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Enhancing quantum science and technology in South Korea: A strategic investment framework

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Abstract

This study identifies investment priorities for the strategic and cost-effective promotion of quantum science and technology, designated by the Korean government as one of its 12 national strategic technologies. To establish these priorities, an Analytic Hierarchy Process (AHP) analysis was conducted to assess the weighted significance of various evaluation factors at multiple levels. Simultaneously, a novel network centrality measure was applied to analyze the interconnections and relative importance of core tasks. The findings indicate that quantum computing holds the highest priority, with an optimal investment sequence of talent development, fundamental research support, and service infrastructure establishment. Furthermore, given the intricate interdependencies among key initiatives, fostering an innovation ecosystem and advancing quantum science and technology should be prioritized to ensure sustainable growth and development.

Keywords: AHP, core tasks, Development strategy, Eigenvector centrality, Investment priorities, Quantum industry, Science and technology policy.

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1. Introduction

The Korean government has designated quantum technology as one of its 12 national strategic technologies and has formulated mid- to long-term development strategies across three key domains: quantum computing, quantum communication, and quantum sensing, with the overarching goal of fostering a robust domestic quantum industry. In the quantum computing sector, a phased roadmap has been established to develop and commercialize a 50–1,000 qubit quantum computer. In quantum communication, efforts are focused on advancing core technologies, conducting initial demonstrations of intercity quantum networks, and laying the groundwork for a nationwide quantum Internet. For quantum sensing, the strategy aims to commercialize high-tech industry applications while simultaneously developing world-class quantum sensor convergence systems for defense, medical, and semiconductor applications. The government's overarching objectives include reaching 85% of the technological capabilities of leading quantum nations by 2035, training 2,500 specialized quantum professionals, expanding the domestic quantum market share to 10%, and nurturing 1,200 companies involved in quantum technology supply and utilization. With 2024 marking the launch of Phase 1 (2023–2027) of the development strategy, strategic investment planning is essential to maximize the efficiency of limited financial resources. While annual project-specific budget requests and allocations are part of the existing framework, a holistic approach is required to determine investment priorities based on importance, urgency, and overall impact. Given South Korea's current technological standing and the strategic importance of fundamental quantum technologies, a selective and concentrated investment strategy is imperative for achieving rapid technological catch-up. This study leverages insights from Korea's National Quantum Strategy to develop an evaluation model for deriving investment priorities and strategic recommendations for core quantum initiatives.

The paper is structured as follows: Chapter 1 introduces the study by outlining its background, necessity, and academic significance. Chapter 2 reviews prior research on quantum science and technology policies, emphasizing this study's differentiation and novelty while providing an overview of the theoretical foundation for the employed methodology. Chapters 3 and 4 present the analytical framework, methodology, and results. Finally, Chapter 5 concludes the study by summarizing key findings, discussing policy implications, and addressing its limitations.

2. Literature Review and Theoretical Background

This study establishes its distinctiveness, progressiveness, and novelty by conducting a comprehensive review of the relevant literature while also evaluating its academic contributions. Although research on quantum-related policies and strategies has been consistently pursued, the volume of such studies remains significantly lower than that of technological advancements in the field. To address this gap, this study selects relatively recent and highly cited papers from diverse national contexts, ensuring a comprehensive and up-to-date perspective.

Raymer and Monroe [1] examine the motivations and objectives behind the U.S. National Quantum Initiative (NQI), detailing the legislative processes that facilitated its establishment in Congress. Raymer and Monroe [1] also discuss the implications of this initiative. Knight and Walmsley [2] analyze the UK's National Quantum Technologies Program, which has significantly enhanced the country's capacity to develop future quantum information technologies. The study highlights the program's first phase, which involved an investment exceeding £385 million across multiple government agencies, and evaluates its role in fostering sectoral growth [2]. Similarly, Yamamoto et al. [3] review Japan's national quantum information science and technology initiative, emphasizing key developments such as quantum key distribution systems and coherent Ising machines. Additionally, the study introduces Japan's latest efforts to advance quantum technology for societal applications [3].

Kop et al. [4] propose a structured framework for responsible quantum innovation, anchored in three fundamental principles—safeguarding, engaging, and advancing (SEA). These principles align with the core values of Responsible Research and Innovation (RRI) and are assessed through a literature-based methodology underpinned by a global equity normative framework, according to Kop et al. [4]. Dang [5] offers a multidimensional analysis of quantum technologies, covering intellectual property rights, regulatory frameworks, and standardization efforts, while also addressing their ethical and societal implications.

The study critically examines the dual-use nature of quantum technologies and the potential risks associated with a widening "quantum divide," advocating for equitable access and international cooperation to ensure an inclusive and ethically grounded quantum future, as stated by Dang [5]. Coccia and Roshani [6] investigate the evolution of emerging technologies through an S-curve model applied to patent data, identifying critical trends in the development trajectory of quantum technologies.

The study reveals that the technological cycle for recent quantum advancements has shortened from approximately 66 years to 45 years compared to older technologies predating 1980 [6]. In a separate study, Coccia [7] maps the technological trajectories of quantum computing by analyzing an extensive dataset, encompassing 10,089 scientific publications on 'quantum computing' (1989–2020) and 19,266 on 'quantum computers' (1967–2020), along with patent data. The research identifies key breakthrough directions in quantum technologies, including quantum optics, quantum information, quantum algorithms, quantum entanglement, quantum communication, and quantum cryptography [7].

The literature review highlights the current state and future trajectory of quantum technology development programs, major government-led initiatives, and national innovation strategies. Notably, even in leading quantum nations, there is a scarcity of research focusing on policy implementation frameworks or priority-setting mechanisms for execution. This is likely because these countries benefit from stable quantum industry ecosystems driven predominantly by market forces. In contrast, nations with emerging quantum sectors, where government-led industrial development is essential due to a nascent ecosystem and limited market participants, require proactive policy interventions to foster sustainable growth. Rather than striving for independent technological competitiveness, firms in such economies must leverage government-supported infrastructure, skilled human resources, and R&D funding. Consequently, strategic policymaking should emphasize selective and concentrated investment approaches, prioritizing initiatives with the highest potential for economic and technological impact.

Next, the theoretical background of the main methodologies, Analytic Hierarchy Process (AHP) and network analysis, can be described as follows. First, the AHP is a multi-criteria decision-making model that hierarchizes the evaluation models of alternatives and estimates the priority of alternatives through pairwise comparisons of evaluation factors and alternatives. It estimates the weights of the evaluation factors through pairwise comparisons of the evaluation factors and derives the priorities of the alternatives through pairwise comparisons of the alternatives.

Specifically, it identifies the decision objectives, influencing factors, and alternatives for stratification of the evaluation model. From this, the structure of the tiers is designed, and the number of tiers and the influencing factors per tier are selected. Weights for relative influence are estimated through pairwise comparisons for each tier's influencing factors. The relative level is expressed on a 9-, 13-, and 17-point Likert scale with 1 as the center, with larger numbers indicating greater influence. Considering the number n of influencing factors, n(n-1)/2 responses are performed. The pairwise comparison results collected from multiple experts are converted into a single geometric mean value and coded into a comparison matrix for each influencing factor, as shown in Table 1.

The comparison matrix has the form of a reciprocal matrix with the property that the element values of the main diagonal are all 1. A is the influencing factor, Xij is the geometric mean, and Xij is an estimate of the relative weight of I for influencing factor j.

Table 1.
Comparison matrix by influencing factors.

	A	**B**	**C**
A	1	X_{AB}	X_{AC}
B	1/ X_{BA}	1	X_{BC}
C	1/ X_{CA}	1/ X_{CB}	1

The weights for each influencing factor are standardized based on the columns of the comparison matrix and then arithmetically averaged again based on the rows of the standardized values. Pairwise comparison of alternatives for each influencing factor is performed through the same process as calculating weights for each influencing factor. Lastly, the overall score for selecting priorities for each alternative is derived by comprehensively considering the weight of each influencing factor and the preference of alternatives for each influencing factor [8-10].

Next, for network analysis, we use the eigenvector centrality indicators that weight the importance of connected nodes among various centrality indexes of network analysis. This is because it is absolutely necessary to consider the influence of breaststroke items linked in the designated evaluation and comprehensive evaluation items, as the whole cycle evaluation system is considered.

Unlike the existing network analysis, this paper applies new weights for each evaluation item. The reason for applying the weight is to additionally reflect the distribution of points for each evaluation item in the existing network analysis for each evaluation point. Since network analysis represents the relationship between evaluation items as a matrix consisting of only 0 and 1, it is necessary to derive a more accurate level of improvement by applying points that represent quantitative levels. The weight, W_N, considers the distribution of points for each evaluation item and is calculated as shown in Equations 1 to 2. N is the score of the evaluation items, S_1 is the total score of the designated evaluation item, and S_2 is the total score of the comprehensive evaluation item.

$$d_N = \frac{N}{S_1}(N \longrightarrow A\sim D),\ d_N = \frac{N}{S_2}(N \longrightarrow E\sim I) \qquad (1)$$

$$W_N = \frac{d_N}{\sum d_N} \qquad (2)$$

The calculated weight is reflected in the matrix value as in Equation 3. V is an existing matrix value and V_M is a matrix value considering weights [11-13].

$$V_M = W_N \cdot V. \qquad (3)$$

3. Research Procedures and Model Design

The research procedure for determining government investment priorities in quantum science and technology is outlined in Figure 1. The study first examined national policies and strategic initiatives related to quantum science and technology, identifying key factors that influence investment directions. These factors were derived based on the policy objectives and core tasks outlined in Korea’s National Quantum Strategy, as announced by the Ministry of Science and ICT [14]. To systematically evaluate investment priorities, a hierarchical model was designed, structured into two tiers to reflect the policy hierarchy and the influencing factors. Investment priorities were categorized into three key areas: quantum computing, quantum communication, and quantum sensors.

A survey was conducted among quantum experts and attendees of a quantum conference, utilizing a pairwise comparison approach for each factor. Participants were asked to evaluate factors using a 13-point Likert scale, and the relative importance of each factor was determined accordingly. The weight of each factor was calculated using the geometric mean reference matrix, with Consistency Ratio (CR) verification set at a threshold of 0.1 to ensure logical consistency in the analysis [15, 16]. Data processing and statistical analysis were conducted using Excel and R-based programs.

The hierarchical decision-making model, depicted in Figure 2, is structured into two tiers. Tier 1 consists of three overarching policy objectives: (A) Creating an ecosystem, (B) Quantum science and technology development, and (C) Technology-industrial convergence. Tier 2 comprises 12 strategic tasks derived from these policy goals, encompassing key initiatives such as quantum talent development, early quantum network demonstration, and the creation of quantum utilization demand, ensuring a comprehensive approach to advancing quantum science and technology.

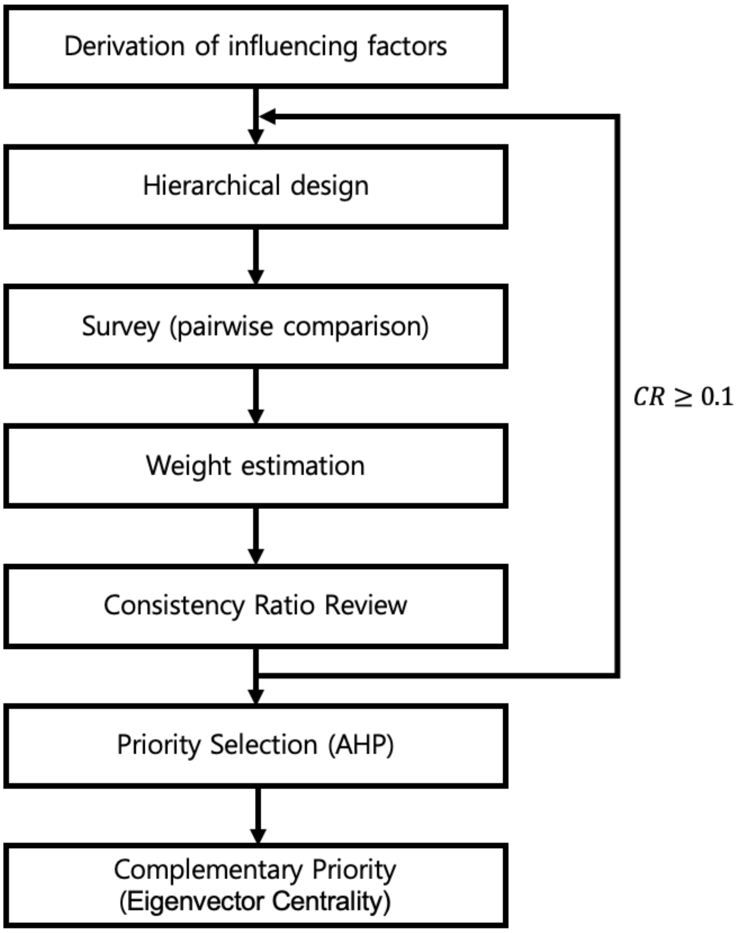

Figure 1.
Research procedure.

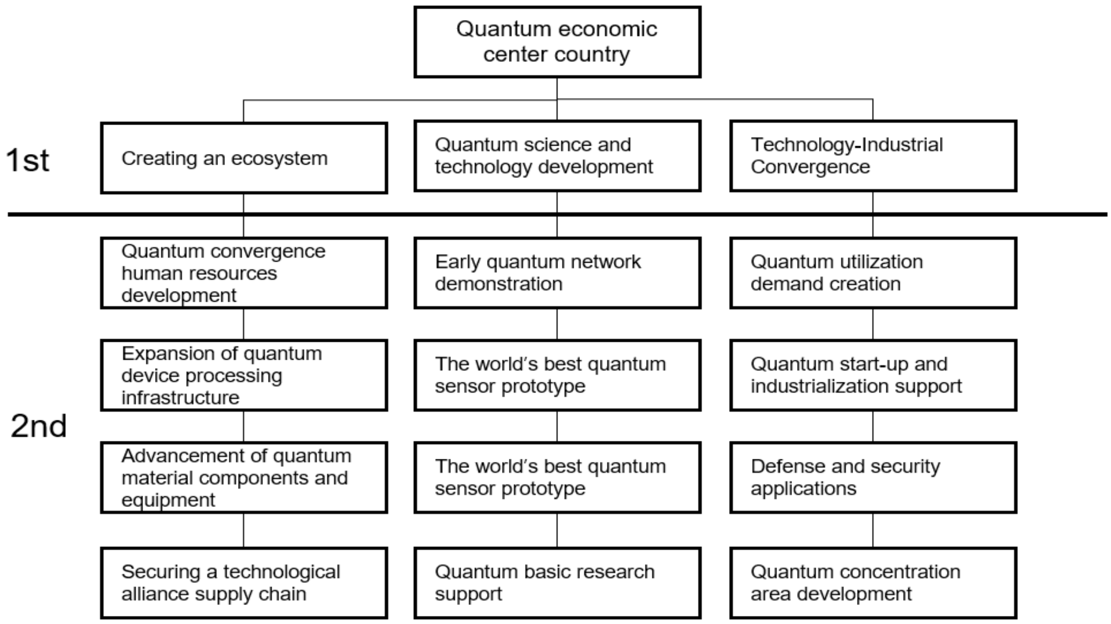

Figure 2.
AHP model.

For AHP analysis, the coding of factors was as shown in Table 2. The tier 1 was designated as A, B, and C, and the tier 2 was designated as a1~a4, b1~b4, and c1~c4.

Table 2.
Label of influencing factors.

T1	Factor	T2	Subfactor
A	Creating an ecosystem	a1	Quantum convergence in human resources development
		a2	Expansion of quantum device processing infrastructure
		a3	Advancement of quantum material components and equipment
		a4	Securing a technological alliance supply chain
B	Quantum science and technology development	b1	Korean quantum computer service
		b2	Early quantum network demonstration
		b3	The world's best quantum sensor prototype
		b4	Quantum basic research support
C	Technology-Industrial Convergence	c1	Quantum utilization demand creation
		c2	Quantum start-up and industrialization support
		c3	Defense and security applications
		c4	Quantum concentration area development

The alternative was set to be the government's three key investment areas: quantum computing, quantum communication, and quantum sensors. The investment priority model for alternatives can be expressed as Equation 4. x_an, x_bn, x_cn represent the weight of each alternative. n is the number of alternatives. Based on the overall score for each alternative, priority is determined in order of relatively high score.

$$Y_n = \sum_{n=1}^{k} a_n \cdot x_{an} + \sum_{n=1}^{k} b_n \cdot x_{bn} + \sum_{n=1}^{k} c_n \cdot x_{cn} \quad (4)$$

4. Analysis

The geometric mean standard matrix and weights for Tier 1 are presented in Table 3. The reference matrix values were normalized, and weights were obtained through arithmetic averaging. The calculated weights for A (Creating an ecosystem), B (Quantum science and technology development), and C (Technology-industrial convergence) were 0.494, 0.311, and 0.195, respectively.

Table 3.
Geometric Mean Pairwise Comparison Matrix (A~C).

	A	**B**	**C**	**Weight**
A	1.000	1.741	2.316	0.494
B	0.574	1.000	1.741	0.311
C	0.432	1.000	1.000	0.195

The geometric mean standard matrices and weights for Tier 2 are shown in Tables 4 to 6. The weight values for A's subfactors (a1–a4) were 0.409, 0.213, 0.145, and 0.233, while the weights for B's subfactors (b1–b4) were 0.290, 0.276, 0.130, and 0.304. Similarly, C's subfactors (c1–c4) had weights of 0.396, 0.362, 0.095, and 0.146.

Table 4.
Geometric Mean Pairwise Comparison Matrix (a1~4).

	a1	**a2**	**a3**	**a4**	**Weight**
a1	1.000	2.048	2.46	1.888	0.409
a2	0.488	1.000	1.644	0.871	0.213
a3	0.407	0.608	1.000	0.608	0.145
a4	0.53	1.149	1.644	1.000	0.233

Table 5.
Geometric Mean Pairwise Comparison Matrix (b1~4).

	b1	**b2**	**b3**	**b4**	**Weight**
b1	1.000	1.084	2.371	0.871	0.290
b2	0.922	1.000	2.297	0.871	0.276
b3	0.422	0.435	1.000	0.488	0.130
b4	1.149	1.149	2.048	1.000	0.304

Table 6.
Geometric Mean Pairwise Comparison Matrix (c1~4).

	c1	**c2**	**c3**	**c4**	**Weight**
c1	1.000	1.149	3.565	3.129	0.396
c2	0.871	1.000	3.438	2.993	0.362
c3	0.28	0.291	1.000	0.488	0.095
c4	0.32	0.334	2.048	1.000	0.146

Based on these Tier 2 weights, a composite weight for the lowest-tier evaluation items was derived (Table 7). a1 (Quantum convergence human resources development) had the highest composite weight (0.202), while c3 (Defense and security applications) had the lowest (0.019).

Table 7.
Composite Weight.

Tier 1 Weight	Tier 2 Weight	Composite Weight
A (0.494)	a1(0.409)	0.202
	a2(0.213)	0.105
	b3(0.145)	0.072
	a4(0.233)	0.115
B (0.311)	b1(0.290)	0.090
	b2(0.276)	0.086
	b3(0.130)	0.040
	b4(0.304)	0.095
C (0.195)	c1(0.396)	0.077
	c2(0.362)	0.071
	c3(0.095)	0.019
	c4(0.146)	0.029

To determine the final priority, alternative weights for investment options were calculated (Table 8). The results indicate that quantum computing received the highest AHP value (0.654), followed by quantum communication (0.204) and quantum sensors (0.142), as shown in Table 9.

Table 8.
Alternative weights.

	xa1	xa2	…	Xc3	Xc4
Quantum computing	0.654	0.662		0.651	0.677
Quantum communication	0.204	0.217		0.227	0.201
Quantum sensor	0.142	0.121		0.122	0.122

Table 9.
Alternative weights.

	AHP value	Rank
Quantum computing	0.654	1
Quantum communication	0.204	2
Quantum sensor	0.142	3

A consistency analysis was conducted to verify the reliability of these priority derivation results (Table 10). Since all C-Ratio values were below 0.1, the consistency of the data is deemed reasonable.

Table 10.
Alternative weights.

	λ-max	CI	C-Ratio
A	4.011	0.004	0.004
B	4.010	0.003	0.004
C	4.044	0.015	0.016
a1	3.003	0.001	0.002
a2	3.034	0.017	0.030
a3	3.048	0.024	0.041
a4	3.019	0.009	0.016
b1	3.038	0.019	0.033
b2	3.029	0.015	0.025
b3	3.054	0.027	0.047
b4	3.021	0.010	0.018
c1	3.035	0.018	0.030
c2	3.019	0.009	0.016
c3	3.023	0.011	0.020
c4	3.036	0.018	0.031

To explore further academic implications, network analysis was performed for Tier 2 factors within quantum computing, which had the highest priority. This analysis utilized eigenvector centrality, which considers not only the number of connected nodes but also their influence. UCINET 6.0 was used for this network analysis, and the results are summarized in Table 11. The highest standardized eigenvector value was 0.157 (a1: Quantum convergence human resources development), while the lowest was c3 (Defense and security applications).

When categorized by strategic tasks, A (Creating an ecosystem) and B (Quantum science and technology development) had similar average eigenvector values (0.097 and 0.098, respectively), whereas C (Technology-industrial convergence) was approximately 56% of A and B. These findings highlight the relative importance of different investment priorities within the quantum technology sector.

Table 11.
Eigenvector value.

Factor	Subfactor	Eigen Vector	Norm(Eigen Vector)	Avr(Norm(Eigen Vector))
A	a1	0.503	0.157	0.097
	a2	0.264	0.083	
	a3	0.260	0.081	
	a4	0.210	0.066	
B	b1	0.320	0.100	0.098
	b2	0.300	0.094	
	b3	0.263	0.082	
	b4	0.370	0.116	
C	c1	0.235	0.073	0.055
	c2	0.252	0.079	
	c3	0.001	0.000	
	c4	0.220	0.069	

To achieve the policy goal of becoming a quantum economy-centered nation, the highest priority should be given to developing quantum computing-related technologies. The most effective strategy is to pursue core tasks in the following order: nurturing quantum computing talent (a1), supporting basic research (b4), and building services using quantum computers (b1). An analysis of the standardized eigenvector values shows that ecosystem creation (A) and quantum science and technology development (B) have similar average values, indicating a strong interconnection between them. This suggests that these two factors significantly influence the overall core tasks, and their relationship should be carefully considered when setting priorities. Additionally, key tasks with relatively higher eigenvector values, such as quantum startups and industrialization support (c2) and quantum utilization demand creation (c1), should be prioritized alongside the core tasks of A and B. Lastly, quantum computing applications for national defense and security received the lowest priority. However, this does not imply low importance; rather, it reflects the fact that this task is designed for a specific sector, whereas other core tasks address broader, purpose-driven goals.

5. Conclusion

This study designed an investment model and analyzed investment priorities for core tasks to establish an effective strategy for Korea's quantum science and technology policy. The analysis results indicate that investment priorities should be allocated in the order of quantum computing, quantum networks, and quantum sensors. Specifically, within quantum computing, the most critical areas are talent development, basic research support, and service establishment. Furthermore, considering the interconnectivity between core tasks, those related to ecosystem creation and quantum science and technology development should be prioritized. These findings provide strategic guidance for the early stages of government-led quantum science and technology initiatives, ensuring alignment with economic policies and performance objectives. Additionally, the results serve as foundational data for determining the appropriate timing, duration, and technological milestones for each core task, facilitating the development of a mid- to long-term roadmap. From a policy perspective, this study is significant as it not only addresses quantum science and technology in the public sector but also models existing policies, quantifies key factors, and establishes investment priorities. However, there are limitations as this study does not specify the quantitative/qualitative goals, detailed implementation plans, or required budget for each core task. Future research should aim to further refine these aspects to enhance policy precision and applicability.

References

[1] M. G. Raymer and C. Monroe, "The US national quantum initiative," *Quantum Science and Technology,* vol. 4, no. 2, p. 020504, 2019. https://doi.org/10.1088/2058-9565/ab0441

[2] P. Knight and I. Walmsley, "UK national quantum technology programme," *Quantum Science and Technology,* vol. 4, no. 4, p. 040502, 2019.

[3] Y. Yamamoto, M. Sasaki, and H. Takesue, "Quantum information science and technology in Japan," *Quantum Science and Technology,* vol. 4, no. 2, p. 020502, 2019. https://doi.org/10.1088/2058-9565/ab0077

[4] M. Kop *et al.*, "Ten principles for responsible quantum innovation," *Quantum Science and Technology,* vol. 9, no. 3, p. 035013, 2024.

[5] K. Dang, "Quantum Frontiers: Navigating the Legal and Policy Challenges of Next-Generation Technologies," *Available at SSRN 4768688,* 2024.

[6] M. Coccia and S. Roshani, "Evolutionary phases in emerging technologies: Theoretical and managerial implications from quantum technologies," *IEEE Transactions on Engineering Management,* 2024. https://doi.org/10.1109/tem.2024.3385116

[7] M. Coccia, "Technological trajectories in quantum computing to design a quantum ecosystem for industrial change," *Technology Analysis & Strategic Management,* vol. 36, no. 8, pp. 1733-1748, 2024.

[8] M.-C. Choi, "Evaluation of analytic hierarchy process method and development of a weight modified model," *Management & Information Systems Review,* vol. 39, no. 2, pp. 145-162, 2020.

[9] R. W. Saaty, "The analytic hierarchy process—what it is and how it is used," *Mathematical Modelling,* vol. 9, no. 3-5, pp. 161-176, 1987. https://doi.org/10.1016/0270-0255(87)90473-8

[10] J. Choi and D. Lee, "A study on national R&D project proposal evaluation indicator for small-medium business-focusing on R&D project for support marine SMEs," *Ocean Policy Research,* vol. 32, no. 2, pp. 169-189, 2017.

[11] F. Pedroche, L. Tortosa, and J. F. Vicent, "An eigenvector centrality for multiplex networks with data," *Symmetry,* vol. 11, no. 6, p. 763, 2019. https://doi.org/10.3390/sym11060763

[12] F. Tudisco and D. J. Higham, "Node and edge nonlinear eigenvector centrality for hypergraphs," *Communications Physics,* vol. 4, no. 1, p. 201, 2021.

[13] H. Shim and J. Hahm, "Development of a Designation System for Supercomputing Specialized Centers by Application Field," *Journal of Computing Science and Engineering,* vol. 17, no. 4, pp. 169-181, 2023.

[14] Korea's National Quantum Strategy, "Ministry of science and ICT," 2023. Retrieved: https://www.msit.go.kr/bbs/view.do?sCode=user&bbsSeqNo=65&nttSeqNo=3017410. 2023.

[15] H. Raharjo and D. Endah, "Evaluating relationship of consistency ratio and number of alternatives on rank reversal in the AHP," *Quality Engineering,* vol. 18, no. 1, pp. 39-46, 2006. https://doi.org/10.1080/08982110500403516

[16] D. Ergu, G. Kou, Y. Peng, and Y. Shi, "A simple method to improve the consistency ratio of the pair-wise comparison matrix in ANP," *European Journal of Operational Research,* vol. 213, no. 1, pp. 246-259, 2011.