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Economies of the Future RDI National Priority in Saudi Arabia: Analytical Study

Executive summary

Innovation Ecosystem in Focus

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BACKGROUND

Targeting the Vision 2030 goals of a thriving and vibrant modern Saudi Arabian society, this technology pillar seeks to develop and integrate a spectrum of connectivity, mobility, sustainability and automation technologies into urban environments and the living experience of the population. It targets smart and, further, 'cognitive' cities, where data on citizen interaction, movement and behavior is used to tailor their urban living experience.

The pillar also targets changes to the potential living location and computing resource access of the populace, e.g., the development of space technologies and outposts off-Earth and under-sea, research into Artificial general intelligence, and the potential paradigm shift of computing power via quantum technologies. It also includes logistics and routine task automation.

Among Saudi Arabia's research, development and innovation (RDI) aspirations for 2040 is the focus on four national priority areas. This study focuses on the priority area Economies of the Future and, in particular, the following RDI missions:

- Mission 4.3 - Going beyond Smart Cities: Establish five Cognitive cities in Saudi Arabia by 2040

- Mission 4.4: Create a safe artificial intelligence (AI) that learns and realizes autonomous work in favor of humans by 2050.
- Mission 4.5: Develop a programmable fault-tolerant quantum computer by 2040.
- Mission 4.10 - Future of connectivity: Build sustainable 6G technologies by 2035.

The Economies of the Future national priority covers a broad array of industries, missions and aspirations for Saudi Arabia.

New frontier and hazardous environment technologies such as Deep Sea and space exploration underpin key ambitions for establishing habitats on the Moon by 2040 and Mars by 2050. Cognitive city and Urban architecture covering technologies such as Cognitive city (Predictive analytics, Air quality, Citizen engagement) and Urban architecture (Low emissions, Sustainable buildings, Autonomous vehicles and Urban air mobility via vertical take-off vehicles) exemplify the ambition and vision of Saudi Arabia.

Progress towards such technologies is seen in Neom and Qiddiya's Giga-projects. Next-generation foundational technologies for economies and revenue streams cutting across all industries will include



Quantum computing, 6G, Internet of Things (IoT), Cloud computing, Semiconductors and AI.

Within Economies of the Future related technologies, there are specific intellectual property (IP) and regulatory factors to consider:

- Software and AI-driven innovations may be applicable in fields such as Autonomous vehicles, Digital twins, Intelligent manufacturing and Predictive maintenance. However, across global jurisdictions, there are differing requirements for software and patentability, regularly requiring technical effect.
- Business methods are also patentable in the United States, but innovators may need help patenting business-related improvements elsewhere.

- Regulatory factors to consider may include rapidly advancing responsible AI and AI ethics regulations in jurisdictions such as the United States, European Union and Mainland China.
- Additional regulatory and legal factors to consider include responsible data processing linked to the monitoring of individuals in jurisdictions such as Germany or, in many jurisdictions globally, the processing of health data for applications such as health insurance.

The complete list of research topics that define the national priority area of Economies of the Future 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 Economies of the Future (2014-2023).



OVERVIEW

The Economies of the Future RDI national priority area represents a significant opportunity to transform Saudi Arabia's innovation ecosystem and deploy applied research globally through research topics such as, but not limited to, Cognitive cities, Deep sea, Space architecture, Sustainable 6G and Urban architecture.

The Research Development and Innovation Authority (RDIA) is dedicated to steering and executing the Kingdom's RDI strategies across the four national priorities. It has led the organization of capacity-building activities, equipping Saudi leaders and practitioners with the vital skills needed for digital innovation. This remit is essential in the development of viable research topics like 6G, Cognitive cities, Space architecture and OpenRAN, that can transform connectivity and communications across diverse industries. Saudi Arabia has academic-corporate partnerships (ACP) within 6G materials and research papers or inventions from the Kingdom.

However, it has minimal research or inventions in the other research topics. In several research topics, we observe King Saud University, King Abdulaziz University, King Abdullah University of Science and Technology (KAUST), King Fahd University of Petroleum and Minerals (KFUPM), Prince Sattam Bin Abdulaziz University, and Umm Al Qura

University among the top five publishing entities in Saudi Arabia.

Economies of the Future has the most extensive range of Technology Readiness Level (TRL) out of the four national priority areas with Deep-sea – eDNA Analytics TRL 1 and Semiconductors TRL 9. There is additionally a noticeable variety in the global invention filing volumes across the research topics strongly linked to the TRL. The complexity is combined when considering AI in ICT's potential impact on various research topics within Economies of the Future. This complexity extends into many other research topics such as, but not limited to, Electric vehicles, Industry 4.0, and Digital health research topics.

Economies of the Future has a very diverse set of research topics. Academic corporate partnerships across numerous groups of global corporations are required to accelerate research and invention yield from local academic research. This includes existing corporations such as Saudi Aramco and future private corporation creation through vehicles such as joint ventures, spinouts and incubators.

Key opportunities to consider within Economies of the Future include:

- **Prioritize higher-performing and higher-commercial-potential research topics:** Key research topics within Economies of the Future have significant commercial potential. For

example, AI in ICT and Semiconductor research topics are predicted to generate a combined \$0.86bn USD to the Saudi Arabian economy if 3,334 inventions are protected, generating the expected yield of high-strength inventions, and are subsequently successfully commercialized. Semiconductor research levels heavily outweigh inventions in Saudi Arabian academia, which highlights an opportunity for technology transfer.

- **Accelerate private organization creation through industry-leading partnerships:** AI in ICT is a fast-moving field facing patentability difficulties in algorithms, software and potential open-source models in AI. Partnering with leading international corporations may significantly boost Saudi Arabia's AI innovation ecosystem. The combination of AI in ICT, Quantum computing and Semiconductor research topics is evident from the industry leadership of international corporations such as, but not limited to, Nvidia, TSMC, Intel and Samsung.
- **Further emphasis in areas of existing difference and leadership:** There is significant opportunity and white space in the technology landscape for Saudi Arabia to lead the way in further developing Cognitive city innovation, which can be deployed into giga-projects such as Neom.

- **Leverage leading global academia through academic partnerships:** The strength of leading academic Institutions should be considered for further academic partnerships, with Mainland China in research topics such as Cognitive cities. Health and wellness research topics exhibit similar key opportunities for research acceleration.

Ultimately, the research topics within Economies of the Future could change the face of every industry and deliver on national missions such as establishing habitats on Mars by 2050, achieving net-zero aviation by 2050 and Future of Connectivity: building sustainable 6G technologies by 2035. A diversified and precise ACP strategy will further enhance Saudi Arabia's strong research base and deliver the desired economic and societal returns.

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

KEY FINDINGS

Drawing upon the insights from research and invention performance, ACPs and technology maturity evaluation for Saudi Arabian and global organizations, this section provides key opportunities tailored to the relative position of Saudi Arabia for each technology by using industry-leading metrics to give the next steps. These findings outline the potential of the research topics specifically for Saudi Arabia, where to invest, and ultimately, whether more academic funding is required, the need for further ACPs, the transfer of technology from academic to private entities, and the potential to continue existing strategies.

Table 1: Economies of the Future 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
AI in ICT	37393	15977	0.8%	1.9	4	10.9%
Air quality, traffic, energy or resource management	2208	0	0.8%	1.4	5	6.5%
Citizen engagement	244	71	0.0%	0.3	3	10.6%
Data ownership & privacy	1296	31	1.0%	1.9	3	0.0%
Predictive analytics, decision algorithms	2644	67	0.8%	2.1	2	11.3%
Virtual cities	131	36	0.0%	0.8	3	10.8%
OpenRAN	0	0	0.0%	0	3	12.5%
Quantum computing	735	1537	0.7%	1.1	5	9.4%
Semiconductors	16601	8054	1.6%	1.7	9	7.4%
Space architecture - Habitats	1368	0	1.4%	0.7	5	9.4%
Space architecture - Mining	419	0	1.6%	1	3	8.9%
Sustainable 6G - Automatic management	12	0	0.0%	0.6	4	6.2%
Sustainable 6G - Energy efficient edge infrastructure	10	0	0.0%	2.3	4	9.6%
Sustainable 6G - Materials	1665	71	3.5%	1.2	6	7.0%
Autonomous vehicles	820	1328	2.1%	0.8	7	7.7%
Urban Air Mobility	1789	0	0.6%	1.5	6	9.1%

Table 1 contains factors analyzing Saudi Arabia's position per research topic they are defined as:

- **Research strength:** Total number of Saudi Arabian research publications multiplied by Category Normalized Citation Impact (CNCI). A document's CNCI is calculated by dividing the actual count of citing items by the expected citation rate for documents with the same document type, year of publication and subject area.
- **Invention strength:** Total number of Saudi Arabian inventions multiplied by the Derwent Strength Index (DSI). This is 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:** ACP percentage for research publications and inventions in Saudi Arabia.
- **Research productivity:** Productivity relative to global productivity is measured by the number of Saudi Arabian publications on a specific research topic divided by the number of global publications on 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:** Compound Annual Growth Rate (CAGR) extrapolated from historic inventions level.

AI in ICT in Saudi Arabia has very high research and invention strength, the highest research strength across all RDI priority research topics. The partnership level is relatively low at 0.8%, and medium-level research productivity at 1.9. There is a high predicted growth of 10.9% and a medium technology maturity of 4. With 21,983 research papers and 561 inventions, this balance is expected for a high-growth, low-technology maturity field. Saudi Aramco leads Saudi Arabian AI in ICT inventions with 175 inventions, accompanied by King Abdulaziz University with 11 relatively strong inventions; KFUPM has 33 inventions of slightly older age. The strong research base is led by King Abdulaziz University, followed by King Saud

University and Prince Sattam Bin Abdulaziz University (with 3799, 3367 and 1982 publications respectively).

Leading organizations in AI, as seen in Figure 2, include Amazon, Samsung, Alphabet, IBM, Microsoft, Capital One, Alibaba, Baidu, and Tencent. Notably, LG has a small but robust AI portfolio, too. Samsung, for example, has 88 inventions via an ACP with Seoul National University.

As AI in ICT is such a fast-moving field, and patentability difficulties of algorithms, software and potential open-source models in AI, partnering with leading international corporations may significantly impact Saudi Arabia's AI innovation ecosystem, such as those Saudi Arabian entities in Figure 3.

Notable international academic institutions include the South China University of Technology, Xi'an Jiatong University, Beijing University of Technology, Xidian University, and Beihang University, all of which have over 1,200 inventions in AI in ICT.

It is predicted that AI in ICT could add \$0.28bn USD to Saudi Arabia's economy; if 1,667 inventions are protected in this field, the likely yield would be around six very strong inventions.

"AI in ICT in Saudi Arabia has very high research and invention strength. It is predicted that AI in ICT could add \$0.28bn USD to Saudi Arabia's economy if 1,667 inventions are protected in this field.



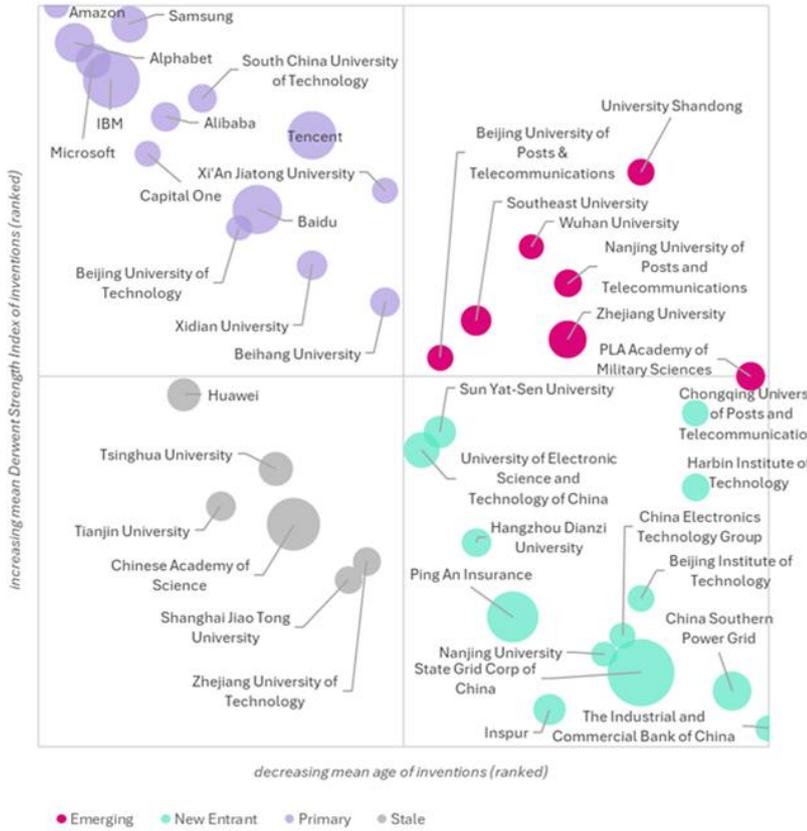


Figure 2: Commercial dynamics model for the top global patent assignees in research topic 'AI in ICT.'

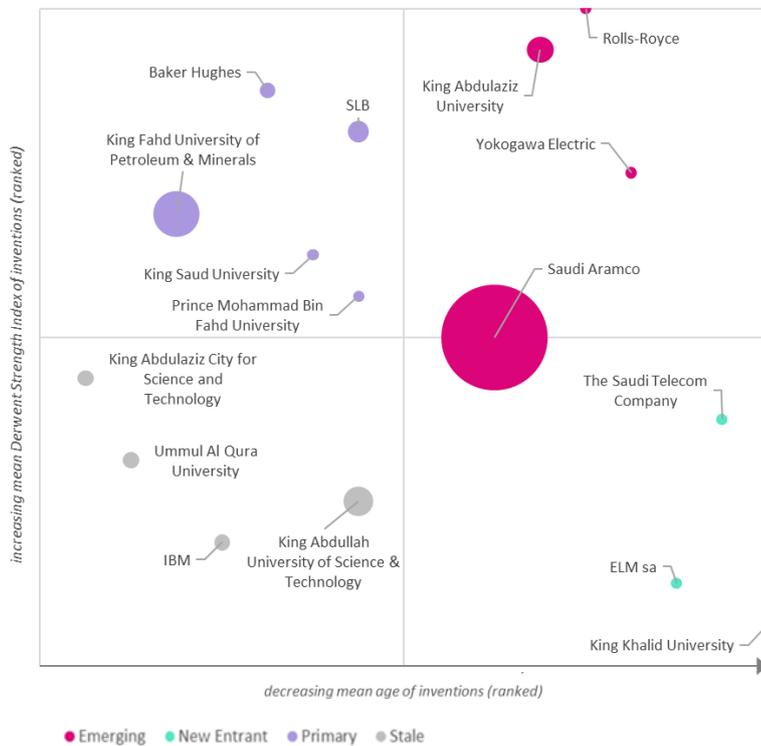


Figure 3: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the research topic AI in ICT.

Quantum computing has a low research strength derived from the volume of papers and CNCI. In contrast, it has a relatively high invention strength score for Saudi Arabia. ACP levels are low at 0.7%, research productivity mid-level at 1.1, and medium technology at 5, with medium predicted growth of 9.4%.

There were 662 research papers compared to only 45 inventions. Considering the medium technology maturity, it could be suitable to focus on early-stage academic research through local institutions such as established Quantum computing researchers such as KAUST and KACST, alongside slightly newer King Abdulaziz University, Imam Abdulrahman Bin Faisal University, Saudi Aramco, and King Fahd University of Petroleum & Minerals.

International collaborations with established innovators such as Samsung, Alibaba, Alphabet, Toshiba, Microsoft, D-Wave, Huawei, NEC and Northrop Grumman are observed. Newer high-strength innovators include IBM, Baidu and BOE, alongside academic institutions such as Fuzhou University, Central South University, University System of Maryland, Tsinghua University and the most significant innovator in the dataset, the Chinese Academy of Sciences (holding 1,026 inventions).

Semiconductors perform similarly to AI in ICT for Saudi Arabia, as a high-research and invention-strength technology with high technology maturity. Semiconductors have low predicted growth compared to other research topics. However, there are high invention levels globally. High ACP and research productivity are observed as well.

Overall, over 11,000 Semiconductor research papers have been published in the last 10 years, compared to only 254 inventions, which suggests a low translation of academic research into commercially applied research.

Subsequently, it could be suitable to focus on converting more research papers into inventions from King Saud University, followed by KAUST and King Abdulaziz University, with 2,078, 2,051, and 1,848 publications, respectively, indicating relatively high research paper output.

The increase of research papers in Saudi Arabia is illustrated in Figure 4.

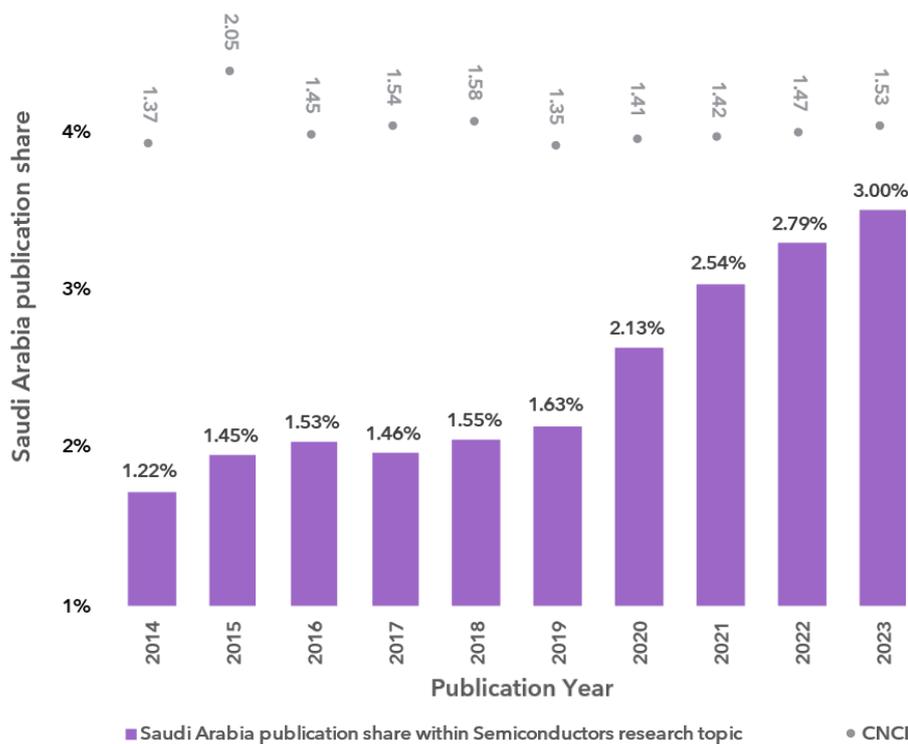


Figure 4: The share of Saudi Arabia from global publications in the research topic and the CNCI of Saudi Arabia publications in the research topic 'Semiconductors' in the period 2014-2023.

Key actions include partnering with corporations such as: TSMC, Samsung, Infineon, Applied Materials, STMicroelectronics, SK Hynix, Intel, KIOXIA Corporation, Fuji Electric, Micro, Sony, Global Foundries, Tokyo Electron, BOE, Hon Hai Precision, Semiconductor Energy Laboratory, ams-OSRAM, LG or Shin-Etsu Chemical.

The local Saudi Arabian organizations with the highest semiconductor output are KAUST, Saudi Aramco and KACST. Further organizations are seen in Figure 5, such as King Abdulaziz University and Imam Abdulrahman Bin Faisal University, which have produced a relatively strong portfolio of 15 and 5 inventions, respectively.

It is predicted that Semiconductors could add \$0.58bn USD to Saudi Arabia's economy if 1,667 inventions are protected in this field; the likely yield would be around 13 very strong inventions.

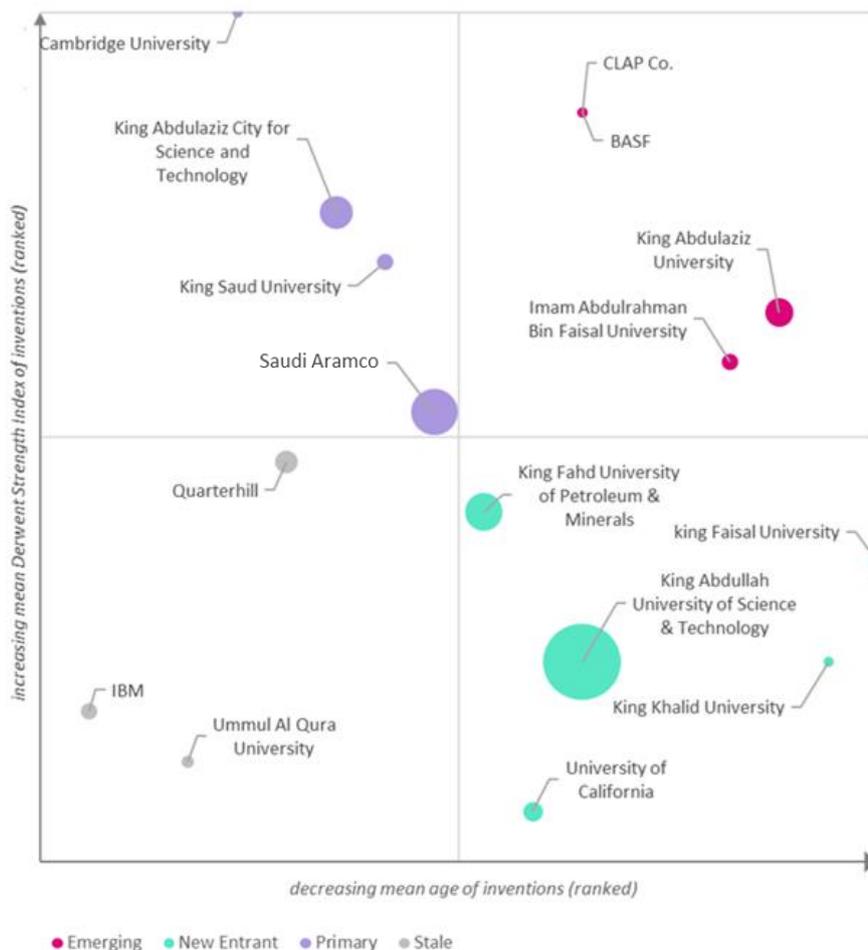


Figure 5: Commercial dynamics model for the top patent assignees active in Saudi Arabia in the Semiconductors research topic.

Sustainable 6G - Automatic management, Sustainable 6G - energy-efficient edge infrastructure and Sustainable 6G - materials represent a group of highly specialized research topics that operate in the area of telecommunications, which is often led by a small group of very large telecommunications organizations.

Automatic management and Energy-efficient edge infrastructure have low research strength, compared to medium research strength of Materials. Interestingly, 6G materials have high ACP levels and a strong invention strength. However, with no ACPs, both 6G - automatic management and Energy-efficient edge infrastructure have no inventions from Saudi Arabia.

All three research topics have medium technology maturity and low to medium predicted growth. Saudi Aramco holds one invention in the field of 6G materials, as

6G development appears not to be a strategic initiative for Saudi Aramco; this technology may be more appropriate for organizations such as STC within Saudi Arabia or to **fund local academic institutions, who have contributed to 6G material research publication**, to apply the scholarly research to more commercial use cases. International organizations with significant invention portfolios in these 6G areas include Qualcomm, ZTE, Intel, Apple, Sony, Verizon, TSMC, Baker Hughes, ConocoPhillips and Halliburton.

OpenRAN is a **white space area for Saudi Arabia** with no research papers or inventions from the Kingdom, notably OpenRAN has very low inventions levels globally, and a technology maturity level of 3. It is a **technology worth monitoring, and ad hoc funding of foundational academic research** as it has a high predicted invention level growth of 12.5%.

“OpenRAN is a technology worth monitoring, as it has a high predicted invention level growth of 12.5%”

Cognitive cities research topics span **Air quality, Traffic, Energy or Resource management, Citizen engagement, Data ownership & privacy, Predictive analytics, Decision algorithms and Virtual cities** in Saudi Arabia has been medium research strength across Data ownership & privacy, Air quality, Traffic, Energy or Resource management and Predictive analytics. However, there is low invention volume and strength, and ACPs across all five research topics within Cognitive cities.

These research topics align with Mission 4.3 - Going beyond smart cities: Establish five cognitive cities in Saudi Arabia by 2040. The low levels of inventions are expected due to the low technology maturity in all research topics apart from Air quality, Traffic, Energy or Resource management, which is a medium-maturity technology. There is high research productivity in Data ownership & privacy and Predictive analytics Decision algorithms.

Overall, the invention levels are low compared to other research topics from Saudi Arabia, with Saudi Aramco owning one invention in each of Citizen engagement, Predictive analytics, Decision algorithms and Virtual cities. The importance of developing Cognitive cities is evident for Saudi Arabia. The giga-project Neom

showcases the capability to lead in cutting-edge technology, design and re-imagining how cities operate for decades into the future.

An option could be to capture and protect the innovation created in these mega-projects to be re-purposed into future projects or commercialized into international territories. Micro-topics of focus are seen in Table 2.

King Saud University and King Abdulaziz University are among the top three organizations in all these subcategories, as shown in Figure 6.

International organizations excelling in Cognitive city-related technology are notably populated with many academic institutions from Mainland China, further signaling the immaturity of these research topics.

Large established organizations such as IBM, Johnson Controls, Capital One, Sense Time hold small portfolios in Virtual cities, Hitachi, Ping An Insurance in Citizen engagement, TongTech, Tele-Commuter Resources in Data ownership & privacy, and CAVH LLC, Ping AN Insurance, Chengdu Qinchuan IOT Technology in Predictive analytics.

The presence of numerous Mainland Chinese corporations, Universities and public institutes showcases the aligned ambitions of Saudi Arabia and Mainland China to build future-proof, cutting edge Cognitive cities.

Table 2: Top 10 micro-topics identified in Saudi Arabia research output in the research topic 'Data ownership & privacy' in the period 2014-2023.

Topic	Number of Saudi Arabia documents in the period 2014-2023
Cognitive Cities - Data Ownership & Privacy	1026
Phishing	107
Watermarking	79
Image Encryption	77
Intrusion Detection	76
Blockchain	66
Random Oracle Model	58
Internet Of Things	48
Differential Privacy	43
Privacy	26
Malware	25

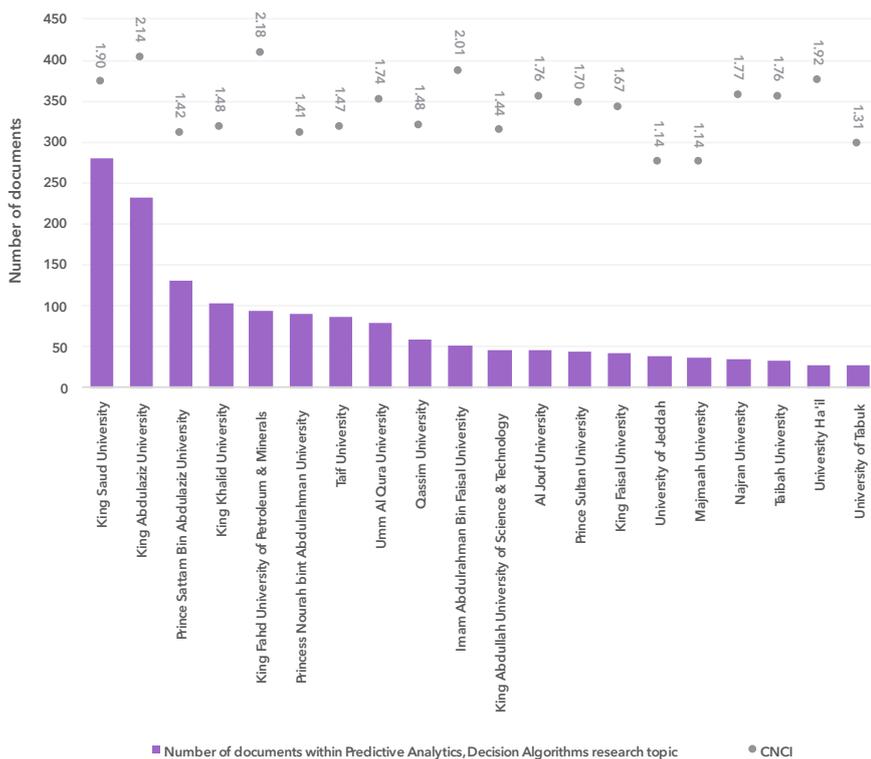


Figure 6: Top 20 Saudi organizations in terms of research publications in the research topic 'Predictive analytics, Decision algorithms' in the period 2014-2023 and their corresponding CNCI.

Space architecture - habitat and mining research topics in Saudi Arabia linked to Mission 4.1 to establish habitats on Mars by 2050, and 4.2 to establish a permanent output on the Moon by 2040. Habitat research topics have a medium research volume and CNCI, as seen in Figure 7, while having no inventions; mining research topics have a low research volume and CNCI and also no inventions.

There are high levels of research partnerships, no invention partnerships, medium technology maturity for Habitats and low maturity for Mining research topics. Further **research opportunities are possible through funding leading local Universities such as King Abdulaziz University, KAUST and King Saud University to produce more papers.**

Globally, there are low levels of inventions in these two research topics. Corporations with the most extensive and strongest portfolios for habitat technology include Honeywell, Thales, Boeing, Airbus NASA, and RTX Corporations. Notably, these organizations have **space, aviation or defense-related focus**, which explains their innovation relationship with hazardous environment. Within the Space - mining research topics, Airbus and Boeing have small portfolios of 2-3 inventions, while Astrobotic holds three newer and stronger inventions.

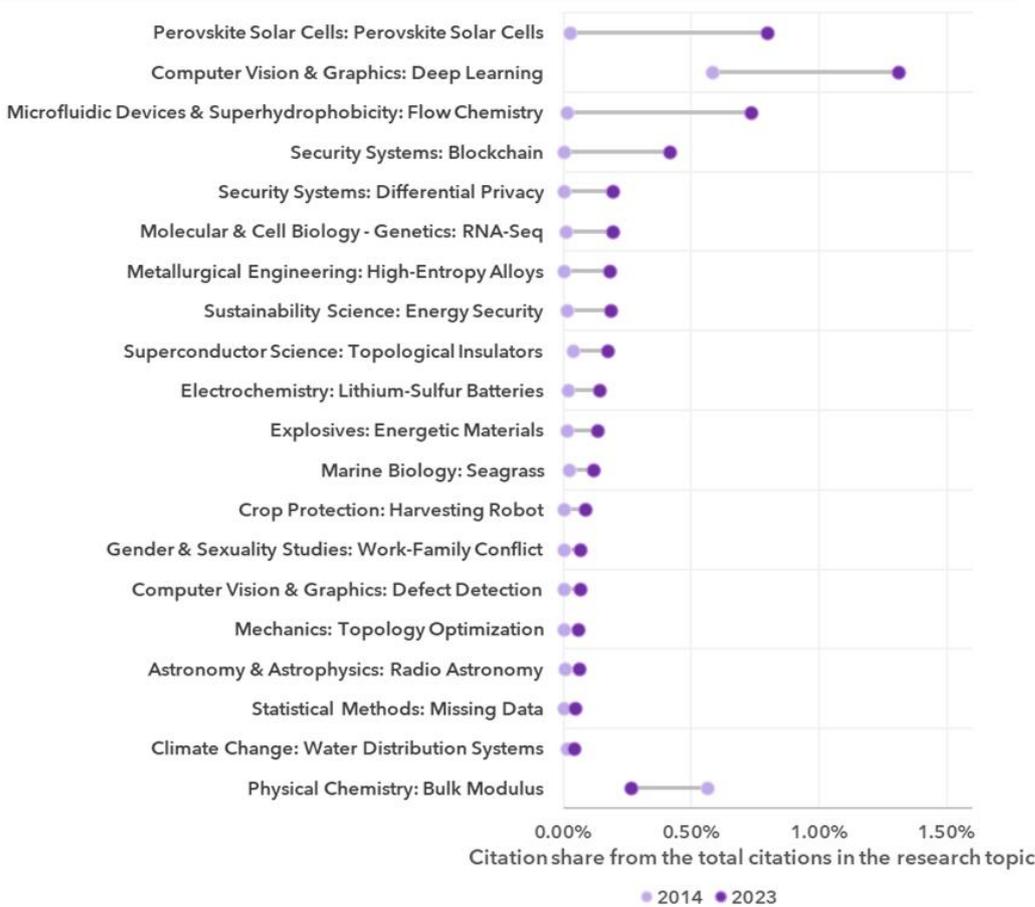


Figure 7: Top 20 emerging micro-topics globally in the research topic 'Space architecture habitats' in the period 2014-2023.

Urban architecture research topics related to **Autonomous vehicles** and **Urban air mobility** are complementary to the Cognitive city research topics and relate more to research topics flowing within the architecture and management of passenger transportation.

While Autonomous vehicles have low research volume and CNCI coupled with medium invention volume and strength, Urban air mobility has the reverse scores. This can be correlated to high collaboration and technology maturity for Autonomous vehicles. In contrast, Urban air mobility has low collaboration and medium technology maturity. **Urban air mobility should prioritize translation of papers into patents from local academia seen in Figure 8** along with leveraging industry corporations such as Valeo, Zhejiang Geely Holding Group, Airbus, Boeing and Honeywell.

Autonomous vehicles would benefit from further ACP to boost invention levels. Inventions in Saudi Arabia have been generated by Saudi Aramco, KAUST, Imam

Abdulrahman Bin Faisal University, KFUPM and Umm Al Qura University, these organizations hold between 4 and 20 inventions, as seen in Figure 8.

International organizations in this field with both high-volume and high-strength established portfolios include Komatsu, Johnson Matthey, General Motors, Continental, Vitesco, Volvo, Umicore, Honda, Toyota, Denso, Zhejiang Geely Holding Group, and Burelle. Newer high-strength portfolios include NGK Insulators, Cummins, Ford, Hyundai, Porsche Automobile Holdings, Kia and Forvia.

Ford, Porsche Automobile Holdings, Hyundai and Toyota each hold over 500 inventions, which could significantly boost Saudi Arabia’s ACP-generated inventions and overall invention numbers.

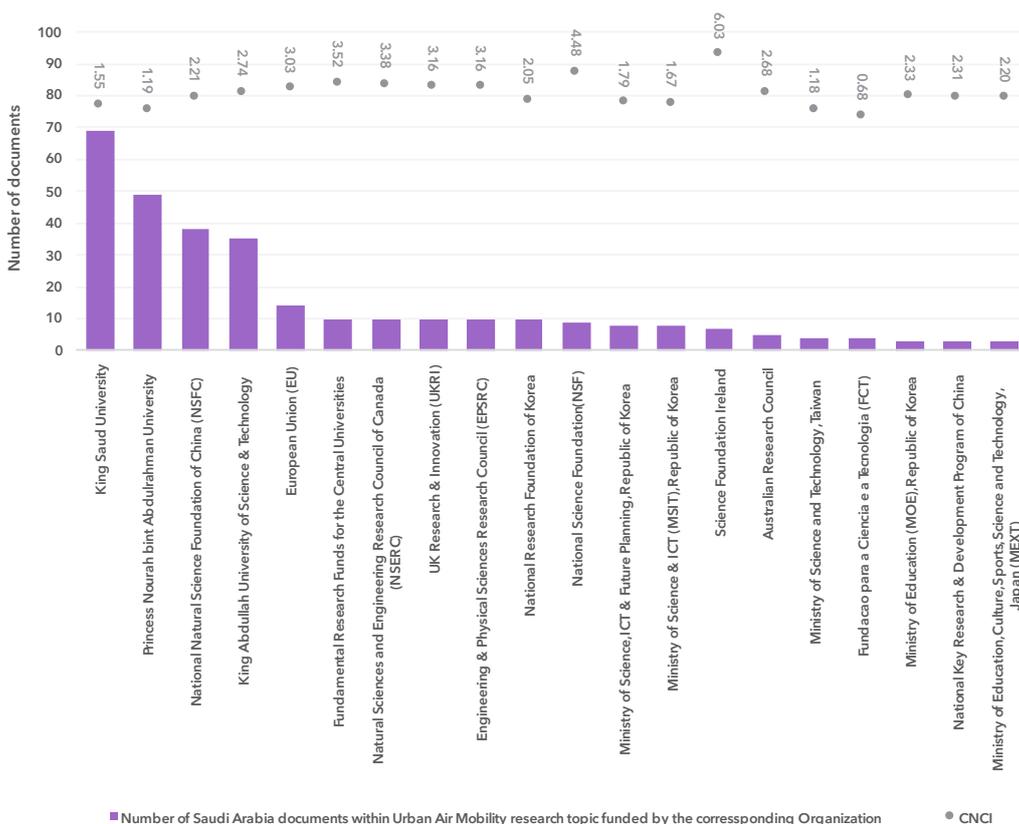


Figure 8: Top 20 funding organizations of Saudi Arabia publications in the research topic 'Urban air mobility' in terms of number of publications in the period 2014-2023.

In conclusion, Economies of the Future contains many diverse research topics, including the sixteen areas that the deep-dive section of this study highlighted. Only semiconductors and autonomous vehicles are high-maturity technologies. Semiconductors area has relatively high volume and strong inventions within Saudi Arabia.

Saudi Arabia has recently established the National Semiconductor Hub - which plans to attract 50 semiconductor design companies to Saudi Arabia by 2030. AI in ICT is another large research and invention strength for Saudi Arabia, led by Saudi Aramco with 175 inventions; Saudi Aramco also has an ACP with KAUST, underpinned by the AI Hub at Saudi Aramco.

Due to the size and speed at which AI research topics are moving globally, it could be suitable for Saudi Arabian academic institutions and Saudi Aramco to further partner with international leaders in AI research topics and Mainland China Universities, many of which hold 1,000+ AI inventions each.

**Four national alliances announced -
Semiconductors, Agritech, Quantum and
OpenRAN.**



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