*energies*

*Article*

# Strategic Public Relations Policy for Accelerating Hydrogen Acceptance: Insights from an Expert Survey in South Korea

**Minhyuk Cho [1], Youhyun Lee [2,*], Youngjin Kim [3,*] and Min Chul Lee [4,*]**

[1] Regulatory Policy Research Center, CG Inside Co., Ltd., 122 Mapo-daero, Mapo-gu, Seoul 04213, Republic of Korea; cmh5057@ihopper.co.kr
[2] Department of Public Administration, Ajou University, 206 Worldcup-ro, Yeongtong-gu, Suwon 16499, Republic of Korea
[3] Department of Mechanical Engineering, Hannam University, 70 Hannam-ro, Daedeok-gu, Daejeon 34430, Republic of Korea
[4] Department of Safety Engineering, Fire Disaster Prevention Research Center, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon 22012, Republic of Korea
* Correspondence: youhyun@ajou.ac.kr (Y.L.); kimyj@hnu.kr (Y.K.); lmc@inu.ac.kr (M.C.L.)

**Abstract:** Hydrogen has great growth potential due to its green, carbon-neutral nature, but public acceptance is low due to negative perceptions of the dangers associated with hydrogen energy. Safety concerns, particularly related to its flammability and explosiveness, are an obstacle to hydrogen energy policy. In South Korea, recent hydrogen-related explosions have exacerbated these concerns, undermining public confidence. This study developed public relations (PR) strategies to manage risk perception and promote hydrogen energy acceptance by analyzing the opinions of government officials and experts using SWOT factors, the TOWS matrix, and the analytic hierarchy process. The findings highlight the importance of addressing weaknesses and threats in PR efforts. Key weaknesses include Korea's technological lag and the low localization of core hydrogen technologies, both of which hinder competitiveness and negatively impact public perception of hydrogen energy. Notable threats include deteriorating energy dependency and expanding global carbon regulations. This information can be used to influence attitudes and foster public acceptance of hydrogen energy policies. Emphasizing weaknesses and threats may result in more effective PR strategies, even if they do not directly address the primary concerns of scientific experts. The persuasive insights identified in this study can support future policy communication and PR strategies.

**Keywords:** hydrogen policy; policy PR; hydrogen risk; expert survey; SWOT-AHP

check for updates

**Citation:** Cho, M.; Lee, Y.; Kim, Y.; Lee, M.C. Strategic Public Relations Policy for Accelerating Hydrogen Acceptance: Insights from an Expert Survey in South Korea. *Energies* **2024**, *17*, 4325. https://doi.org/10.3390/en17174325

Academic Editor: Giovanni Esposito

Received: 28 June 2024
Revised: 17 August 2024
Accepted: 23 August 2024
Published: 29 August 2024



## 1. Introduction

Global hydrogen use reached 95 Mt in 2022, exhibiting a nearly 3% growth per year in all major hydrogen-consuming regions, except for Europe, probably due to increasing natural gas prices [1]. Since 1975, global hydrogen demand has grown significantly, increasing by over 3.5 times [2]. This rapid growth has led to a pressing need for hydrogen energy-related policies. Hydrogen energy, which can be harnessed from a diverse range of sources, exhibits an exceptional growth potential due to its eco-friendly, carbon-neutral characteristics [3–6]. Based on announced and targeted investment estimates worldwide, the global hydrogen energy market is projected to reach USD 500 billion by 2050 [7]. As a consequence, governments are taking several measures to bolster technological advantages in this market, including legislation and increased budgets to promote hydrogen technology development and energy distribution. Recent studies suggest that the growth of the global hydrogen market is further accelerated by governmental support and technological advancements. For example, China anticipates rapid growth in its hydrogen market from 2020 to 2060, driven by cost reductions and increasing demand [8]. Additionally, hydrogen energy is expected to play a crucial role in the next decade's major energy transitions, with extensive research and development activities worldwide [9]. European countries are also strengthening their hydrogen energy strategies in alignment with the European Union's policy goals [10]. In 2022 alone, the South Korean government allocated KRW 171.8 billion (USD 120 million) to hydrogen energy research and development, encompassing production, utilization, storage, and safety technology [11]. Furthermore, various policy initiatives fostering collaboration between hydrogen energy-related industries and the private sector have been implemented.

Recent research emphasizes the importance of effective PR strategies for promoting hydrogen energy policies. For instance, the European Union, the United Kingdom, and the United States have adopted diverse policy approaches to promote hydrogen energy and decarbonization [12]. Moreover, the United States has launched a national clean hydrogen strategy and roadmap to accelerate the hydrogen economy [13].

Despite these governmental interventions, public sentiment is predominantly characterized by a negative perception of the dangers associated with hydrogen energy. Safety concerns originate from the flammability and explosiveness of hydrogen and constitute an obstacle hindering significant development [4,14,15]. In South Korea, a series of explosion incidents involving hydrogen tanks and factories in Gangneung, Yeosu, and Gunsan has fueled concerns, eroding public trust in hydrogen energy [14,15]. Accidents amplify perceived risks beyond actual probabilities, ultimately creating skepticism and undermining the effectiveness of policies aimed at expanding the use of hydrogen energy.

Risk perception is an aspect of human psychology that transcends the bounds of verifiable truth and logical fact-based reasoning. Consequently, fostering public support for hydrogen energy requires a comprehensive approach involving policy considerations and PR strategies. This study aims to enhance public acceptance and support for hydrogen energy policies in South Korea by establishing an effective PR strategy. This study employs a combined SWOT (Strength–Weakness–Opportunity–Threat) analysis and analytic hierarchy process (AHP) to systematically evaluate the strengths, weaknesses, opportunities, and threats related to hydrogen energy policies in South Korea. SWOT analysis is used to identify the key internal and external factors impacting the policy landscape, while the AHP technique prioritizes these factors based on expert evaluations. The results are then utilized in a TOWS (Threat–Opportunity–Weakness–Strength) matrix, which helps in formulating strategic action plans by matching internal strengths and weaknesses with external opportunities and threats [16]. The TOWS matrix enables the development of strategies that can attack, defend, improve, or avoid specific scenarios based on the identified priorities, ultimately aiming to enhance public acceptance of hydrogen energy.

Hydrogen energy is poised to play a significant role in the energy transition over the next decade [9]. Recognizing this, European countries have identified the importance of effective PR strategies in their hydrogen energy policies [10]. It may also be helpful for South Korea to consider how it can communicate and persuade the public, considering risk perceptions, to build a hydrogen energy ecosystem. Additionally, sharing South Korea's experience may offer valuable insights to many countries that are facing similar challenges in expanding the adoption of hydrogen energy.

## 2. Theoretical Background

The advantages of adopting any technology are often intertwined with inherent risks. For instance, car transportation is challenged by the risk of rear-end accidents due to high-speed driving associated with the expansion of the human activity radius. Similarly, while nuclear power generation can offer cost-effective city-level electricity, it is also susceptible to accidents that can devastate entire cities. The human process of weighing potential benefits against risks can be modeled through the concept of risk perception. Risk perception studies have primarily focused on human perspectives and biases, which often result in an overestimation of risks due to the lack of an objective method for risk probability calculation [17,18]. While there are objective statistics such as accident rates and mortality that reflect the actual risk level of any technology, biases stemming from fear and anxiety tend to magnify and exaggerate these risks [19,20]. The tendency to exaggerate the risks of technology to the point of overshadowing its benefits is a common phenomenon, as demonstrated in the widespread fear of air travel compared to car travel. Despite the fact that, in terms of deaths per 100 million miles, cars are 635 times more dangerous than commercial airplanes [21], a significant number of individuals still harbor a greater fear of flying.

Risk perception plays a pivotal role in shaping public attitudes toward adopting or resisting specific technology-related behaviors and policies. High levels of public-perceived risk associated with a particular technology tend to increase resistance to policies that promote its development and distribution. Numerous studies have demonstrated that risk perception varies with the level of information and benefits, which can counteract risk biases [20]. In the context of South Korea's government policies promoting hydrogen energy, entailing both benefits and risks, specific incidents have served as catalysts in altering public sentiment by diminishing the perceived benefits in relation to the risks involved. Extreme events, such as disasters, overshadow the perceived advantages of technology and draw significant attention, subsequently raising risk awareness [22]. In South Korea, incidents such as the Gangneung hydrogen tank explosion (2019), the Yeosu hydrogen plant incident (2022), and the Gunsan hydrogen tank explosion (2023) have collectively led to widespread resistance against hydrogen energy. According to Kim et al. [23], who conducted a study on public attitudes towards hydrogen energy, there is a strong lack of acceptance and increased concerns regarding the risks associated with hydrogen energy. Under these unfavorable public risk perception conditions, policies aimed at promoting hydrogen energy face opposition from public opinion, which hinders their progress and implementation.

To help the public comprehensively grasp the risks and benefits of hydrogen energy and make informed decisions for or against it, a unique PR process tailored to hydrogen energy policies is imperative. In this context, "PR" refers to a strategic communication process designed to foster mutually beneficial relationships between organizations and their stakeholders [19]. Typically, PR strategies involve promotions and mass campaigns utilizing various media channels. Furthermore, government officials often view PR as a tool for advancing their political agendas and projecting a positive public image, focusing on message control and portraying the government in the best possible light, while media reports and press conferences are often prioritized over long-term relationship building [24,25]. Even though these methods may yield tangible and positive short-term results, recognizing that PR is a strategic communication process for managing relationships with stakeholders capable of influencing public attitudes and behaviors is essential. The essence of PR philosophy lies not solely in disseminating messages but also in understanding and addressing the underlying concerns that influence the stakeholder's perceptions. On such a basis, solid public support is cultivated over time through consistent communication and actions rather than relying on isolated campaigns or press releases. Approaching information dissemination carefully is crucial for mediating persuasion and achieving a gradual but powerful change in public perceptions that may be predisposed to risk aversion [26,27]. Kim et al. [23] suggested that, given the current limited awareness and knowledge concerning hydrogen energy in South Korea, the importance of providing accurate and regular information should not be underestimated. This highlights the necessity of a strategy aimed at effectively communicating the future implications of hydrogen energy policies, their potential benefits, and their external influencing factors to the public to transform public opinion into a driving force for policy decisions.

Many scientific organizations have been utilizing PR to enhance communication with the public, create and maintain trust with their stakeholders, and achieve strategic goals [28,29]. Key communication strategies include information-sharing and public engagement. Public engagement focuses on building relationships through active involvement, while information-sharing emphasizes enhancing public education and understanding [30,31]. Among the PR tools used by scientific organizations, new technologies such as blog posts serve as standard and effective means for information-sharing, bridging the gap between science and the public and improving public understanding and familiarity with science that influences everyday culture [32]. Two paradigms have been used in science communication PR studies to categorize the relationship between science and the public. One is the traditional knowledge-deficit model, which is characterized by the phrase "the more you know, the more you will love it" [33]. This model centers on addressing potential information deficits to enhance citizen scientific literacy, which, in turn, is expected to boost public support for scientific research [34,35]. Thus, the knowledge-deficit model perspective requires the improvement of scientific understanding in different types of audiences to achieve effective scientific communication [36,37]. However, the validity of this hypothesis has been consistently challenged due to a lack of empirical evidence [38]. Efforts to address knowledge gaps have led to some enhancements in public understanding, but these efforts are constrained in terms of fostering trust and credibility [31,34]. In contrast, the public engagement model considers the relationship between the public and science as a reciprocal exchange of information. Unlike the one-way transmission of the knowledge-deficit model, public engagement emphasizes the active role and involvement of the public [39,40]. In the later model, communicating science involves an interaction or dialogue between the public and science, encompassing not only scientific but also ethical, legal, and social issues [41–43]. However, public engagement assumes that participating individuals possess a high level of scientific knowledge [44] and a positive attitude towards science prior to their engagement [45]. Both models share the premise of a dynamic interaction between science and the public, which may be unrealistic.

To address the limitations of the previous paradigms, an alternative model has been proposed by Scheufele [31], adding a new perspective. This model introduces the concept of "mediated realities" and emphasizes the significance of the public's cognitive abilities and daily exposure to information. According to Scheufele [31], scientific facts and realities are transformed into "mediated realities" through daily exposure to scientific information via mass or online media, influencing public attitudes and opinions. The above model is considered to be more reflective of reality as it acknowledges the public's cognitive tendencies, which are often overlooked by traditional paradigms. The subset of the public willing to invest time and effort in understanding complex knowledge and actively participate in engagement is limited to those with a high level of scientific literacy. The conversion of scientific facts into mediated realities is achieved through an agenda-setting process performed by the media, which determines their relationships with the public. In this light, this study aimed to establish a PR strategy by identifying information priorities for promoting the public acceptance of the hydrogen energy policy in South Korea.

## 3. Research Design and Methods

Under the context of South Korea's ongoing goal of establishing hydrogen energy policies, it is crucial to explore the types of information that can control negatively biased public risk perceptions and form effective PR based on the capabilities and external environments of the South Korean government. To this end, this study used SWOT analysis, an environmental analysis technique used for establishing an organization's strategy, combined with AHP techniques, used for multi-standard decision-making. SWOT analysis is the most popular strategic tool for exploring systematic decision-making by reviewing external environments and internal capabilities. This analytical method is used to identify the strengths, weaknesses, opportunities, and threats an organization faces, while AHP is used to analyze the priorities of these factors and determine the optimum course of action.

The combined technique (SWOT-AHP) constitutes a more comprehensive and systematic decision-making approach because it considers both quantitative and qualitative factors that affect the organization. Under this framework, strengths refer to internal attributes that offer a competitive advantage to the organization, including resources, skills, and procedures, whereas weaknesses correspond to internal attributes that can hinder success and refer to insufficient resources, skills, or procedures. Opportunities, on the other hand, are external attributes that can positively impact a market expansion or a development concerning the technological environment, law, or institution. Finally, threats are external attributes that can have negative impacts on the organization, such as a market reduction, intensified competition, and economic recession. The competencies and environmental factors under this context are used as criteria for the AHP twin comparison. Factors with relatively high priority can be quantitatively identified by evaluating the weight of each criterion provided by government officials and experts. This evaluation can then be used to construct a TOWS matrix, which can help explore a specific strategic orientation based on the identified factors and their corresponding weights. While the SWOT analysis is a planning tool, the TOWS matrix can serve as an action plan [16]. Combining competency and environmental factors can be used to establish four types of strategies: SO (Attack), ST (Defend), WO (Improve), and WT (Avoid). Strategies can be identified as important factors using SWOT-AHP analysis [46,47] (See Figure 1 below).

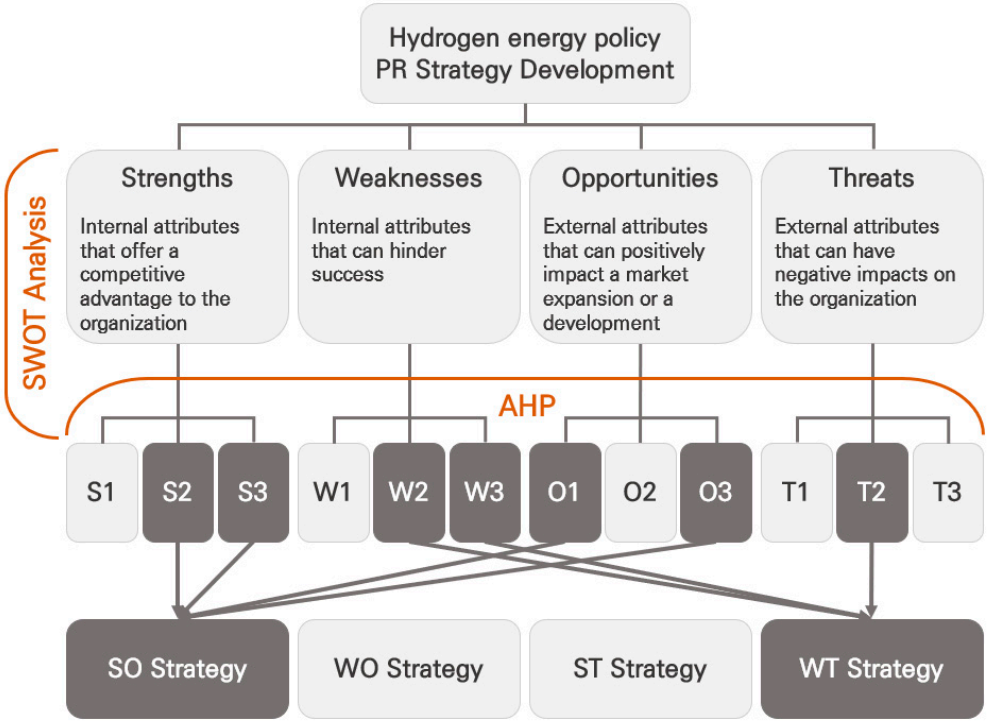


**Figure 1.** SWOT-AHP flow chart.

Lee et al. [48] explored a strategy to improve the public acceptance of hydrogen charging stations using the SWOT-AHP approach similar to the analytical approach adopted in the present study, focusing on the relationship between technology and the public. However, their study specifically examined hydrogen charging stations, whereas the present study focuses on the broader scope of hydrogen energy policy. This broader perspective allows for a more comprehensive analysis of policy implications through result comparisons.

Specifically, this study reviewed government-established plans, corporate reports, and relevant data to identify SWOT factors. This evaluation led to the identification of three strengths and weaknesses in South Korea's hydrogen energy technology, along with external opportunities and threats impacting the South Korean government—the principal body responsible for energy policies. The strengths and weaknesses identified are rooted in the inherent attributes of hydrogen energy and South Korea's technology, whereas opportunities and threats stem from the South Korean government's policy environment. These SWOT factors were found to collectively determine internal competencies and external factors affecting public support or resistance. To enhance the effectiveness of existing PR strategies, we applied AHP to gauge the significance and priority of these SWOT factors within the hydrogen energy policy context.

Overall, the four SWOT factors are summarized in Table 1 below.

1. Strengths.

**Table 1.** SWOT factors influencing public relations policy for hydrogen.

| Factor | |
|---|---|
| Strength | Safety of hydrogen energy |
| | South Korea's technological advancement |
| | Key tools for carbon neutrality |
| Weakness | Price competitiveness of production |
| | South Korea's technological gap |
| | Low localization of core technology |
| Opportunity | Growth of the global hydrogen economy |
| | Reducing the imbalance in electricity demand |
| | Industry for national economic growth |
| Threat | Deteriorating energy dependency |
| | Expansion of global carbon regulation |
| | Increasing energy cost |

The effective communication of the relative safety of hydrogen energy depends on information capable of mitigating public risk perception and is a key element of PR. Although it is a very relative concept, hydrogen can sometimes be safer than conventional fuels. For example, a recent study by Nechyporenko and Jeong [49] found that hydrogen exhibits superior fire behavior compared to traditional marine fuels, suggesting it can be a relatively safe fuel choice. Jeong et al. [50] conducted a risk assessment of fuels, ranking hydrogen < propane (LPG) in terms of risk, indicating that hydrogen fuel can be considered relatively safer than traditional LPG.

This was demonstrated in a study comparing fuel safety based on 11 fuel characteristics, including fuel toxicity, ignition temperature, and explosion energy, which reported that, using hydrogen safety as reference (a value of 1), methane was evaluated as 0.80 and gasoline was evaluated as 0.53. Furthermore, hydrogen is considered to be a clean energy source and key to achieving carbon neutrality. Fueled by the international interest in carbon neutrality, hydrogen demand is increasing worldwide, and its production in 2021 was estimated to be 94 million tons [51]. State-of-the-art hydrogen-related technologies are crucial for persuading the public of the benefits of hydrogen energy. Currently, South Korea has acquired excellent technologies in the utilization sector, with a focus on mobility and fuel cells.

2. Weaknesses.

South Korea's current hydrogen production relies heavily on white hydrogen, which constrains its production capacity. Therefore, investments to ensure stable and long-term hydrogen production are required. Additionally, alternative storage technologies are required for bulk hydrogen transportation beyond gas compression, as current options are still under evaluation and development. As a result, the price competitiveness of hydrogen energy is currently lower than that of conventional energy, which is a significant limitation. South Korea's current technological level is estimated to be approximately seven years behind that of leading hydrogen countries, and efforts are being made to narrow the technology gap to ensure the price competitiveness of hydrogen energy in the future. Additionally, the localization of core technologies and production and storage compartments, such as charging stations (compressors and storage tanks), power generation technologies (catalysts and GDL), and major materials like carbon fibers has been characterized as insufficient.

3. Opportunities.

The expansion of the global hydrogen market has provided the South Korean government with opportunities to establish and promote hydrogen energy policies. Global hydrogen demand is growing at an annual average rate of 6.7%, with the global hydrogen energy market expected to reach USD 500 billion by 2050 [2,7]. Market expansion also serves as an opportunity to improve South Korea's economic and industrial aspects. Hydrogen energy is expected to both drive the development of new energy industries and have a significant economic impact on traditional industries [7,51]. The ability of hydrogen production to address the imbalance between power supply and demand presents a valuable opportunity for strengthening the security of the hydrogen energy policy. Hydrogen is a versatile energy source that can be readily converted into electricity, gas, and heat, making it a viable solution for mitigating the challenges posed by seasonal fluctuations in energy demand and imbalances in energy supply and demand. More specifically, hydrogen is primarily converted into hydrogen gas, which is its most common and straightforward form, through processes such as the electrolysis of water or steam methane reforming. Hydrogen gas conversion has several applications; it can be used for energy storage, fuel cells, industrial processes (such as ammonia production for fertilizers), heating, and transportation (in the case of fuel cell electric vehicles). By converting hydrogen into a gas form, it becomes a flexible and portable energy carrier that can help balance energy supply and demand.

4. Threats.

The various energy policy challenges faced by the South Korean government—the primary authority—are considered environmental factors. South Korea's lower technological competitiveness in hydrogen production compared to leading countries contributes to its reliance on imported energy resources. According to World Intellectual Property Organization (WIPO) statistics for hydrogen production-related patents per country, the US, China, Japan, and Germany hold significantly more patents than South Korea.

Additionally, the country's lower ratio of renewable energy production to energy diversity compared to advanced-energy countries hinders its ability to effectively manage supply risks, making it more vulnerable to fluctuations in the global energy market [52]. South Korea's increased energy dependence leads to a higher impact of the external environment on energy security and higher costs. Recently, energy and raw material prices have been rising due to disturbances in the energy supply chain worldwide and the prolonged fluctuations in oil prices [53]. Such volatility in energy source costs, in combination with a high rate of dependence, reaching 92.8%, threatens South Korea. The increasing demand for global carbon neutrality is an additional external constraining factor. In recent years, due to socioeconomic pressure, the goal of carbon neutrality has been implemented as a practical regulatory measure. As of 2022, 83 countries (responsible for 74.2% of the global greenhouse gas emissions) have committed to achieving carbon neutrality [54]. In 2022, the EU's provisional agreement on the carbon border adjustment mechanism [55] had a significant impact on the global trade market, raising concerns about intensive protectionism.

In an AHP analysis, the level of expertise of the survey subjects is the major determinant of the reliability of the analysis results. Consequently, the qualitative robustness of the study is contingent upon the proper selection of the sample population. In this study, experts in hydrogen energy or those directly involved in energy policies were selected as the initial subjects of the survey, and their responses were recorded. The survey was conducted through a web service designed for AHP analysis, with the survey link distributed via email. Information on respondents, including age, gender, occupation, and education level, was collected, and a pairwise comparison questionnaire for AHP was presented to them. Upon completion of the survey, the results were automatically recorded. The survey included 41 individuals working in government, public research institutes, and universities who were experts in natural science, engineering, or communication with academic and practical experience in hydrogen energy policy or PR strategies. The survey revealed that 13 out of 41 respondents had a consistency ratio exceeding 0.2, and 28 were selected for the final analysis sample. Although a theoretically verified scale based on clear criteria for the minimum sample size in AHP analysis has not been established, studies applying this technique typically use samples ranging from four to nine individuals. This study included a total of 28 participants, comprising six individuals from government energy policy, eight from government PR, five from public research institutes, and nine from school institutions. Thus, the sample size requirements for AHP analysis were met. Details on the experts included in this study are listed in Table 2.

**Table 2.** Expert information.

| ID | Gender | Age | Education | Affiliation | Areas of Expertise |
|---|---|---|---|---|---|
| 1 | Male | 40–49 years | Bachelor | Government | Natural Science |
| 2 | Male | 50–59 years | Bachelor | Government | Social Science |
| 3 | Male | 50–59 years | Bachelor | Government | Engineer |
| 4 | Male | 40–49 years | Bachelor | Government | Engineer |
| 5 | Male | 50–59 years | Bachelor | Government | Engineer |
| 6 | Male | 40–49 years | Bachelor | Government | Engineer |
| 7 | Male | 30–39 years | Bachelor | Government (PR) | Humanities |
| 8 | Male | 40–49 years | Bachelor | Government (PR) | Social Science |
| 9 | Male | 40–49 years | Bachelor | Government (PR) | Social Science |
| 10 | Male | 40–49 years | Master | Government (PR) | Social Science |
| 11 | Male | 40–49 years | Master | Government (PR) | Humanities |
| 12 | Male | 40–49 years | Bachelor | Government (PR) | Social Science |
| 13 | Female | 30–39 years | Bachelor | Government (PR) | Humanities |
| 14 | Male | 40–49 years | Bachelor | Government (PR) | Social Science |
| 15 | Male | 40–49 years | Master | Public Research Institute | Engineer |
| 16 | Male | 40–49 years | Ph.D. | Public Research Institute | Engineer |
| 17 | Male | 30–39 years | Master | Public Research Institute | Engineer |
| 18 | Male | 40–49 years | Ph.D. | Public Research Institute | Engineer |
| 19 | Male | 40–49 years | Ph.D. | Public Research Institute | Engineer |
| 20 | Male | 40–49 years | Ph.D. | University | Engineer |
| 21 | Male | 40–49 years | Ph.D. | University | Engineer |
| 22 | Male | 40–49 years | Ph.D. | University | Engineer |
| 23 | Male | Under 30 | Bachelor | University | Engineer |
| 24 | Male | 40–49 years | Ph.D. | University | Engineer |
| 25 | Male | 30–39 years | Ph.D. | University | Engineer |
| 26 | Female | Under 30 | Master | University | Engineer |
| 27 | Male | 40–49 years | Ph.D. | University | Engineer |
| 28 | Male | Under 30 | Bachelor | University | Engineer |

## 4. Results

Analysis involving (Figure 2) the calculation of the total weight by considering both SWOT factors and sub-criteria weights revealed that weakness is the primary factor to consider when formulating a PR strategy for hydrogen energy policy. Weakness exhibited a total weight of 0.398, signifying its greater importance compared to other factors. This highlights the need to emphasize and convince the public about South Korea's technical and economic weaknesses in energy policy and hydrogen technology, in combination with the significance of the hydrogen energy policy. Threat (0.269) emerged as the second-most-crucial factor, followed by strength (0.185) and opportunity (0.148).

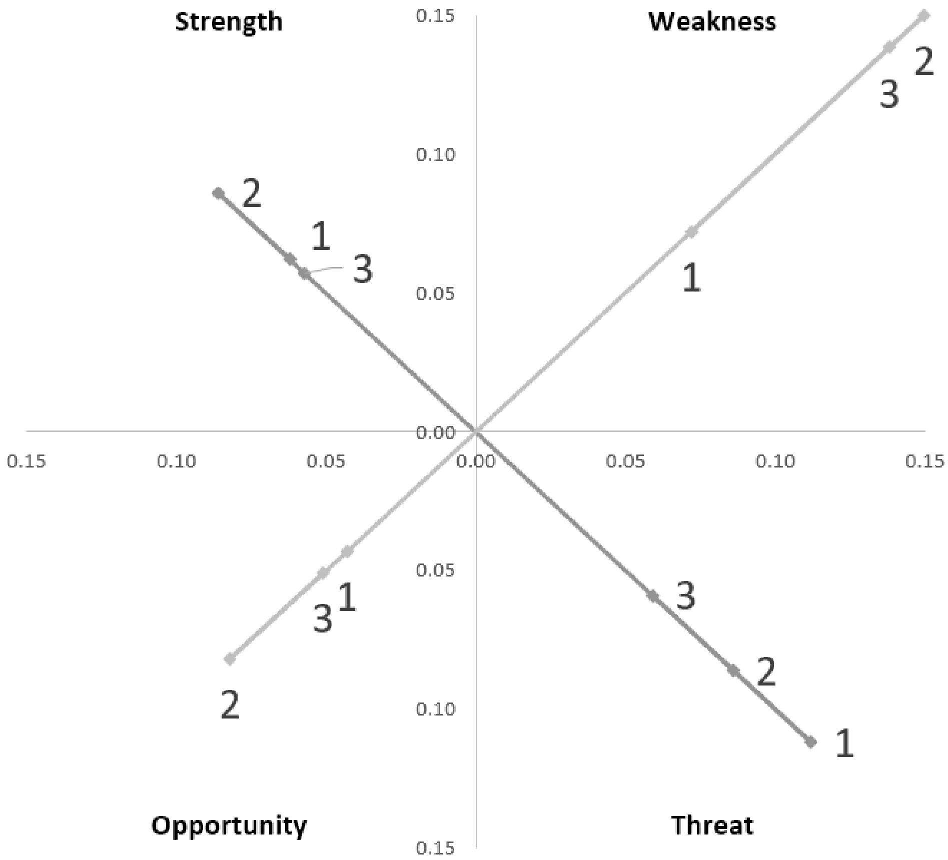


**Figure 2.** SWOT analysis results.

In the sub-criteria of weakness, "South Korea's technical lag" ranked first with a total weight of 0.174, followed by "low localization of core technology" (0.155). The threat factor "Deteriorating energy dependency" (0.110) was also shown to be an important factor affecting hydrogen energy PR policy, as indicated by the high level of its added comprehensive weight. On the other hand, opportunity sub-criteria such as "Growth of global hydrogen economy" (0.035) and "Industry for national economic growth" (0.047) were of relatively low importance. These results comprehensively represent the perspectives of policy experts from government, universities, and research institutes. Furthermore, to persuade the public about the need for a hydrogen energy policy and draw support, it is necessary to focus on certain elements of South Korea's capabilities and environment. The weights of SWOT factors are indicated in Table 3.

The AHP results suggest that, among internal competencies, it is advisable to focus on weaknesses rather than strengths. Likewise, among external environments, highlighting threats rather than opportunities is recommended. Considering these results, the TOWS matrix proposes the adoption of a WT strategy with the core objective of "minimizing weakness to mitigate threats". Specifically, to address threats such as increasing energy dependency and expanding global carbon regulations, persuading the public to focus on compensating for the weaknesses in South Korean hydrogen energy technology is of utmost importance. From a management perspective, the WT strategy is generally associated with an exit strategy involving cutbacks or mergers [16]. However, business closures or withdrawals are not applicable to public policy and government options. Therefore, the WT strategy pertains to a response aimed at survival and avoidance. Analysis revealed that experts from the government, public research institutes, and universities have opted for an "emergency plan" for establishing PR concerning hydrogen energy policies. They propose that the public can be steered towards embracing the policy by highlighting the crises brought about by energy economics, security concerns, and international pressures while also emphasizing the low localization of core technology.

**Table 3.** Weights of SWOT factors.

| | | Factor | Total |
|---|---|---|---|
| Strength (0.205) | 1 | Safety of hydrogen energy | 0.063 |
| | 2 | South Korea's technological advancement | 0.080 |
| | 3 | Key tools for carbon neutrality | 0.042 |
| Weakness (0.360) | 1 | Price competitiveness of production | 0.070 |
| | 2 | South Korea's technological gap | 0.174 |
| | 3 | Low localization of core technology | 0.155 |
| Opportunity (0.177) | 1 | Growth of the global hydrogen economy | 0.035 |
| | 2 | Reducing the imbalance in electricity demand | 0.066 |
| | 3 | Industry for national economic growth | 0.047 |
| Threat (0.257) | 1 | Deteriorating energy dependency | 0.110 |
| | 2 | Expansion of global carbon regulation | 0.094 |
| | 3 | Energy cost increasing | 0.066 |

Sensitivity analyses were conducted to establish confidence in the AHP results and to assess the dependence of the weights assigned to the criteria, following the approach of Hashemizadeh et al. [56]. The weight of the sub-factor "Korea's technological gap", which had the highest weight in the AHP results, was reduced by 10% (Figure 3). This resulted in the lowering of the original weight of 0.174 to 0.157. The remaining 11 sub-factors experienced a slight increase in their weights, but their rankings remained unchanged. Conversely, when the weight of "Korea's technological gap" was increased by 10% (Figure 4), the original weight of 0.174 was increased to 0.191. Although the other 11 sub-factors experienced a slight decrease in weight, there was no change in ranking.

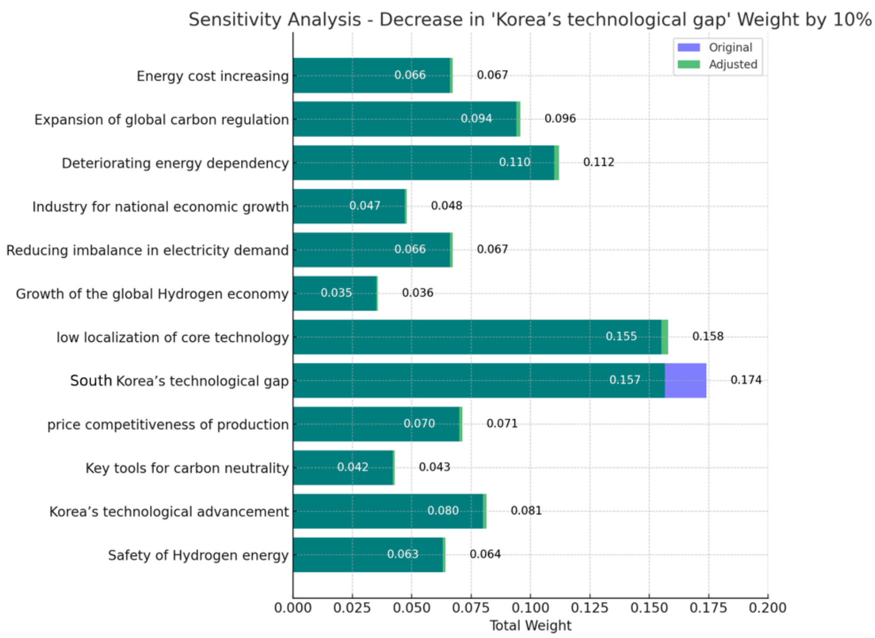


**Figure 3.** Sensitivity analysis (decreased weight by 10%). The overlapped area is expressed in dark green.

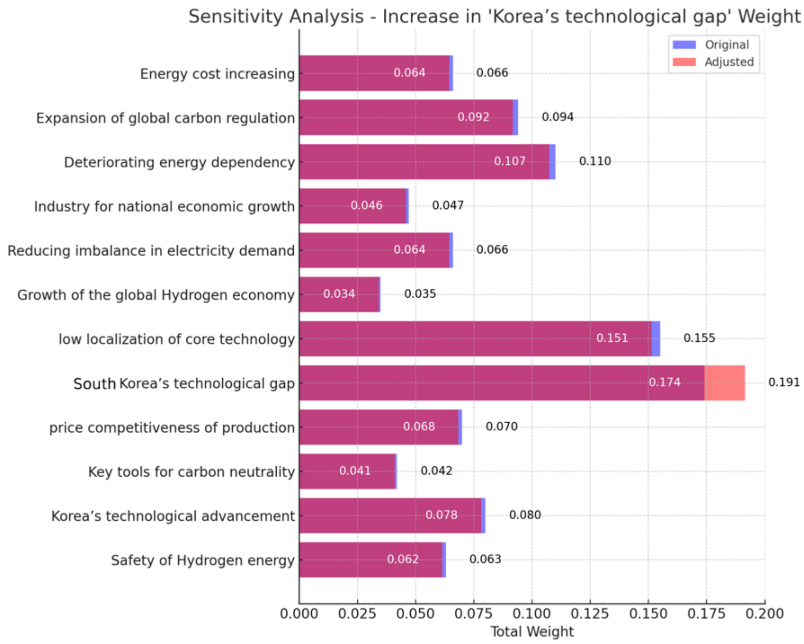


**Figure 4.** Sensitivity analysis (increased weight by 10%). The overlapped area is expressed in rose red.

Interestingly, the prioritization of factors showed distinct patterns based on the affiliations of the expert groups. The respondents were categorized into three affiliations: government (energy policy and PR), public research institutes, and universities.

Respondents belonging to government and public research institutes rated weakness as the factor of highest importance, while the importance of strength was rated highest by those belonging to universities. Specifically, the weight for weakness was 0.408 for government (energy policy), 0.487 for government (PR), and 0.549 for public research institutes, but it was only 0.225 for universities. On the other hand, strength was given higher importance among universities with a weight of 0.306. In contrast, government and public research institutes placed a relatively lower emphasis on strength, with weights ranging from 0.134 to 0.137. A common perception among the three types of respondent groups was that they focused on threats rather than opportunities in the external environment. The threat weights were 0.301 for government (energy policy), 0.287 for government (PR), 0.190 for public research institutes, and 0.259 for universities, which were all higher than the respective weights for opportunities.

Different weights were assigned to each group type for all sub-criteria except for threats. Regarding strengths, respondents from public research institutes, government (PR), and universities emphasized South Korea's existing technological leadership, whereas the government energy policy experts emphasized the importance of hydrogen technology as a tool for carbon neutrality. In the case of weaknesses, experts from the government and universities placed a high weight on technological backwardness, while public research institutes assigned a weight of 0.323 to the low localization of core technologies. Participants from government and universities both selected the same sub-criterion—"Reducing Imbalance in Electricity Demand"—for opportunities, while public research institutes prioritized "Growth of Global Hydrogen Economy". In the case of threats, all three groups highlighted the significance of addressing energy dependency, emphasizing the core role of PR in promoting public investment in hydrogen energy. Only government (PR) officials gave priority to the expansion of global carbon regulations.

The action plan based on the TOWS matrix differed depending on the respondents' affiliations. The government and the public research institutes recognized that the WT strategy, which compensates for weaknesses and avoids threats, aligns well with the establishment of PR-supporting hydrogen energy policies. Government officials working in energy policy and PR shared the same view. However, experts from universities opted for an ST strategy, focusing on countering threats. This decision stemmed from the belief that effective crisis management should focus on validating the policy rather than prioritizing an emergency plan to avoid threats. This variability can be attributed to differences in perception between university experts and government officials, with the latter considering a broader spectrum of stakeholders and political conditions. The overall results of the analysis are shown in Table 4 and Figure 5.

**Table 4.** Summary of results.

| | Government (Energy Policy) | Public Research Institute | University | Government (PR) |
|---|---|---|---|---|
| Strengths | 0.136 | 0.134 | 0.306 | 0.137 |
| Safety of hydrogen energy | 0.037 | 0.036 | 0.102 | 0.060 |
| South Korea's technological advancement | 0.046 | 0.060 | 0.136 | 0.060 |
| Key tools for carbon neutrality | 0.053 | 0.037 | 0.068 | 0.017 |
| Weaknesses | 0.408 | 0.549 | 0.225 | 0.487 |
| Price competitiveness of production | 0.057 | 0.071 | 0.065 | 0.060 |
| South Korea's technological backwardness | 0.191 | 0.155 | 0.102 | 0.235 |
| Low localization of core technology | 0.160 | 0.323 | 0.059 | 0.192 |
| Opportunities | 0.156 | 0.128 | 0.211 | 0.089 |
| Growth of the global hydrogen economy | 0.029 | 0.050 | 0.041 | 0.020 |
| Reducing the imbalance in electricity demand | 0.086 | 0.044 | 0.104 | 0.035 |
| Industry for national economic growth | 0.041 | 0.033 | 0.066 | 0.035 |
| Threats | 0.301 | 0.190 | 0.259 | 0.287 |
| Deteriorating energy dependency | 0.111 | 0.097 | 0.110 | 0.098 |
| Expansion of global carbon regulation | 0.107 | 0.053 | 0.092 | 0.110 |
| Energy cost increasing | 0.082 | 0.041 | 0.056 | 0.079 |

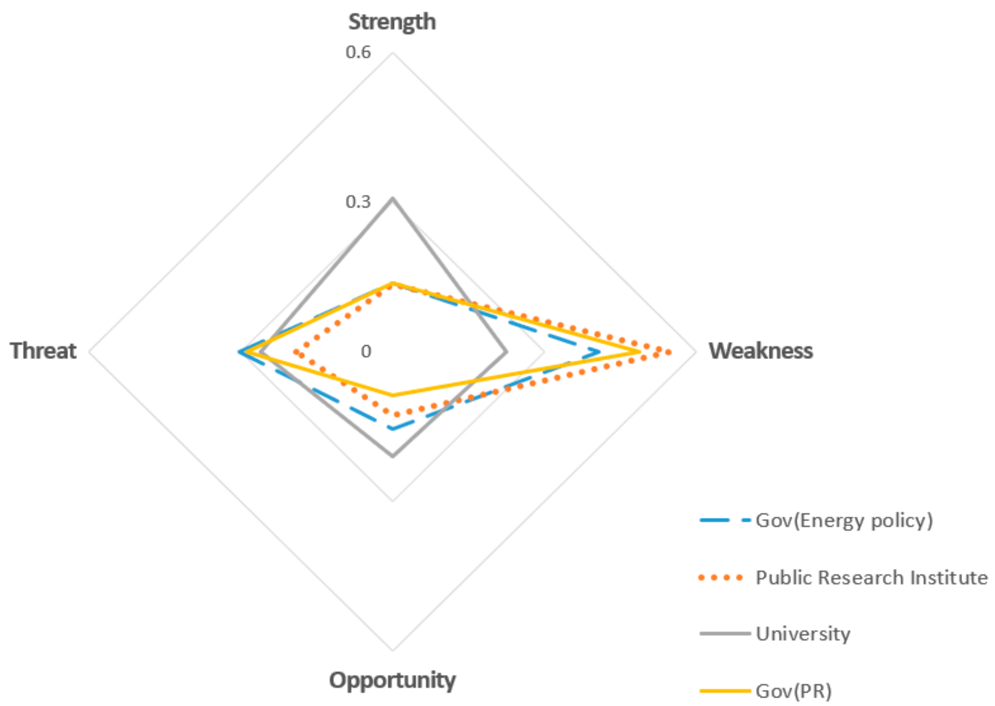


**Figure 5.** SWOT results.

## 5. Discussion

The global demand for carbon neutrality and the expansion of the global hydrogen energy market have intensified the South Korean government's awareness of the necessity to invest in hydrogen technology R&D and infrastructure. Nevertheless, recurring hydrogen-related accidents continue to undermine public confidence in hydrogen energy. This study developed PR strategies to support hydrogen energy policies by mitigating negative public risk perceptions. By conducting an AHP analysis involving government officials, public research institutes, and university experts, focusing on the SWOT factors from the existing literature, we identified informative content that can enhance public support. Additionally, we explored strategies aligned with the TOWS matrix. From a comprehensive perspective, the WT strategy emerged as a high priority, indicating a consensus on the need to address threats and weaknesses in PR. However, when subdividing the action plan according to different groups, the university experts emphasized the strengths of hydrogen technology in South Korea, diverging from the approach taken by other groups. They suggested that rather than focusing on technological vulnerabilities and the urgency of supplementation, it would be more effective to raise public awareness of the existing superiority and advantages of the technology.

Lee et al. [48] emphasized the importance of a strategy that highlights the strengths of hydrogen refueling stations as a means of improving public acceptance of these facilities. However, an evaluation of the SWOT factors for PR strategies covering a broad range of hydrogen energy policies revealed weaknesses as an important factor, in contrast to the findings of Lee et al. [48]. From the perspective of government and public research institutes, emphasizing weaknesses rather than strengths was perceived as more convincing to the public. This suggests that it is an effective strategy to share current limitations and weaknesses with the public and convey the validity of the policy when targeting a broad policy area (such as hydrogen energy) rather than a localized policy area (such as hydrogen refueling stations). Furthermore, information on external threats was considered useful for public persuasion. Communicating with the public about the threats South Korea faces regarding energy security could help mitigate the public risk perception of hydrogen energy.

The limitations of the knowledge-deficit and public engagement models, which have dominated discussions on science communication and PR, can be attributed to their failure to acknowledge the importance of the public's cognitive abilities and daily exposure to information. As an alternative, the mediated realities model of Scheufele [31] focuses on information to mediate between the public and scientific facts. Based on the SWOT factors identified in this study, information related to weaknesses and threats should be explored and utilized from a PR perspective. Interpreting these results solely in terms of scientific knowledge or factual importance would be insufficient. Instead, this information should be seen as a means to shape attitudes and foster public acceptance of the necessity for hydrogen energy policies. This implies that emphasizing weaknesses and threats can lead to more effective PR strategies, even if they do not directly address the primary scientific expert concerns.

Hydrogen has significant potential to transform society by reducing global reliance on fossil-based fuels. Despite its widely recognized environmental benefits, achieving public approval is crucial for hydrogen to attain public acceptance, gain legitimacy, and ensure sustainable support. However, due to continuous explosions and accidents, the current perceived risk of hydrogen in South Korea is much higher than the actual risk. Thus, the government needs to focus its efforts on conveying accurate information that enables the public to make rational judgments. The persuasive information generated from government officials and experts in this study is expected to serve as a foundation for future policy communication and PR strategies.

**Author Contributions:** Conceptualization: Y.L. and M.C.; Data curation, Y.L., M.C.L. and Y.K.; Formal analysis, Y.L. and M.C.; Funding acquisition, Y.K.; Investigation, M.C.L. and Y.K.; Methodology, Y.L. and M.C.; Project administration, M.C.L. and Y.K.; Resources, M.C.L. and Y.K.; Software, M.C.; Supervision, M.C.L.; Validation, Y.K.; Visualization, M.C.; Writing—original draft, M.C.; Writing—review & editing, Y.L. and M.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was supported by an Incheon National University Research Grant in 2024.

**Data Availability Statement:** Data are contained within the article.

**Conflicts of Interest:** Author Minhyuk Cho was employed by the company CG inside Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## References

1. IEA. *Global Hydrogen Review 2023*; IEA: Paris, France, 2023. Available online: https://www.iea.org/reports/global-hydrogen-review-2023 (accessed on 21 June 2024).
2. IEA. *The Future of Hydrogen: Seizing Today's Opportunities*; IEA: Paris, France, 2019.
3. Saha, P.; Akash, F.A.; Shovon, S.M.; Monir, M.U.; Ahmed, M.T.; Khan, M.F.H.; Sarkar, S.M.; Islam, M.K.; Hasan, M.M.; Vo, D.V.N.; et al. Grey, blue, and green hydrogen: A comprehensive review of production methods and prospects for zero-emission energy. *Int. J. Green Energy* **2023**, *21*, 1383–1397. [CrossRef]
4. An, Y.; Loh, T.Y.; Sujith Bhaskara, P.S.; Sin, S.M.I. Review of safety regulations, codes, and standards (RCS) for hydrogen distribution and application. *Int. J. Green Energy* **2024**, *21*, 1757–1765. [CrossRef]
5. Yusaf, T.; Laimon, M.; Alrefae, W.; Kadirgama, K.; Dhahad, H.A.; Ramasamy, D.; Kamarulzaman, M.K.; Yousif, B. Hydrogen energy demand growth prediction and assessment (2021–2050) using a system thinking and system dynamics approach. *Appl. Sci.* **2022**, *12*, 781. [CrossRef]
6. Ren, J.; Gao, S.; Liang, H.; Tan, S.; Dong, L. The role of hydrogen energy: Strengths, weaknesses, opportunities, and threats. In *Hydrogen Economy*; Academic Press: Cambridge, MA, USA, 2017; pp. 1–33.
7. Mckinsey. *Hydrogen Insights 2022: An Updated Perspective on Hydrogen Market Development and Actions Required to Unlock Hydrogen at Scale*; McKinsey & Company: Chicago, IL, USA, 2022.
8. Xu, D.; Liu, Z.; Zhu, J.; Fang, Q.; Shan, R. Linking cost decline and demand surge in the hydrogen market: A case study in China. *Energies* **2023**, *16*, 4821. [CrossRef]
9. Le, P.A.; Trung, V.D.; Nguyen, P.L.; Phung, T.V.B.; Natsuki, J.; Natsuki, T. The current status of hydrogen energy: An overview. *RSC Adv.* **2023**, *13*, 28262–28287. [CrossRef] [PubMed]
10. Saatloo, A.M.; Mehrabi, A.; Marzband, M.; Mirzaei, M.A.; Aslam, N. Local energy market design for power- and hydrogen-based microgrids considering a hybrid uncertainty controlling approach. *IEEE Trans. Sustain. Energy* **2024**, *15*, 398–413. [CrossRef]
11. Ministry of Trade, Industry and Energy. *Support for Demonstration of 1000 Tons of Green Hydrogen Production per Year in 26 Years in Korean*; Ministry of Trade, Industry and Energy: Seoul, Republic of Korea, 2022.
12. Moura, J.; Soares, I. Financing low-carbon hydrogen: The role of public policies and strategies in the EU, UK and USA. *Green Finance* **2023**, *5*, 265–297. [CrossRef]
13. Granholm, M.J. US releases National Clean Hydrogen Strategy and Roadmap. *MRS Bull.* **2023**, *48*, 707–708. [CrossRef]
14. Lee, Y.; Cho, M.H.; Lee, M.C.; Kim, Y.J. Evaluating hydrogen risk management policy PR: Lessons learned from three hydrogen accidents in South Korea. *Int. J. Hydrogen Energy* **2023**, *48*, 24536–24547. [CrossRef]
15. Li, Z.; Sun, K. Quantified risk assessment on life and property loss from road collision vehicle fires with hydrogen-fueled tank. *Int. J. Green Energy* **2019**, *16*, 583–589. [CrossRef]
16. Weihrich, H. The TOWS matrix—A tool for situational analysis. *Long Range Plann.* **1982**, *15*, 54–66. [CrossRef]
17. Siegrist, M. Trust and risk perception: A critical review of the literature. *Risk Anal.* **2021**, *41*, 480–490. [CrossRef]
18. Gaynor, K.M.; Brown, J.S.; Middleton, A.D.; Power, M.E.; Brashares, J.S. Landscapes of fear: Spatial patterns of risk perception and response. *Trends Ecol. Evol.* **2019**, *34*, 355–368. [CrossRef]
19. Fischhoff, B.; Bostrom, A.; Quadrel, M.J. Risk perception and communication. *Annu. Rev. Public Health* **1993**, *14*, 183–203. [CrossRef]
20. Slovic, P.; Peters, E. Risk perception and affect. *Curr. Dir. Psychol. Sci.* **2006**, *15*, 322–325. [CrossRef]
21. Savage, I. Comparing the fatality risks in United States transportation across modes and over time. *Res. Transp. Econ.* **2013**, *43*, 9–22. [CrossRef]
22. Birkland, T.A.; Schwaeble, K.L. Agenda setting and the policy process: Focusing events. In *Oxford Research Encyclopedia of Politics*; Oxford University Press: New York, NY, USA, 2019.

23. Kim, S.H.; Kim, J.H.; Shin, H.Y. Exploring strategies for implementing hydrogen society based on psychological attitudes towards hydrogen fuel: Focused on risk perception, familiarity and acceptability. *Trans. Korean Hydrog. New Energy Soc.* **2022**, *33*, 267–283. [CrossRef]
24. Fraser, P.S. *The Practice of Public Relations*, 13th ed.; Pearson Education: London, UK, 2017.
25. Wilcox, D.L. *Public Relations Writing and Media Techniques*, 6th ed.; Pearson: London, UK, 2016.
26. Lu, X.; Jin, Y. Information vetting as a key component in social-mediated crisis communication: An exploratory study to examine the initial conceptualization. *Public Relat. Rev.* **2020**, *46*, 101891. [CrossRef]
27. Coleman, G.J. Educating the public: Information or persuasion? *J. Vet. Med. Educ.* **2010**, *37*, 74–82. [CrossRef]
28. Shipman, M. Public relations as science communication. *J. Sci. Commun.* **2014**, *13*, C05. [CrossRef]
29. Borchelt, R.E.; Nielsen, K.H. Public relations in science: Managing the trust portfolio. In *Routledge Handbook of Public Communication of Science and Technology*, 2nd ed.; Bucchi, M., Trench, B., Eds.; Routledge: New York, NY, USA, 2014; pp. 58–69.
30. Kurath, M.; Gisler, P. Informing, involving or engaging? Science communication, in the ages of atom-, bio- and nanotechnology. *Public Underst. Sci.* **2009**, *18*, 559–573. [CrossRef]
31. Scheufele, D.A. Science communication as political communication. *Proc. Natl. Acad. Sci. USA* **2014**, *111* (Suppl. S4), 13585–13592. [CrossRef] [PubMed]
32. Sanchez-Mora, M.C. Evolution of evaluation in science museums and centres. *J. Sci. Commun.* **2014**, *13*, C02. [CrossRef]
33. Bauer, M.W.; Allum, N.; Miller, S. What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Underst. Sci.* **2007**, *16*, 79–95. [CrossRef]
34. Kappel, K.; Holmen, S.J. Why science communication, and does it work? A taxonomy of science communication aims and a survey of the empirical evidence. *Front. Commun.* **2019**, *4*, 55. [CrossRef]
35. Seethaler, S.; Evans, J.H.; Gere, C.; Rajagopalan, R.M. Science, values, and science communication: Competencies for pushing beyond the deficit model. *Sci. Commun.* **2019**, *41*, 378–388. [CrossRef]
36. Andersen, I.-E.; Jaeger, B. Scenario workshops and consensus conferences: Towards more democratic decision-making. *Sci. Public Policy* **1999**, *26*, 331–340. [CrossRef]
37. Miller, J.D. Civic Scientific Literacy in the United States in 2016: A Report Prepared for the National Aeronautics and Space Administration by the University of Michigan. *Retrieved March* **2016**, *14*, 2023.
38. Scheufele, D.A. Communicating science in social settings. *Proc. Natl. Acad. Sci. USA* **2013**, *110* (Suppl. S3), 14040–14047. [CrossRef]
39. Bucchi, M.; Trench, B. (Eds.) *Routledge Handbook of Public Communication of Science and Technology*; Routledge: New York, NY, USA, 2021.
40. Chilvers, J.; Kearnes, M. Remaking participation in science and democracy. *Sci. Technol. Hum. Values* **2020**, *45*, 347–380. [CrossRef]
41. Dietz, T. Bringing values and deliberation to science communication. *Proc. Natl. Acad. Sci. USA* **2013**, *110* (Suppl. S3), 14081–14087. [CrossRef] [PubMed]
42. Kleinman, D.L.; Delborne, J.A.; Anderson, A.A. Engaging citizens: The high cost of citizen participation in high technology. *Public Underst. Sci.* **2011**, *20*, 221–240. [CrossRef]
43. Rowe, G.; Frewer, L.J. A typology of public engagement mechanisms. *Sci. Technol. Hum. Values* **2005**, *30*, 251–290. [CrossRef]
44. Scheufele, D.A. *Modern Citizenship or Policy Dead End? Evaluating the Need for Public Participation in Science Policy Making, and Why Public Meetings May Not Be the Answer*; Joan Shorenstein Center on the Press, Politics and Public Policy Research Paper Series Paper R-34; Harvard University Press: Cambridge, MA, USA, 2011.
45. Corley, E.A.; Scheufele, D.A. Outreach gone wrong? When we talk Nano to the public, we are leaving behind key audiences. *Scientist* **2010**, *24*, 22.
46. Asadpourian, Z.; Rahimian, M.; Gholamrezai, S. SWOT-AHP-TOWS analysis for sustainable ecotourism development in the best area in Lorestan Province, Iran. *Soc. Indic. Res.* **2020**, *152*, 289–315. [CrossRef]
47. Oreski, D. Strategy development by using SWOT-AHP. *TEM J.* **2012**, *1*, 283–291.
48. Lee, Y.; Kim, Y.J.; Lee, M.C. Improving public acceptance of H2 stations: SWOT-AHP analysis of South Korea. *Int. J. Hydrogen Energy* **2021**, *46*, 17597–17607. [CrossRef]
49. Nechyporenko, V.; Jeong, B. Comparative safety analysis of engine room fires with different marine fuels of MGO, LPG and H2. *J. Int. Marit. Safety, Environ. Aff. Shipp.* **2023**, *7*, 2269346. [CrossRef]
50. Jeong, S.Y.; Jang, D.; Lee, M.C. Property-based quantitative risk assessment of hydrogen, ammonia, methane, and propane considering explosion, combustion, toxicity, and environmental impacts. *J. Energy Storage* **2022**, *54*, 105344. [CrossRef]
51. IEA. *Global Hydrogen Review 2022*; OECD Publishing: Paris, France, 2022.
52. Jin, C.; Xiao, J.; Hou, J.; Wu, X.; Zhang, J.; Du, E. Flexibility improvement evaluation of hydrogen storage based on electricity–hydrogen coupled energy model. *Glob. Energy Interconnect.* **2021**, *4*, 371–383. [CrossRef]
53. Jang, Y.C.; Bang, K.Y.; Lee, K.Y.; Kim, K.N. Analysis of Energy Security by the Diversity Indices: A Case Study of South Korea. *J. Energy Eng.* **2014**, *23*, 93–101. [CrossRef]
54. Simchi-Levi, D.; Haren, P. How the war in Ukraine is further disrupting global supply chains. *Harv. Bus. Rev.* **2022**, *17*. Available online: https://hbr.org/2022/03/how-the-war-in-ukraine-is-further-disrupting-global-supply-chains (accessed on 21 June 2024).

55. Stern, N. Towards a carbon neutral economy: How government should respond to market failures and market absence. *J. Gov. Econ.* **2022**, *6*, 100036. [CrossRef]
56. Hashemizadeh, A.; Ju, Y.; Bamakan, S.M.H.; Le, H.P. Renewable energy investment risk assessment in belt and road initiative countries under uncertainty conditions. *Energy* **2021**, *214*, 118923. [CrossRef]