen Storage and Transportation in the period 2014-2023

Table 29: Top 10 Micro-topics identified in Saudi Arabia research output in the research topic Hydrogen Storage and Transportation in the period 2014-2023

Topic	Number of Saudi Arabian publications in the period 2014-2023
Hydrogen Storage and Transportation research topic	666
Hydrogen Chemistry & Storage: Hydrogen Storage	183
Inorganic & Nuclear Chemistry: Metal-Organic Frameworks	94
Water Resources: Enhanced Oil Recovery	57
Power Systems & Electric Vehicles: Unit Commitment	31
Power Systems & Electric Vehicles: Distributed Generation	19
Thermodynamics: Organic Rankine Cycle	19
Synthesis: Dimethyl Carbonate	17
2D Materials: Boron Nitride	16
Catalysts: Fischer-Tropsch Synthesis	15
2D Materials: Carbon Nanotubes	12

4.2 Invention performance in the selected priority research topics

Saudi Arabia's applied research has more established sustained strength within the Energy and Industrias priority technologies of COTC Processes, COTC Products, Hydrogen Production and Renewable – Solar Farms.

Recently there has been high strength investment in smaller volumes into Hydrogen Storage and Transportation, Sustainable Mining – Waste Management, Energy Storage – Solid State and Construction Robots. Renewables – PV Modules, Renewables – Wind Turbines, and Renewables – Tidal/ Wave have yielded lower volumes of older inventions.

Autonomous Mining – Smart Drilling, Net Zero – Vehicle Emissions and Sustainable Mining – Low Emissions have yielded the highest lower strength inventions with volumes of 115, 37 and 33 inventions respectively.

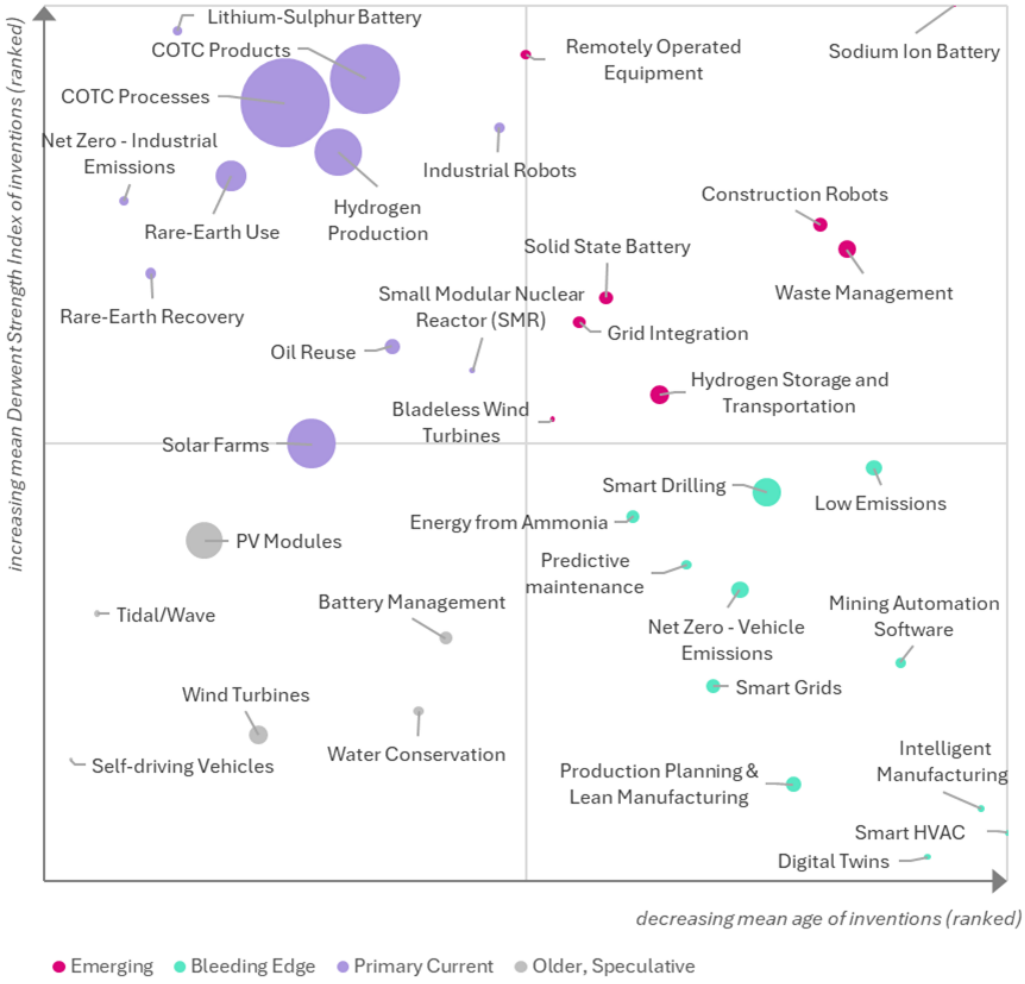


Figure 91: Technical dynamics model for the technologies within the Energy and Industrials priority area from Saudi Arabian organizations.

In Figure 91, Saudia Arabia's applied research has more established sustained strength within the Energy and Industrials priority technologies of COTC Processes, COTC Products, Hydrogen Production and Renewable – Solar Farms. Recently, there has been high-strength investment in smaller volumes into Hydrogen Storage and Transportation, Sustainable Mining – Waste Management, Energy Storage – Solid State and Construction Robots. Renewables – PV Modules, Renewables – Wind Turbines, and Renewables – Tidal/ Wave, have yielded lower volumes of older inventions. Autonomous Mining – Smart Drilling, Net Zero – Vehicle Emissions and Sustainable Mining – Low Emissions, have yielded the highest lower strength inventions with volumes of 115, 37 and 33 inventions, respectively.

Saudi Arabia focuses more heavily on COTC Processes and Products than global applied research dynamics.

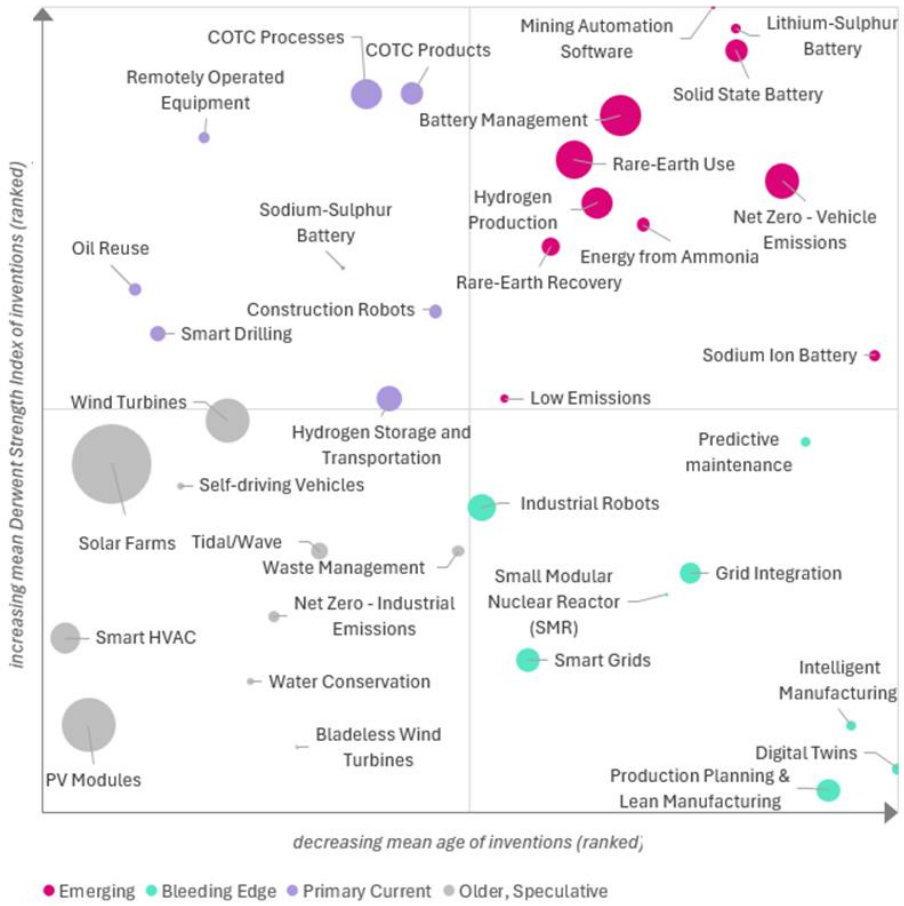


Figure 92: Technical dynamics model for the technologies within the Energy and Industrials priority area from global organizations

In Figure 92, Global innovators have focused on Renewables – Solar Farms, PV Modules and Wind Turbines by volume with over 100K inventions respectively, followed by Energy Storage – Battery Management which mirrors the Sustainability and Essential Needs trend seen with high volume, high-strength investment into Electric Cars.

The above three global renewable technologies are more established strengths of relatively low mean strength. However, this is regularly seen in portfolios of very high volumes. In Saudi Arabia, these technologies are also established focuses, with Solar Panels being an area of high mean invention strength.

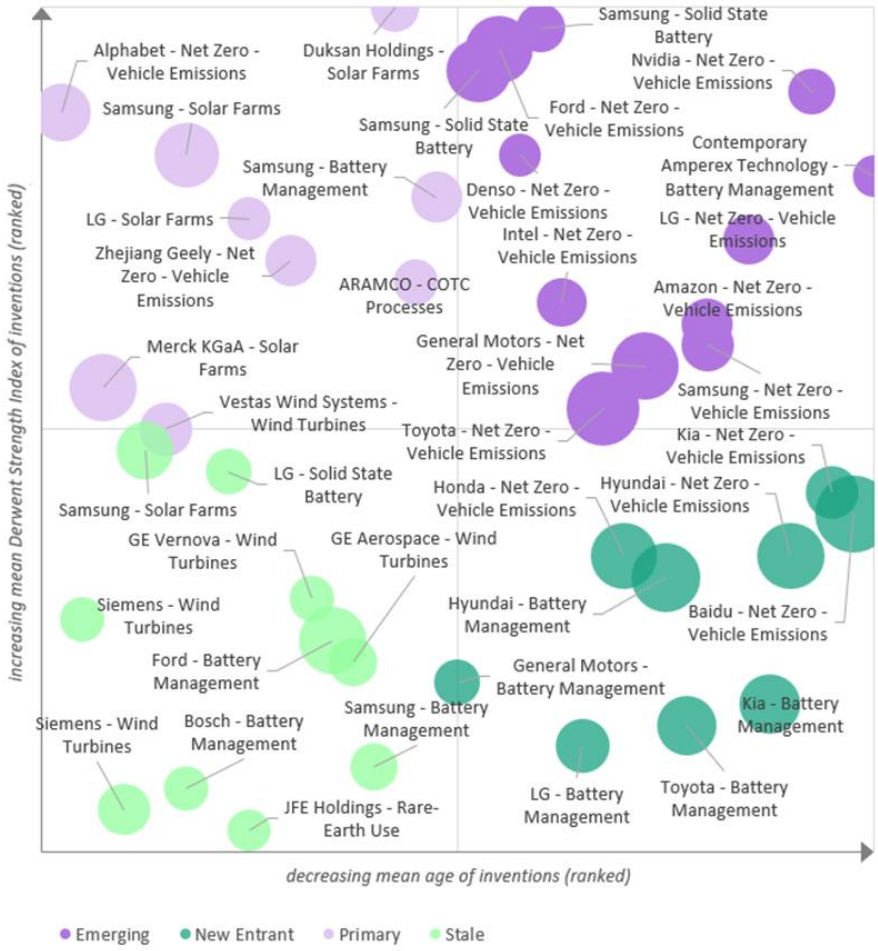


Figure 93: Top forty global organizations with the strongest inventions awarded a score of 80+/100 on the Derwent Strength Index within the priority area of Energy and Industrials

In Figure 93, within the top left quadrant are the sustained high-strength invention portfolio with a wide variety of technologies compared to the other three priority areas: Vehicle Emissions, Solar Farms, Battery Management, Wind Turbine and COTC Processes.

In the top right quadrant Vehicle Emissions is highly prevalent, only accompanied by Samsung's Solid State Battery technology.

Samsung is a stand-out innovator in Figure 93 appearing across four different technologies: Battery Management, Solar Farms, Solid State Batteries and Wind Turbines. Noticeably, South Korean and Japanese automotive and electronics companies have a strong presence across all four quadrants.

Saudi Aramco's COTC Processes invention portfolio is found within the primary, slightly older high invention strength portfolio. GE Vernova and Vestas are the only renewable energy specialists in the figure both represented by their Wind Turbine technologies.

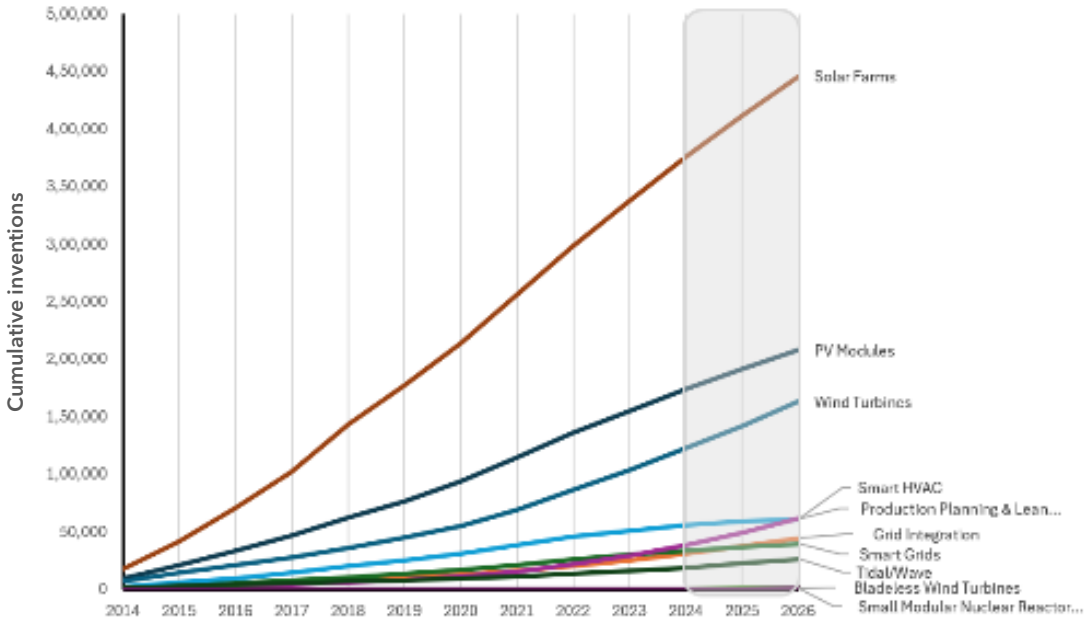


Figure 94: Cumulative inventions globally between 2014-2023 across Renewables and Power Distribution research topics within the Energy and Industrials priority area

In Figure 94, Solar Farm technologies have both the highest volume and highest acceleration of invention numbers across Renewables and Power Distribution technologies within Energy and Industrials globally. PV Modules and Wind Turbines follow behind with the next highest invention volumes and growth trajectories.

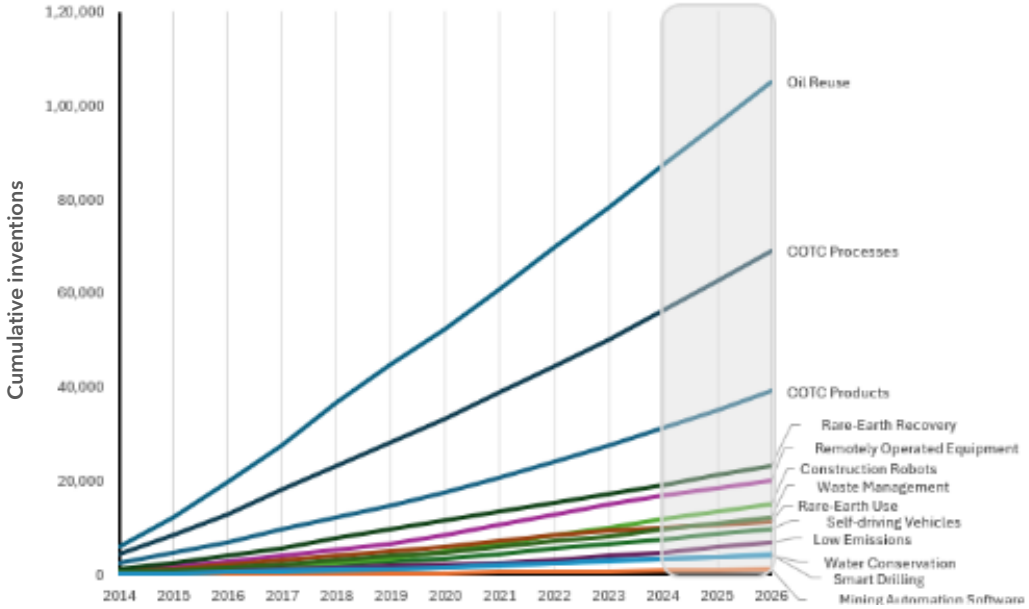


Figure 95: Cumulative inventions globally between 2014-2023 across COTC, Sustainable Mining, Re-use & Recycle related research topics within the Energy and Industrials priority area

In Figure 95, Re-use and Recycling – Oil Reuse technologies have the highest volume and acceleration in volumes. within Figure 95, followed by COTC Processes and COTC Products. The other technologies are steady however much lower growth rates in comparison.

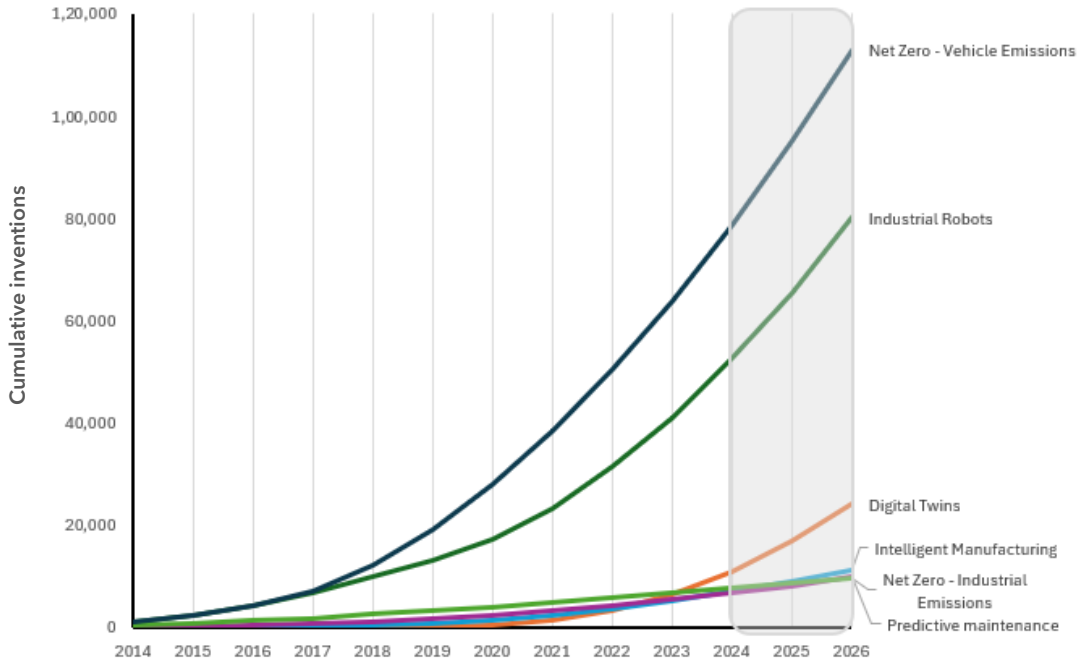


Figure 96: Cumulative inventions globally between 2014-2023 across Industry 4.0 and Net Zero research topics within the Energy and Industrials priority area

In Figure 96, Net Zero – Vehicle Emissions and Industry 4.0 – Industrial Robots have significantly higher volumes and growth rates than other Net Zero and Industry related technologies within Energy and Industrials priority area. Industry 4.0 Digital Twins has increased its growth rate globally in the last two years, with rapid growth predicted through 2026.

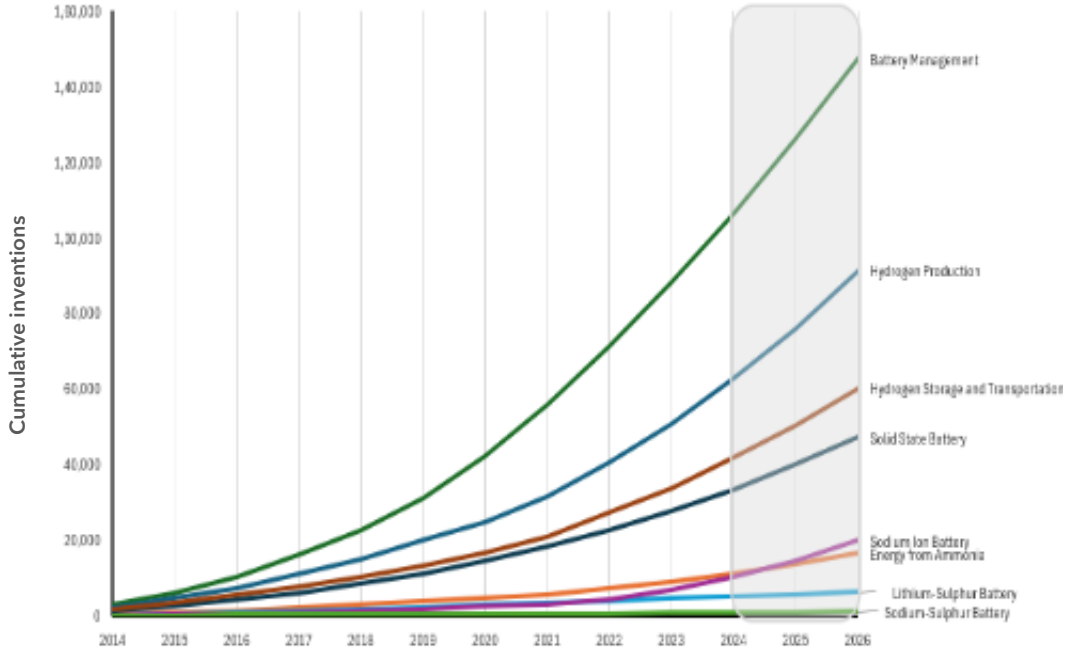


Figure 97: Cumulative inventions globally between 2014-2023 across Energy Storage and Hydrogen research topics within the Energy and Industrials priority area

In Figure 97, Energy Storage – Battery Management and Hydrogen Production technologies have the highest invention volumes and growth rates globally, followed by Hydrogen Storage and Transportation, and Energy Storage – Solid State, with sustained and predicted increase in growth rates.

4.2.1 COTC Processes

Mainland China leads in the field of COTC processes with 32,275 inventions in Figure 98, followed by the United States with 7,036, Japan with 3,221, South Korea with 2,333 and Germany with 1,266. Saudi Arabia ranks 10th and holds 1,050 inventions.

Saudi Iron & Steel is placed in the top left quadrant of Figure 99 with five established high-strength inventions, as shown in Figure 99.

KFUPM holds the highest number of inventions from Saudi Arabia with 62 inventions with a mean invention strength of 58.7, this is followed by KAUST with 44 inventions with a mean invention score of 44, KACST holds 11 inventions with a mean invention score of 49.2.

Figure 98: Global distribution of inventions related to COTC Processes. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

China Petrochemical Corporations holds 6,825 inventions with a mean invention strength of 44.4. However, it falls in older, lower-strength invention portfolios within Figure 100.

Saudi Aramco holds 1,253 inventions with a mean invention score of 58.7, placing its invention portfolio in the high-strength, more recent invention portfolios. Saudi Aramco is notably classed as sourcing these inventions from outside of Saudi Arabia.

The Chinese Academy of Sciences has the next largest portfolio of 1,117 and is also found in the top right quadrant with Saudi Aramco. The high-strength top quadrants contain many leading energy companies such as but not limited to Shell, Linde, ExxonMobil, Chevron, Chevron Phillip and TotalEnergies.

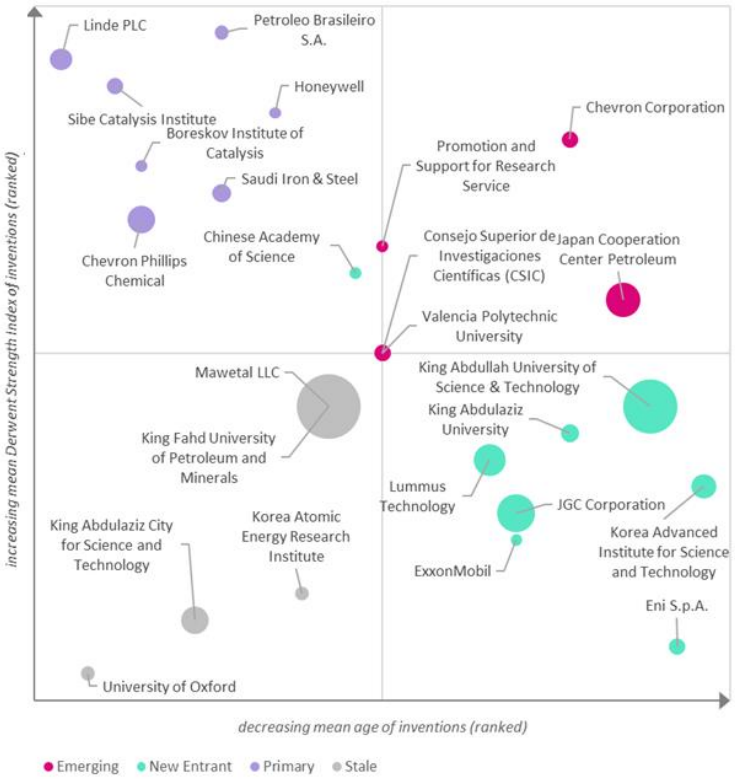


Figure 99: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of COTC Processes

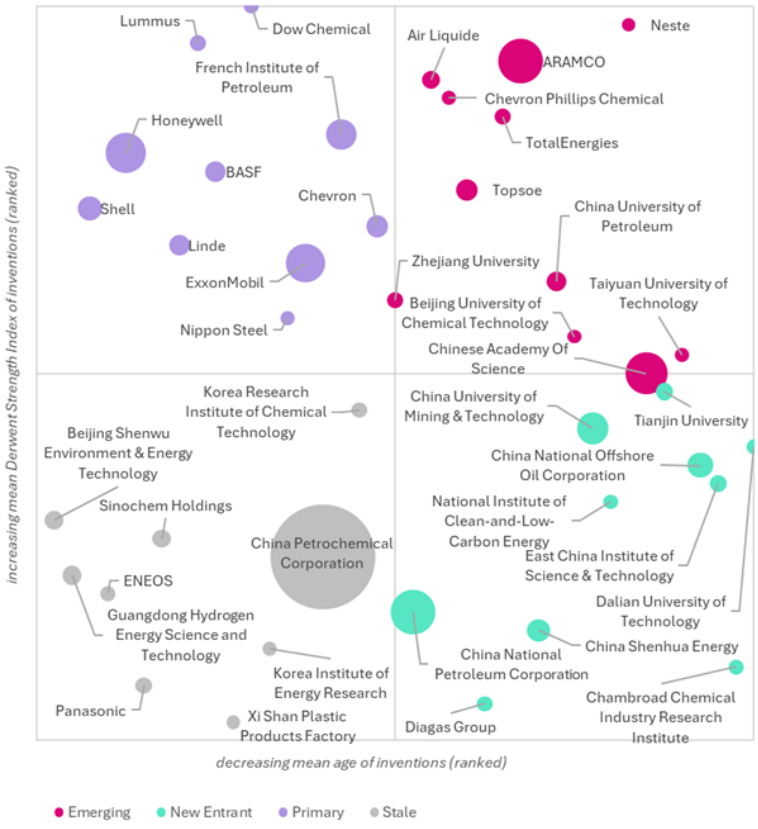


Figure 100: Commercial dynamics model for the top global patent assignees in the technology area of COTC Processes

4.2.2 COTC Products

Mainland China leads the COTC Products source of inventions with 19,329 inventions between 2014 and 2024 in Figure 101. They are followed by the United States with 4,047 inventions, Japan with 1,189 inventions, Russia with 909 inventions and Saudi Arabia with 657 inventions.

Figure 101: Global distribution of inventions *related* to COTC Products. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

KAUST holds the highest strength and the highest volume of inventions in COTC Products, as seen above in Figure 102, with 24 inventions, and a mean invention score 56.7, this is followed by KFUPM holds 45 inventions, with a mean score of 51.2.

Saudi Aramco holds the largest high-strength, recent invention portfolio of 741 inventions with a mean invention score of 60.1 in Figure 103, the Saudi Aramco portfolio within COTC Products is classed as having a geographical source outside of Saudi Arabia, such as but not limited to the US.

The next largest portfolio is held by China Petrochemical Corporation, holding 2,937 inventions with a mean invention score of 45.7. However, it is placed in the more recent but lower-strength quadrant.

The top left quadrant contains many large energy and chemicals companies such as but not limited to ExxonMobil, Honeywell, Emerson Electric, Halliburton, Chevron, Idemitsu Kosan, BASF, ENEOS, Dow Chemical, Baker Hughes, SLB, Ecolab, Linde and Lummus.

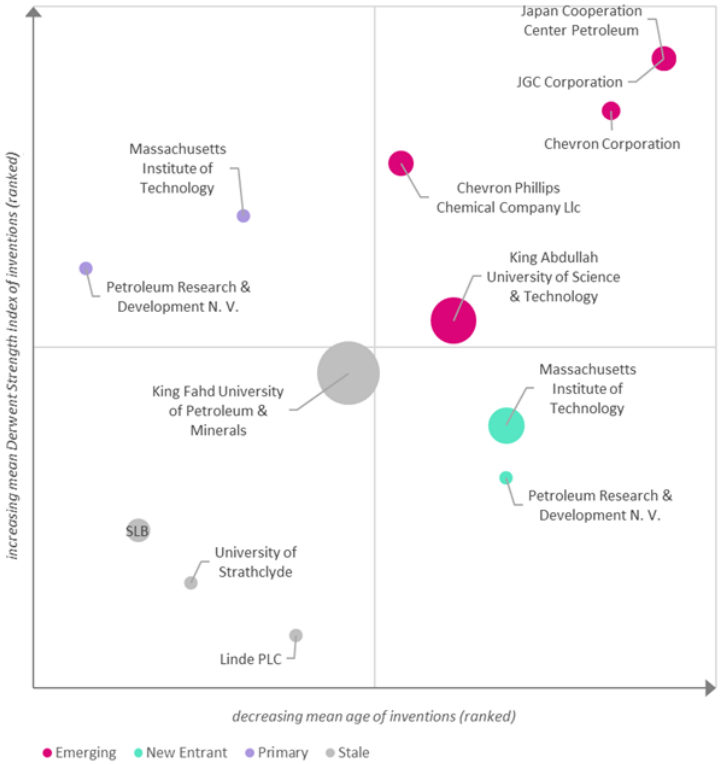


Figure 102: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of COTC Products

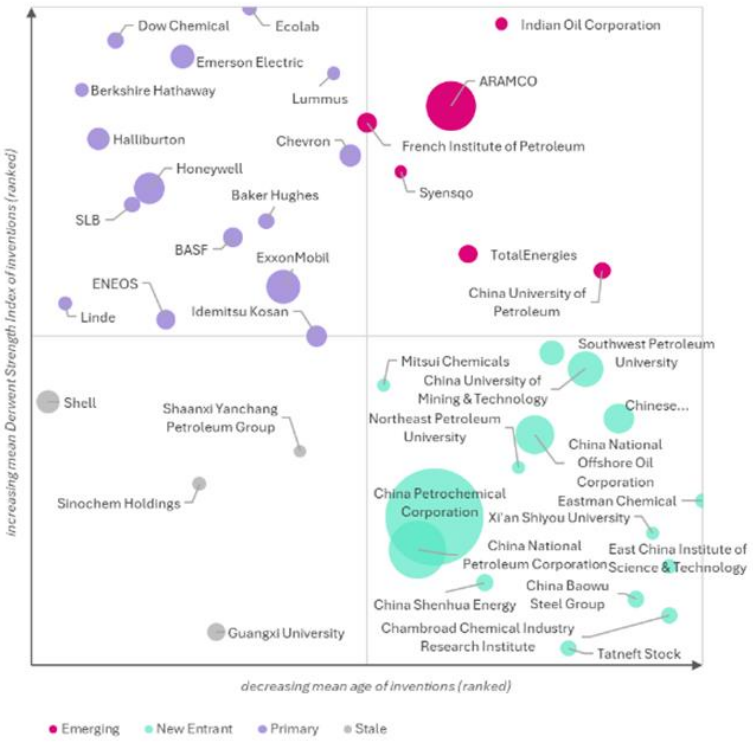


Figure 103: Commercial dynamics model for the top global patent assignees in the technology area of COTC Products

4.2.3 Sustainable Mining Waste Management

Mainland China is the leading source of Sustainable Mining – Waste Management, producing 7,374 inventions between 2014 and 2024 in Figure 104 . Followed by the United States with 217, South Korea with 139, India with 106 and Russia with 91.

The University of Shandong has the largest high-strength recent invention portfolio, holding 157 inventions, with a mean invention strength of 46.9 seen in the top right quadrant of Figure 105, and mean remaining years 15.1.

Saudi Aramco has a very high mean invention score of 58.2 across 24 inventions. Central South University, Chinese Academy of Science and China University of Mining & Technology all hold 100+ inventions with a mean invention strength score of 42-45 – further showcasing the strength of Mainland China's Academic innovation in the field of Sustainable – Waste Management.

Figure 104: Global distribution of inventions *related* to Sustainable Mining Waste Management. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

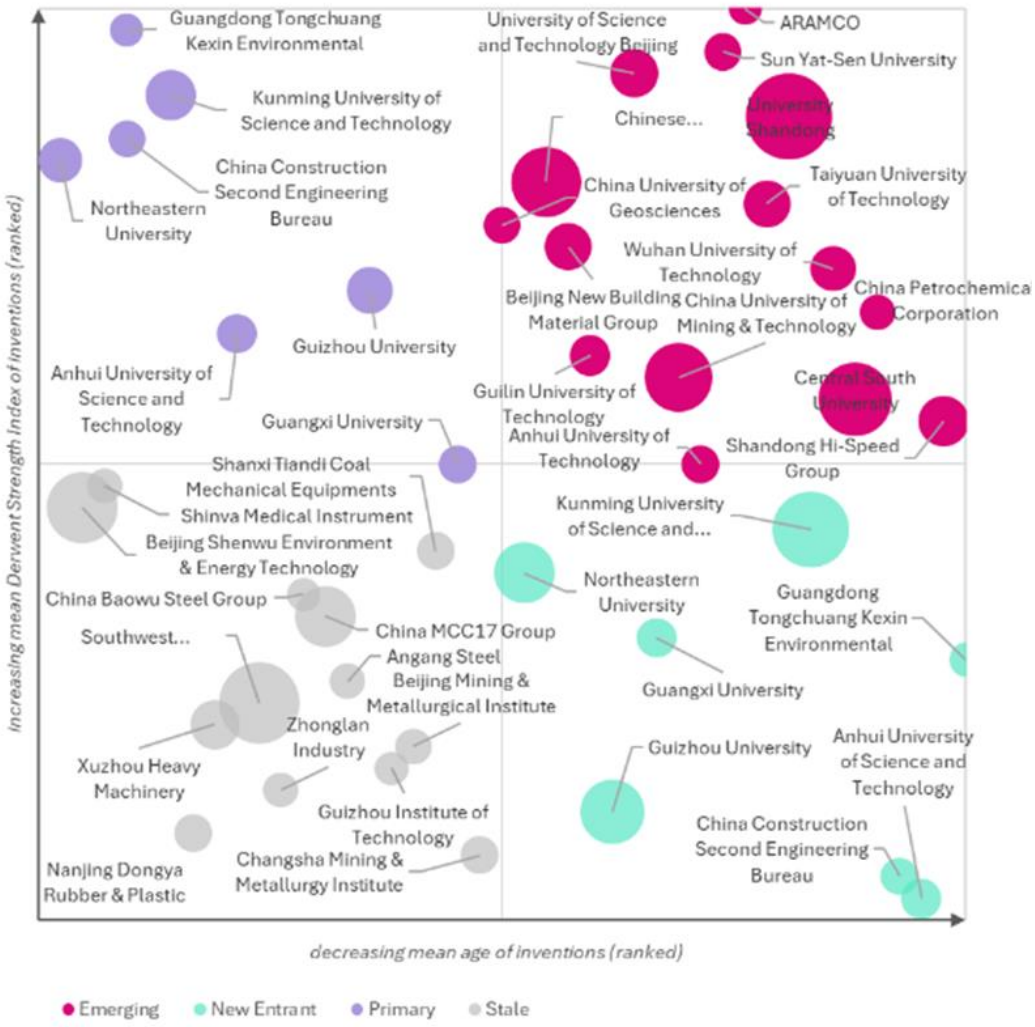


Figure 105: Commercial dynamics model for the top global patent assignees in the technology area of Sustainable Mining Waste Management

4.2.4 Digital Twins

Mainland China led the production of inventions between 2014 and 2024 in the field of Industry 4.0 - Digital Twins, with 5,111 inventions in Figure 106 . The US is ranked second with 569 inventions, followed by South Korea with 424, India with 206 and Germany with 173.

Saudi Aramco holds the largest, high mean strength, established invention portfolio of three inventions in the field of Industry 4.0 – Digital Twins seen in Figure 107 . Followed by KFUPM with one invention with a mean invention strength of 35.8, and King Khalid University with one invention with a mean strength of 14.8.

Figure 106: Global distribution of inventions *related* to Industry 4.0 - Digital Twins. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

In Figure 108, State Grid Corporation of China holds the largest number of inventions globally in Industry 4.0 – Digital Twins holding 407 inventions, however with a mean invention score of 34.5 it is found within the recent, lowest strength quadrant.

Only Chinese organizations are found within the top right quadrant containing recent, high-strength portfolios: Dalian University of Technology, Wuhan University of Technology, Chongqing University, Southeast University, University of Electronic Science and Technology of China and Zhengzhou University of Light Industry, holding between 24-34 inventions each.

Within the high-strength more established portfolios, there are four corporations: Siemens, Johnson Controls, GE Aerospace and Bosch – holding between 25-106 inventions. The significant presence of Organizations and the absence of corporations signifies a relatively immature field of technology.

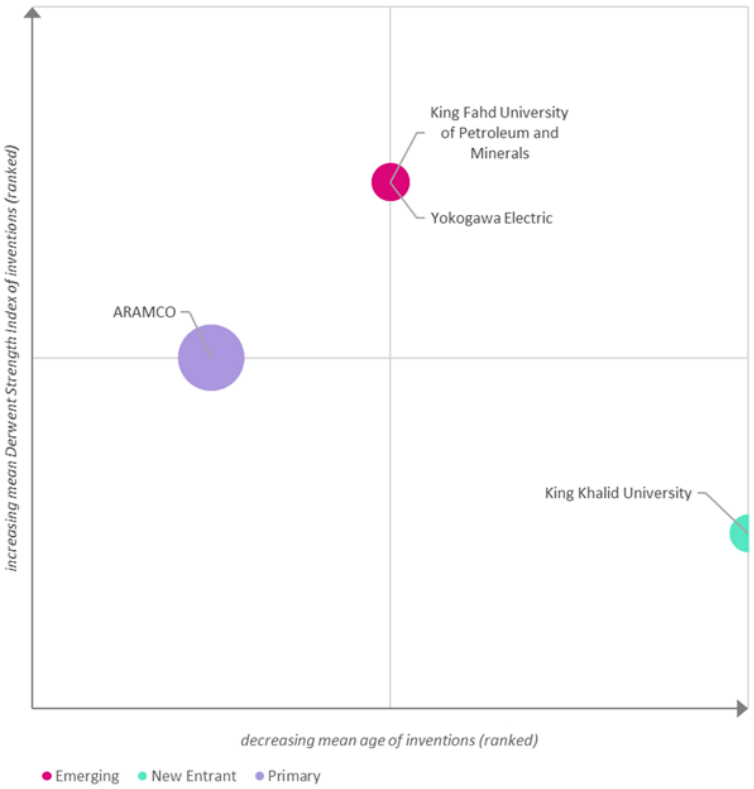


Figure 107: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of Industry 4.0 - Digital Twins.

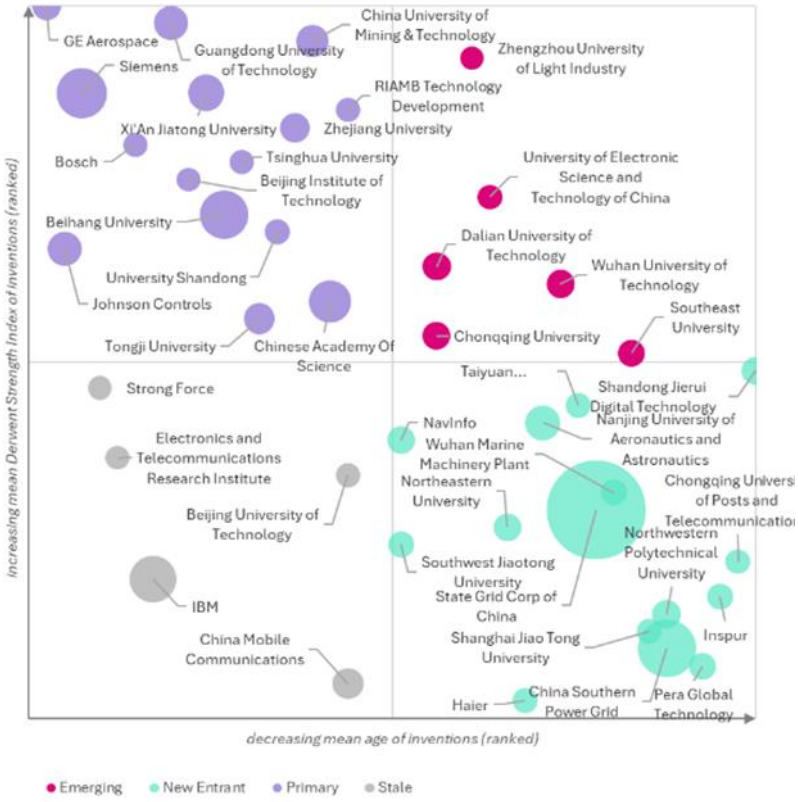


Figure 108: Commercial dynamics model for the top global patent assignees in the technology area of Industry 4.0 - Digital Twins

4.2.5 Net Zero - Industrial Emissions

In Figure 109 Mainland China is the leading source of inventions in the field of Net Zero – Industrial Emissions producing 5,311 inventions between 2014 – 2024. Mainland China is followed by South Korea with 476, US with 247, Japan with 238 and India with 169.

Figure 109: Global distribution of inventions *related* to Net Zero - Industrial Emissions. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

The leading organizations from Saudi Arabia in the field of Net Zero – Industrial Emissions seen in Figure 110 are Saudi Aramco holding eight inventions with a high mean invention strength score of 61.1, KFUPM holding three inventions with a mean invention strength score of 58.4, KAUST holding one invention with a mean invention strength score of 22.8.

Chinese Academy of Science leads global invention portfolios in the field of Net Zero – Industrial Emissions, holding 71 inventions with a mean invention strength score of 48.7, and appears in the top right quadrant of Figure 111.

Followed by Tsinghua University with 24 inventions, Zhejiang University with 17 inventions and Sun Yat-Sen University with ten inventions.

In the top left quadrant of established high-strength inventions portfolio, there are corporations GE Aerospace with 26 inventions, Toshiba with 21 inventions, Mitsubishi Heavy Industries with 18 inventions and Siemens with ten inventions.

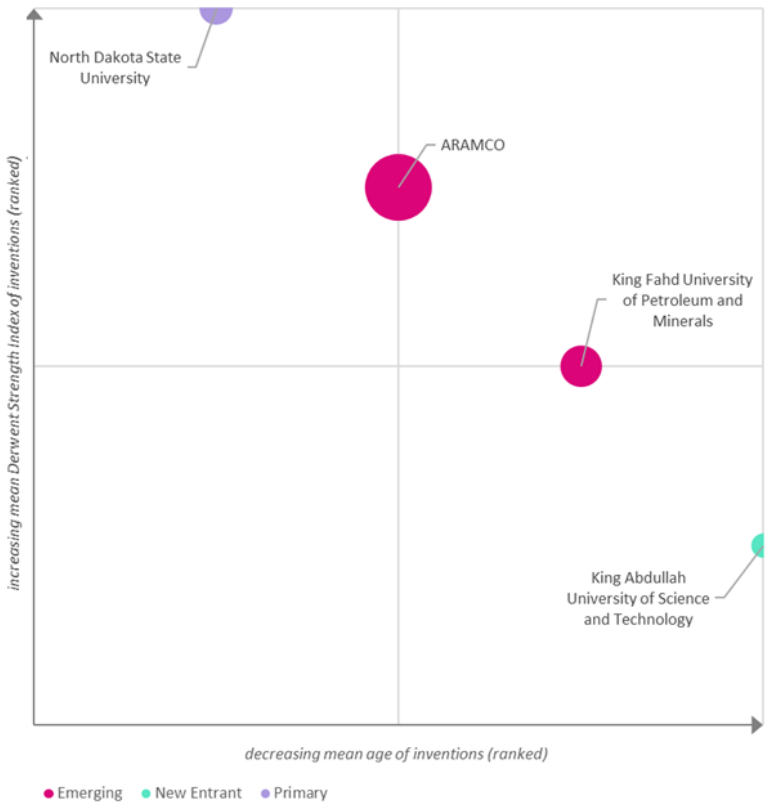


Figure 110: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of Net Zero - Industrial Emissions

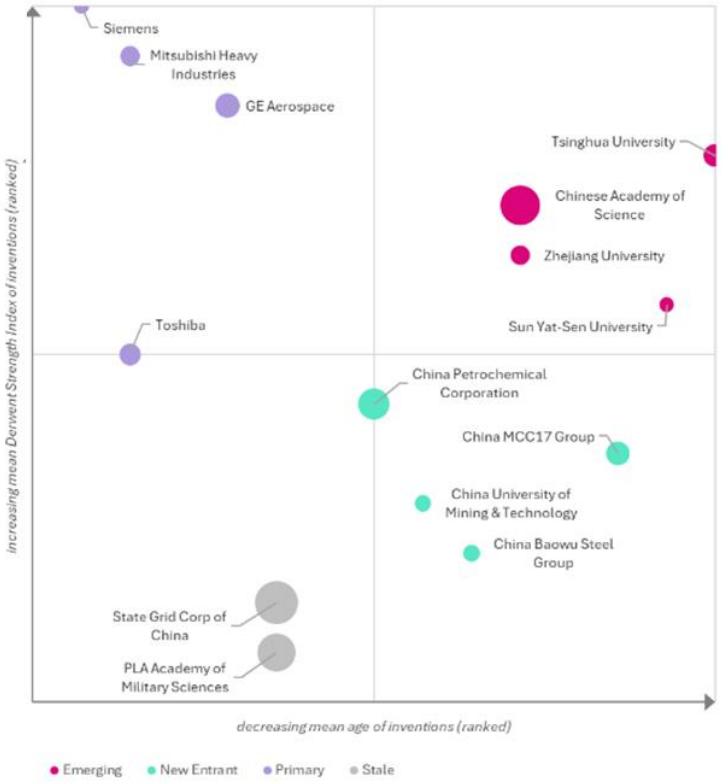


Figure 111: Commercial dynamics model for the top global patent assignees in the technology area of Net Zero - Industrial Emissions

4.2.6 Smart Grids

Mainland China is the leading geographical source of inventions in the field of Power Distribution – Smart Grids seen in Figure 112 , producing 24,425 inventions between 2014 – 2024. Followed by the US with 1,634, Japan with 1,608, South Korea with 1,485 and India with 537 inventions.

Figure 112: Global distribution of inventions *related* to Smart Grids. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

KFUPM holds the leading invention portfolio within the technology of Smart Grids, holding 16 inventions with a mean invention strength score of 48, as seen in Figure 113.

It is followed by Saudi Aramco, holding three inventions with a mean invention strength score of 55.3; King Abdulaziz University, holding one invention with a mean invention strength score of 49.4; and Imam Abdulrahman Bin Faisal University, holding one invention with an invention strength score of 63.

In Figure 114 Samsung holds the largest high-strength portfolio internationally within the technology area of Power Distribution – Smart Grids, holding 297 inventions with a mean invention strength score of 49.2, followed by Hitachi with 190 inventions, LG holds a more recent invention portfolio of 230 inventions, with a mean invention strength score of 44.9.

Figure 113: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of Smart Grids

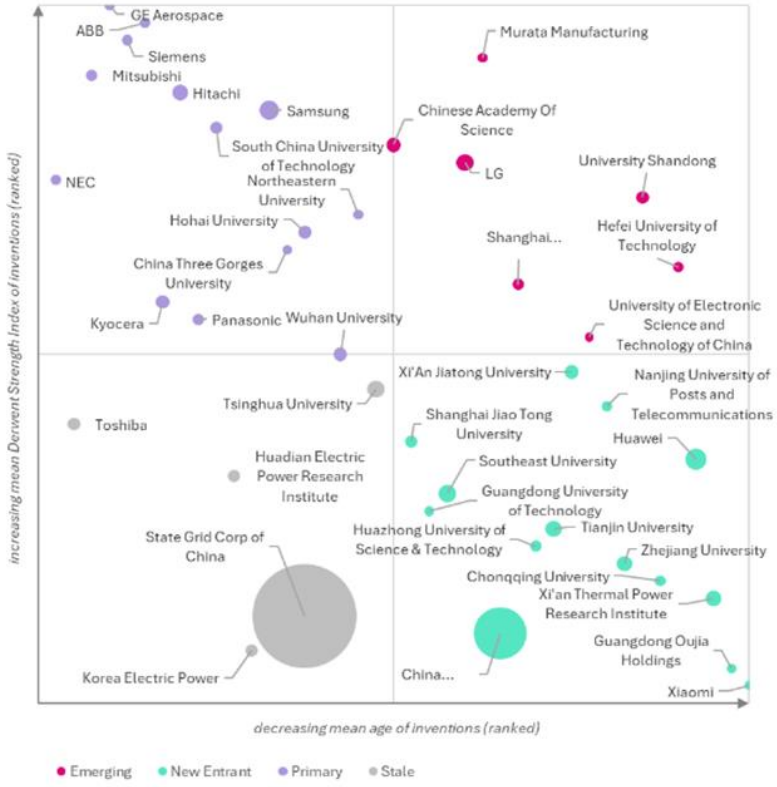


Figure 114: Commercial dynamics model for the top global patent assignees in the technology area of Smart Grids

4.2.7 Hydrogen Production

Mainland China is the leading source of inventions in the field of Hydrogen Production between 2014 – 2024 seen in Figure 115 , holding 33,737 inventions. Followed by Japan with 5,240 inventions, South Korea with 3,661 inventions, the United States with 3,148 inventions and Germany with 1,476 inventions.

Figure 115: Global distribution of inventions related to Hydrogen Production. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

Saudi Aramco has the largest invention portfolio from Saudi Arabia in the technology of Hydrogen Production, holding 202 inventions with an average strength of 57.

In the top right quadrant of Figure 116 contain high-strength, recent invention portfolios. King Abdulaziz University has ten inventions, King Saud University has two, and King Faisal University has one.

Many Chinese Academic institutions are found in the top right quadrant with high-strength, recent invention portfolios for Hydrogen Production technologies such as Zheijiang University with 270 inventions, Shaanxi University of Science and Technology 247, Jiangsu University with 220.

In the top left quadrant of Figure 117 with more established strong inventions Chinese Academy of Science holds 1,366 inventions, Toshiba with 278 inventions and Saudi Aramco with 266 inventions. Notably only 202 inventions for Saudi Aramco are sourced from Saudi Arabia.

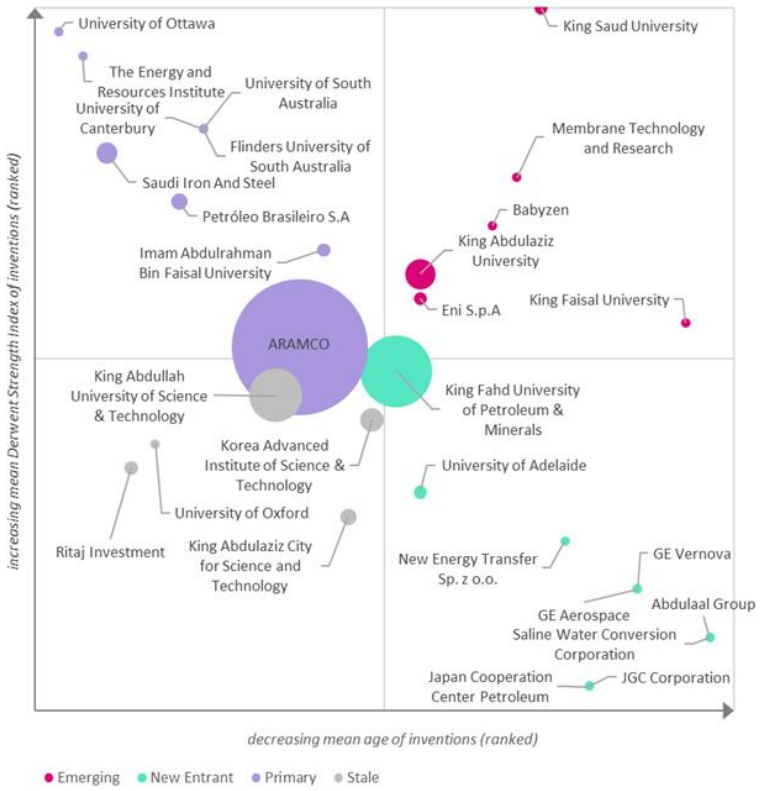


Figure 116: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of Hydrogen Production

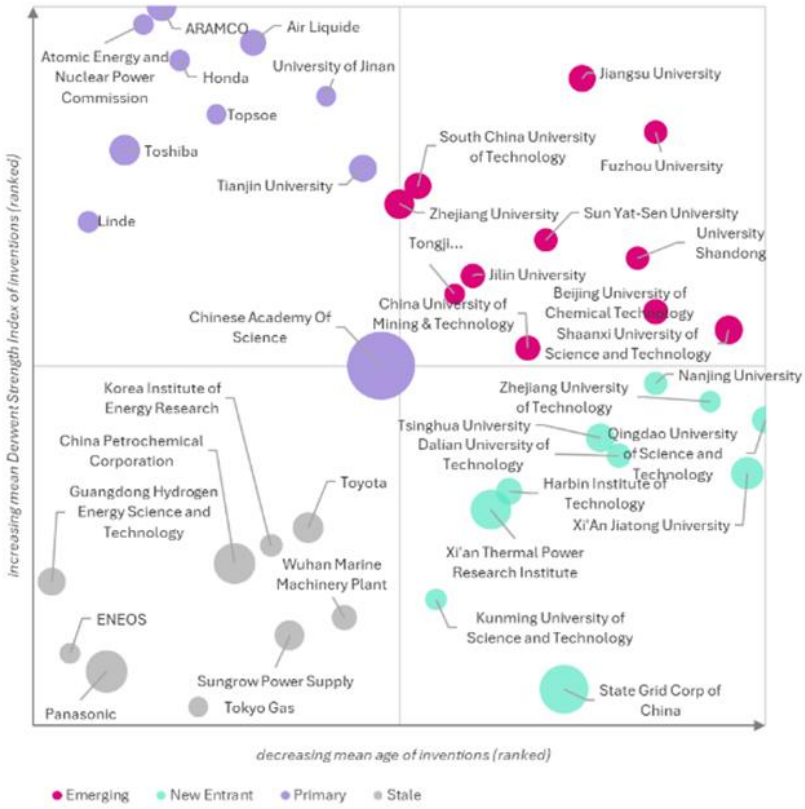


Figure 117: Commercial dynamics model for the top global patent assignees in the technology area of Hydrogen Production

4.2.8 Hydrogen Storage and Transportation

In Figure 118 Mainland China is the leading source of inventions in the technology of Hydrogen Storage and Transportation between 2014 – 2024 holding 23,185 inventions. Followed by Japan with 4,131 inventions, South Korea with 2,885 inventions, US with 1,127, and Germany with 1,111 inventions.

Figure 118: Global distribution of inventions *related* to Hydrogen Storage and Transportation. The size of each bubble corresponds to the number of unique inventions published in that country or jurisdiction.

Saudi Aramco holds the largest high-strength invention portfolio in the field of Hydrogen Storage and Transportation, as seen in Figure 119 Holding 28 inventions, with a mean invention strength score of 55.6, followed by KFUPM with 12 inventions, King Faisal University with one invention and Saline Water Conversion Corporation with one invention.

KAUST and KACST also hold two inventions, each in the top left quadrant for high-strength, more established inventions.

Chinese Academy of Science holds the largest high-strength, recent invention portfolio within the Hydrogen Storage and Transportation technology, holding 425 inventions seen in Figure 120, followed by Hyundai with 343 inventions, Xi'an Thermal Power Research Institute with 249 inventions and Kia with 233 inventions.

Within the top left quadrant are organizations with high-strength established invention portfolios: Honda holds 139 inventions, Air Liquide 118 inventions, Wuhan Geluofu Hydrogen Energy Mobile has 114 inventions, and NavInfo has 100 inventions.

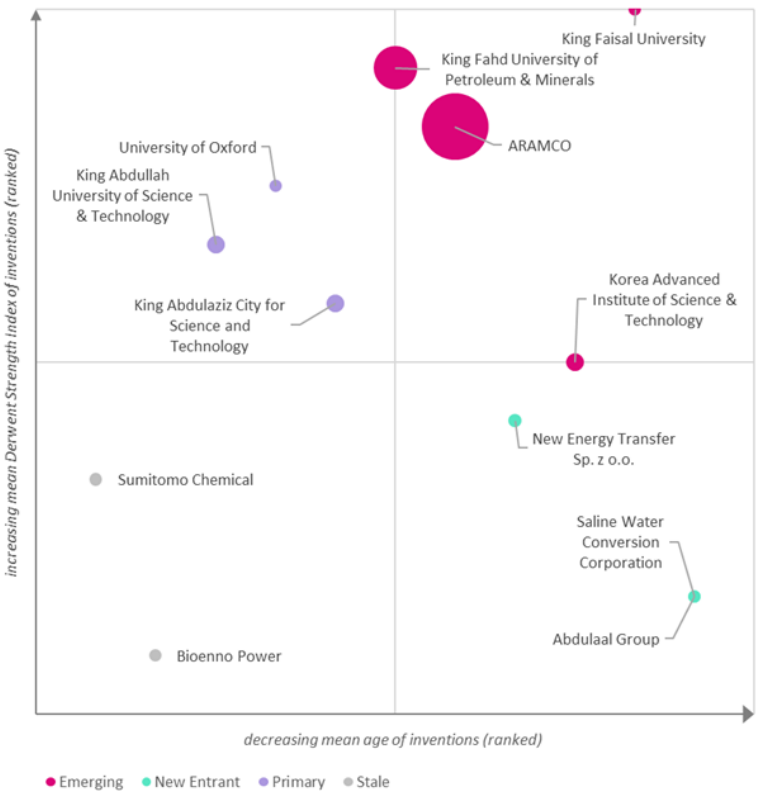


Figure 119: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the technology area of Hydrogen Storage and Transportation

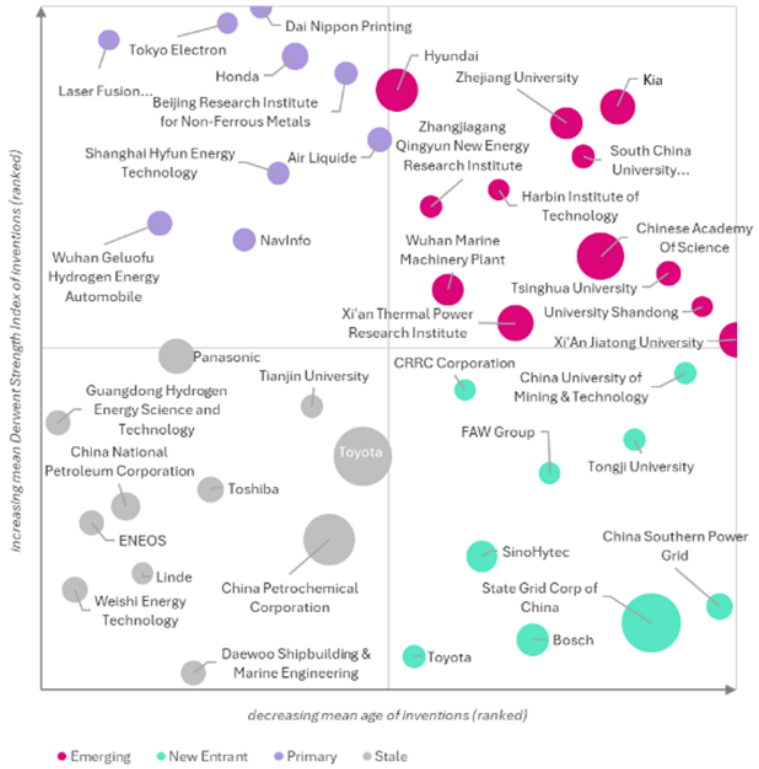


Figure 120: Commercial dynamics model for the top global patent assignees in the technology area of Hydrogen Storage and Transportation

5 Key findings within Energy and Industrials

Drawing upon the insights from research and invention performance, Academic-Corporate Partnerships, and Technology Maturity evaluation for Saudi Arabian and global organizations, this section provides key recommendations tailored to the relative position of Saudi Arabia for each technology by using industry-leading metrics to provide the next steps. These recommendations will outline the potential of the technologies specifically for Saudi Arabia, where to invest, and ultimately whether more academic funding is required, further Academic-Corporate Partnerships, transfer of technology from academic to private entities, and potentially to continue the existing strategies.

Table 30: Energy and Industrials research topic scorecard

				High	Medium	Low
	Saudi Arabia's Research Strength	Saudi Arabia's Invention Strength	Saudi Arabia's Partnership Strength	Saudi Arabia's research productivity	Technology maturity	Future Predicted Growth
COTC Processes	694	42836	5.1%	1.79	8	6.8%
COTC Products	1102	27811	3.9%	2.69	8	7.2%
Hydrogen Production	4657	12534	3.8%	2.47	6	9.3%
Hydrogen Storage and Transportation	1189	1989	0.8%	1.76	5	9.2%
Digital Twins	192	149	3.4%	0.61	3	12.4%
Net Zero - Industrial Emissions	187	518	3.8%	0.98	4	7.5%
Smart Grids	1508	1092	1.3%	2.12	7	7.0%
Sustainable Mining - Waste Management	223	2051	1.6%	1.68	4	7.8%

The scorecard above contains factors analyzing Saudi Arabia's position per research topic. They are defined as:

- **Research Strength:** Total number of Saudi Arabian research papers multiplied by CNCI. The Category Normalized Citation Impact (CNCI) of a document is calculated by dividing the actual count of citing items by the expected citation rate for publications with the same document type, year of publication and subject area.
- **Invention Strength:** Total number of Saudi Arabian inventions multiplied by DSI. A Clarivate metric of the strength and quality of a patented idea. Based on the impact of the invention on others (based on the frequency of downstream citation by the patent applications of third parties), the global footprint of patents granted (based on the % of world GDP covered by the patent asset), the investment level in the invention by the applicant (based on the number of patent jurisdictions in which the applicant sought protection)

and the inventions rarity (based on the number of inventions in the global database that share the same technology mix).

- **Partnership Strength:** The mean partnership % for research papers and inventions in Saudi Arabia.
- **Research Productivity:** The productivity relative to the global productivity is measured by the number of Saudi Arabia papers in specific research topic divided by the number of global publications in the same research topic and period.
- **Technology Maturity:** Each of the research topics within the National Priority Areas has been mapped to individual Technology Maturity Index from 1 – least mature through 9 – most mature.
- **Future Predicted Growth:** CAGR predicted growth extrapolated from historic inventions level.

Hydrogen Storage and Transportation has medium research and invention strength by volume and CNCI/ DSI, low ACP levels of 0.8%, medium research productivity of 1.76 and medium technology maturity of 5. As there are only 53 inventions from Saudi Arabia in the last 10 years, and 340 research papers, it would be suitable to prioritize early-stage academic research into organizations with new strength such as Saudi Aramco, King Fahd University of Petroleum & Minerals and slightly older inventions from KAUST and KACST.

There are also numerous Chinese Academic institutions with significant strength in this area and may boost invention products via an academic partnership, such as Beijing Research Institute for Non-Ferrous Metals, Shanghai Hyfun Energy Technology, Zhejiang University, Zhangjiagang Qingyun New Energy Research Institute and South China University of Technology. It is predicted that Hydrogen storage and transport could add $0.26 billion to Saudi Arabia's economy; if 1,667 inventions are protected in this field, the likely yield would be around six very strong inventions.

Digital Twins technologies have relatively low research and invention strength and volumes of 81 research papers and seven inventions from Saudi Arabia. The ACP level for Digital Twin technology of 3.4% is quite high within Energy and Industrials, whereas research productivity is low at 0.61 and long with three technology maturity. The predicted invention growth level is 12.4% and given the strength of Saudi Arabia's Energy and Industrials sector, shows how much investing in early-stage research could benefit established industries.

Saudi Aramco, KFUPM, and King Khalid University have seven inventions from Saudi Arabia. International ACPs, with potential include GE Aerospace, Siemens, Bosch, and Johnson Controls. Similarly, Academia to-Academia partnerships with Guangdong University of Technology, China University of Mining & Technology, Tsinghua University, Beijing Institute of Technology, Beihang University, Tongji University, and Chinese Academy of Sciences have a consistent track record holding 20+ inventions each, along with newer entrants such as Zhengzhou University of Light Industry, University of Electronic Science and Technology of China, and Dalian University of Technology.

Net Zero Industrial Emissions and Sustainable Mining – Waste Management both have low research strength regarding volume combined with CNCI; however, Sustainable Mining – Waste Management has a medium invention strength. Notably, Net Zero Industrial emissions have a higher average research and invention ACP level of 3.8% compared to 1.6% in Sustainable Mining – Waste Management. Both technologies have a technology maturity level of 4.

Subsequently, to enhance Saudi Arabia's innovation in these technologies, additional funding should be considered for early-stage research. Saudi Aramco leads with eight inventions, followed by King Fahd University of Petroleum and Minerals and King Abdullah University of Science and Technology within Net Zero Industrial Emissions. Similarly, for Sustainable Mining Waste Management, Saudi Aramco leads with 21 inventions, followed by KAUST, the University of Alfaisal and the University of Prince

Sattam Bin Abdulaziz. It is predicted that Sustainable Mining – Waste Management could add $0.70 billion to Saudi Arabia's economy if 833 inventions are protected in this field; the likely yield would be around 23 very strong inventions.

COTC Products and Hydrogen Production technologies both have medium research publication volume and strength, as well as very high invention volume and strength. These are further fuelled by a high average research and invention partnership of 3.9% and 3.8%, and similarly high 2.69 and 2.47 research productivity.

The technology maturity is 6 and 8 respectively which equates to medium and high maturity with 9+% growth predicted. The very low ratio of research papers to inventions of 1 and 7 show these technologies are highly embedded within the Saudi Arabian innovation eco-system. King Fahd University of Petroleum & Minerals holds 45 inventions in COTC Products and 56 in Hydrogen Production, Saudi Aramco holds 202 inventions in Hydrogen Production.

As Saudi Arabia has a strong innovation pipeline in this area with many other innovators in Hydrogen, such as Saudi Iron and Steel, Imam Abdulrahman Bin Faisal University, KAUST and King Abdulaziz City for Science and Technology continuing to transfer technology into the market will maintain growth in this area. It is predicted that Hydrogen production could add $0.70 billion to Saudi Arabia's economy; if 1,667 inventions are protected in this field, the likely yield would be around 16 very strong inventions. ACPs have clearly fuelled this strength, with 47/721 COTC Product inventions and 15/340 inventions generated via ACPs, 16 and 5 from Saudi Aramco partnership with King Fahd University of Petroleum & Minerals, respectively, similarly 21 and 6 between KAUST and Saudi Aramco.

It is predicted that COTC Products could add $0.31 billion to Saudi Arabia's economy if 833 inventions are protected in this field; the likely yield would be around seven very strong inventions.

COTC Processes technology has low research strength by volume and CNCI. However, it has the highest invention strength across Energy and Industrials, a very high research and invention ACP score of 5.1%, medium research productivity of 1.79 and high technology maturity of 8. The research paper to the corporate ratio of 1 relates to a stronger innovation than the research pipeline, which is regularly seen in mature, established technology ecosystems.

Stand-out Saudi Arabian innovators include the King Fahd University of Petroleum and Minerals with 62 inventions and Saudi Iron and Steel with five inventions, scoring on average 75+ DSI. Notably, most of Saudi Aramco's inventions in this field originate from outside of Saudi Arabia and in countries such as the US. It is predicted that COTC Processes could add $0.31 billion to Saudi Arabia's economy if 1,667 inventions are protected in this field; the likely yield would be around 14 very strong inventions.

Smart Grids medium research and invention volumes and strength, mid-level ACP and research productivity, predicted growth and high technology maturity of 7. The research paper-to-invention ratio is 26, which is expected for a mature technology area. Invention levels are fairly low at 34, and no invention yielding ACPs, therefore further focusing on the conversion of academic research into academic inventions in King Abdulaziz, King Fahd University of Petroleum and Minerals and Imam Abdulrahman Bin Faisal University, along with potential ACPs with Aramco would be the most suitable local ACPs. International innovators with strong invention portfolios who could assist in translating academic research into commercially applied research include ABB, GE Aerospace, Siemens, Mitsubishi, Hitachi, Samsung, NEC, LG and Panasonic.

In conclusion for the eight focused technologies within Energy and Industrials Saudi Arabia has very high invention output and volume in COTC Processes, Products and Hydrogen production. All three of these fields are led by the significant research, development and innovation power of Saudi Aramco.

Local Academic-Corporate Partnerships such as between King Saud University and Qudra Energy Co. have even led to Saudi Aramco's intention to purchase a 50% share of Qudra Energy Co. joint venture Air Products Qudra's subsidiary Blue Hydrogen

Industrial Gases Co. Saudi Arabia particularly shows innovation strength in more mature technologies within Energy and Industrials; and therefore should continue to foster Academic-Corporate Partnerships between Saudi Aramco and local Academic Institutions such as but not limited to King Abdulaziz University, KFUPM, KAUST and King Saud University.

The interplay between Energy and Industrials technologies and Sustainability and Essential Needs technologies should not be underestimated, with many technologies being combined or transitioned from one to another across national missions such as 2.4 Achieve net-zero emissions by 2060, 2.6 Reduce summer surface temperatures by 4C by 2040, 3.1 Increase the share of renewable energy sources to ~50% by 2030 and 3.6

Become the 4th largest producer of EV's and EV batteries by 2035. The complex transformation related to the world's energy production and consumption may be underpinned by the next wave of Saudi Arabian technologies; this could be achieved by setting up cross-functional centres of excellence, including incubators to build specialist private organizations to supply cutting edge innovation.

6 Definitions, metrics and data sources

6.1 General definitions

Academic institution

An establishment dedicated to education and research, generally conferring academic degrees across various levels of learning. While academia can more widely be used as a term for primary education through tertiary education, we limit and define the tertiary sector only for the purposes of this study. However, note that we further expand the definition of academia in this study to government research institutions more generally.

Academic-Corporate Partnership

Refers to a collaborative arrangement between educational institutions and business entities, aiming to leverage their respective strengths for mutual benefit, often in the realms of research, technology development, and knowledge exchange. The relationship typically involves shared resources, strategic alignment, and a commitment to achieving common objectives that advance both academic and corporate interests. Defined and identified in this study as a scientific publication or a patent family that contains bibliographic information as authors or inventors from organizations that are both an academic institution and a corporate entity.

Applied Research

Refers to the process of systematic investigation that aims to solve practical problems by applying scientific knowledge. It typically involves collaboration with industry to develop tangible solutions, such as new products, technologies, or processes, that directly address specific challenges in various fields.

Basic Research

Often also called pure or fundamental research, this refers to the process of systematic investigation aimed at gaining a deeper understanding and knowledge of the underlying principles of phenomena and observable facts, without immediate practical application in mind.

Commercialization

Commercialization refers to the process of managing, typically via a business or corporate entity, activities in return for economic or monetary gain. It involves introducing a new product or service to the market and is often associated with the production, distribution, marketing, and sales necessary to achieve commercial success. Frequently used in the context of scaling up business operations to reach a broader market. This study is specific to understanding the level of commercialization activity and the directionality of research areas.

Corporation

A corporate entity is a legally recognized organization designed to conduct business. Typically, a corporation is a body formed and authorized by law to act as a legal person, distinct from the natural persons owning or operating within the entity. Corporate entities can enter contracts, own assets, and are subject to taxation while providing limited liability protection to their owners.

Innovation

Refers to the process of progressing new ideas or inventions into products, services or other economic activity that is valued and in demand by businesses or consumers. As a general principle, innovation can encompass the direction of creativity, technical knowledge, and information and can target the conversion of new and useful products and services. In this study, we focus on the definition of technical innovation and the process of developing and applying new technologies or improving existing ones to create advancements in various fields. It involves the use of technical knowledge and expertise to address challenges, enhance efficiency, and create value through novel solutions.

Invention

A novel or unique method, device, or process developed from research and experimentation, typically patented and designed to solve a specific problem or improve existing solutions. Within this study, due to the database structure of the Derwent World Patents Index, we use "invention" as

synonymous with "patent family" (see definition) - an individual idea meeting the criteria of an invention, as patented at various patent offices around the world. This definition includes patent applications that have not yet been granted. This definition removes the need to deduplicate multiple patent publications surrounding the single invention/idea and, in turn, transforms the collection of multiple patent publications into metadata of invention strength.

Nominal Gross Domestic Product (GDP)

Nominal Gross Domestic Product (GDP) is a macroeconomic metric that measures the total market value of all finished goods and services produced within a country's borders at a specific time, using current prices without adjusting for inflation. Presented here in US dollars.

6.2 Patent related definitions

Patent

A patent is a legal instrument that grants an inventor exclusive rights to use, sell, or manufacture their invention for a limited period, typically 20 years, in exchange for public disclosure of the invention.

Patent Assignee

A patent assignee is the individual or entity that holds the ownership rights to a patent. This transfer of rights is typically formalized through a written contract or assignment agreement, which grants the assignee the exclusive rights to the patented invention, including the right to make, use, sell, or license the invention. The assignee assumes all associated rights and responsibilities from the original patent holder, known as the assignor. Typically, the assignment takes place because of employment contracts that require employees to assign intellectual property rights to their employer for creating an invention during their employment.

Patent Family

A patent family refers to a collection of patent applications or granted patents that are related to each other and cover the same or similar technical content. These related publications are typically filed in different countries, originating from a single priority application or a set of priority applications. The concept of a patent family is instrumental in tracking the legal protection status of inventions globally and is recognized by various patent offices and databases. The family definition used in this study is specific to the Derwent World Patents Index™, which provides for a synonymous relationship between each family and an individual invention – e.g., one specific set of claims language (the section of a patent document detailing what is protected) in each legal jurisdiction in which protection has been sought.

Patent Jurisdiction, Patent-Issuing Authority

Refers to the legal authority granted to a country or region over the creation, use, and enforcement of patents within its territory. This includes the power to grant patents, determine their validity, and adjudicate disputes related to patent infringement. The jurisdiction is defined by the territorial scope within which the patent rights are applicable and enforceable, and it is typically the responsibility of national or regional patent offices to oversee these legal rights. Notably, patents are local rights that are only valid and have exclusivity within the jurisdiction of the patent office. There are multiple "regional" patent jurisdictions, such as the European Patent Convention or the Gulf Cooperation Council Patent Office.

Patentability

In order to be valid, a patent application needs to fully disclose an invention so that it can be understood by the average person with training in the technical field, and it must be novel (never seen in the public domain before), useful (typically, it must have a real world use, and must actually work) and not be an obvious extension of previous technology (typically, simply

combining multiple previous ideas together).

Technical maturity index (TMI)

A mathematical model that aggregates global scientific, engineering and technological structured disclosures (i.e. peer-reviewed scientific papers and patented inventions), alongside assertion of technology, to empirically measure the maturity of a technology field, approach or use case. It can be used to assess differing fields and sectors alongside each other, due to the normalization of measures incorporated into the model.

Technical readiness level (TRL)

A scale is used to estimate the maturity of a technology during the acquisition phase of a program. It provides a consistent and uniform discussion of technical maturity across different types of technologies. The scale ranges from 1 to 9, with 9 being the most mature technology. TRL assessments are critical in managing the progression of technology from conception to deployment. Originally created in the 1970s by NASA as a way of managing technical development readiness and safety for human spaceflight, the TRL system has been widely adopted by the International Standards Organization in 2013 as a qualitative measure of basic, through applied and then commercialized technology progression. In this study, TRL and TMI become synonymous - as the advanced measurement of global public science, research and technology assertion is captured and mathematically modeled so that it maps empirical measures of maturity onto (in relative terms) the structure of a TRL.

6.3 Research related definitions

Citation

An academic citation is a formal reference to a published or unpublished source that is used to support the author's arguments or findings in a scholarly work. It acknowledges the original creator of an idea or piece of information and provides readers with the details necessary to locate the source material themselves. Citations are essential in academic writing to avoid plagiarism, uphold intellectual honesty, and facilitate the verification of facts or ideas presented.

Patent citation is a similar process and refers to any significant document or research paper that a patent applicant, examiner, or third party cites as relevant to the content of a patent application. It serves as a formal acknowledgment of prior art and related work in the field, providing a trail of the intellectual property landscape pertinent to the invention.

In both cases, citation is a significant source of impact metadata, as the aggregation and analysis of papers, patents, topics, organizations and economies via citation measures provides a method of assessing the preponderance of downstream reference research and innovation the work has on others, thereby reflecting the importance and impact of the cited work itself.

Citation Topics

Citation Topics are named document clusters based on cited and citing relationships between publications. They are algorithmically derived citation clusters (using an algorithm developed by CWTS, Leiden). This is a three-level hierarchical document-level classification system. The three levels of the hierarchy and their content according to the 2024 clustering are:

- Macro-topics (10)
- Meso-topics (326)
- Micro-topics (2449)

Macro- and meso-topics are manually labeled based on their contents. Micro-topics are algorithmically labeled with their most significant keyword. As Citation Topics are based on citation relationships and not the content or subject matter of their constituent publications, topics are labeled by inference, and any name may not be descriptive for every

document in the topic. More information and a description of the 2024 schema can be found on the Clarivate website.

Papers/publications/publications

A written document that presents the results of original research or an innovative study in a systematic and standardized format. A core activity of the scientific method, the publication of research via a formal paper is intended to communicate new research and knowledge discovery to the scientific community and to contribute to global and collective knowledge. Such papers are peer-reviewed and published in academic journals, ensuring the integrity and validity of the research presented. Clarivate abstracts publications, including research journal articles, editorials, meeting abstracts and book reviews. The terms “paper,” “document,” “Web of Science Document,” and “publication” are often used interchangeably to refer to printed and electronic outputs of many types. In the analyses presented here, the terms used exclusively refer to substantive journal articles, reviews and proceedings papers.

Researcher Affiliation

Researchers affiliated organization. A single researcher could provide several affiliations in one publication. The publication is then associated with all organizations and, correspondingly, all geographical locations in which these organizations are located.

6.4 Saudi Arabia-specific definitions

Research, development and innovation (RDI)

The Research, Development and Innovation (RDI) sector in Saudi Arabia refers to the collective activities and initiatives aimed at fostering scientific research, technological development, and innovation across various fields. This sector is pivotal to the Kingdom's Vision 2030, driving economic diversification and sustainable development. The RDI sector encompasses a network of institutions, policies, and programs that support and finance scientific research, coordinate activities of research centers, and propose legislation to nurture an environment conducive to innovation and technological advancement.

National Priority Areas

Refers to the strategic objectives set by the Kingdom to guide its development and innovation efforts. These priorities include Health and Wellness, Sustainability and Essential Needs, Energy and Industrials, and Economies of the Future. They are designed to enhance the nation's global competitiveness and align with the goals of Saudi Vision 2030.

Vision 2030

Saudi Vision 2030 is a strategic framework aimed at diversifying Saudi Arabia's economy and transforming the nation into a global investment powerhouse. Launched in 2016, Vision 2030 seeks to foster economic, social, and cultural development by capitalizing on the country's strategic location and enhancing the quality of life for its citizens. It emphasizes three core pillars: a vibrant society, a thriving economy, and an ambitious nation, with a focus on public sector efficiency, private sector growth, research and innovation, and international collaboration.

6.5 Description of data sources

Web of Science™

The data used in this study came from the Clarivate Web of Science databases, which give access not only to journals but also to conference proceedings, books, patents, websites, and chemical structures, compounds and reactions.

Web of Science has a unified structure that integrates all data and search terms together and, therefore, provides a level of comparability not found in other databases. It is widely acknowledged to be the world’s leading source of citation and

bibliometric data. The Web of Science Core Collection is the premier resource on that platform and includes over 22k peer-reviewed, high-quality scholarly journals published worldwide (including Open Access journals), over 308k conferences, over 151k editorially selected books and 92M records going back to 1900. Coverage is both current and retrospective in the sciences, social sciences, arts and humanities. Clarivate has extensive experience with databases on research inputs, activity and outputs and has developed innovative analytical approaches for benchmarking and interpreting international, national and institutional research impact.

InCites™

Additionally, InCites Benchmarking & Analytics was used in this project to generate relevant metrics and indicators.InCites is a customized, citation-based research evaluation tool enabling analysis of productivity and benchmarking of output against peers worldwide, with underlying data drawn from the Web of Science Core Collection™.

InCites provides disambiguated data for all publications in the Web of Science Core Collection.

Darts-ip™

Darts-ip is a comprehensive database and analytics platform that provides detailed information and insights on intellectual property (IP) litigation cases globally.

Derwent World Patents Index™

The Derwent World Patents Index (DWPI) is a comprehensive database that compiles patent applications and grants from 59 patent-issuing authorities worldwide. It provides abstracts in English, detailing the nature and use of inventions, and indexes them into technology categories for easy retrieval. DWPI also defines patent families, linking related patents globally around a Basic Patent (the first disclosure of the invention appearing in the database), facilitating the tracking of an invention's protection status internationally as further applications or granted patents published in multiple patent jurisdictions.

6.6 Metrics

Web of Science Documents

This is an indicator to refer to substantive journal articles, reviews and proceedings papers and excludes editorials, meeting abstracts or other types of publication. It is based on the Web of Science Core Collection™ dating till Sunday, December 31, 2023.

Category Normalized Citation Impact

The Category Normalized Citation Impact (CNCI) of a document is calculated by dividing the actual count of citing items by the expected citation rate for publications with the same document type, year of publication and subject area. When a document is assigned to more than one subject area, an average of the ratios of the actual to expected citations is used. The CNCI of a set of publications, for example, the collected works of an individual, institution or country/region, is the average of the CNCI values for all the publications in the set. CNCI is a valuable and unbiased indicator of impact irrespective of age, subject focus, or document type. Therefore, it allows comparisons between entities of different sizes and different subject mixes.

- A CNCI value of 1 represents performance at par with the global average.
- Values above 1 are considered above average.
- Values below 1 are considered below average.
- A CNCI value of 2 is considered twice the global average.

CNCI is an ideal indicator for benchmarking at all organizational levels (institution, region etc). When dealing with small sets of publications though, for example, the publications of one individual, the CNCI values may be inflated by a single highly cited

paper. More information can be found on InCites website.

Growth and Average Growth

In this study, we visualize the evolution of the number of Web of Science publications for a certain entity and period. In order to quantify the change in the number of publications from one year to another, we use the growth. The growth is then the number of publications in the most recent year (Ny2) subtracted from the number of publications in an earlier year (Ny1) and divided by it and represented as a percentage:

G= (Ny2- Ny1)/ Ny1

The average growth over a certain period is the arithmetic average of the growth from one year to another in that period. Sometimes, a considered entity does not have publications in a certain year, causing division problems for the considered year. In such cases, the growth for that year is excluded from the arithmetic average.

Funding Acknowledgment

The Funding Agencies Explorer in InCites, which includes more than 1000 unified funding organizations found in and curated from Web of Science funding acknowledgments, was utilized to identify publications with funding acknowledgment and the corresponding funding agencies.

Industry Collaboration

Papers that contain two or more Organizations with at least one Organization listing its organization type as corporate or global corporate. An industry collaborative publication is one that lists its organization type as “corporate” or "global corporate" for one or more of the co-author’s affiliations. It's not possible to unify data for every affiliation of all publications in InCites; therefore, only unified entities have an organization type. There will be corporate affiliations that are not yet unified and without an organization type. As such, these affiliations will not identify as an industrial collaboration. Clarivate Analytics has made considerable efforts to identify the largest corporations and unify them; however, these efforts tend to focus on large multinational corporations and may lead to regional bias.

International Collaboration

Papers that contain one or more international co-authors.

Invention Strength

A Clarivate metric of the strength and quality of a patented idea. Based on the impact of the invention on others (based on the frequency of downstream citation by the patent applications of third parties), the global footprint of patents granted (based on the % of world GDP covered by the patent asset), the investment level in the invention by the applicant (based on the number of patent jurisdictions in which the applicant sought protection) and the inventions rarity (based on the number of inventions in the global database that share the same technology mix).

Emerging Trend

To investigate emerging trends globally and in Saudi Arabia in a research topic, we use the micro-topics as defined in the Citation Topics schema that is explained in the section.

Citation Topics

To identify the emerging trends, we identify the top 20 micro-topics in the research topic in terms of the growth of the number of publications in the micro-topic from 2014 to 2023. We then rank the top 20 micro-topics in terms of difference in the share of citations from total citations in the research topic between 2014 and 2023. The growth in terms of publications identifies micro-topics within the research topic that have grown fastest within the considered period. The difference in citation share from the total citations in the research topic identifies micro-topics that have also grown their relative number of citations in the research topic, which reflects that these topics are also trending among the researchers active in the research topic.

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