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FINANCIAL AND REGULATORY APPROACHES OF AZERBAIJANI COMPANIES TO THE HYDROGEN ENERGY TRANSITION

Abstract
The use of hydrogen energy has become more important in recent years, especially as part of the shift to clean and sustainable energy. To grow investment in the hydrogen sector, the active involvement of the private sector is essential. Therefore, it is very important to understand what factors influence private companies to invest in hydrogen. This study looks at Azerbaijan as a case study - a small country that exports oil and gas, but is now focusing on renewable energy and building a green hydrogen value chain to produce hydrogen for the European Union. To explore the challenges and opportunities for Azerbaijani companies in the hydrogen value chain, the study conducted structured interviews with representatives from 65 companies. The findings show that how companies view government regulation depends on their size, sector, and years in operation. For example, medium-sized companies and those in transport and tourism support government involvement, while larger companies and those in the food sector are more cautious. However, the study found that private financial approaches did not vary based on company characteristics.

Keywords: hydrogen energy; private financial approaches; state regulation; renewable resources; sustainability

1. Introduction
Hydrogen has great potential to help make energy and transportation systems more sustainable and to reduce emissions in hard-to-decarbonize sectors like metallurgy and cement, which produce high levels of carbon. Renewable hydrogen is expected to play a key role in energy production, storage, and transport. It can also replace fossil fuels in many areas. One of the main reasons' hydrogen energy is important is its ability to reduce carbon emissions. [1]. When hydrogen is burned or used in fuel cells, it only produces water vapor - no carbon dioxide (CO2) or other greenhouse gases - making it a clean and environmentally friendly energy source. Green hydrogen, which is made using renewable energy, is especially beneficial because it is completely emission-free [2-5]. Using hydrogen in high-emission sectors like transport, industry, and power generation can significantly cut down on carbon emissions.
30 **Hydrogen is the most abundant element in the** universe. While it **is** rarely 31 **found in its pure form in** nature, it is commonly found in compounds like water (H2O) and natural gas (CH4). Hydrogen can be produced from these compounds. When hydrogen is made by using electrolysis of water with renewable energy, it becomes a fully sustainable energy source [6-8].
Hydrogen is also a very effective way to store energy. Renewable sources like solar and wind can be unpredictable and may not always produce energy consistently [9-11]. Hydrogen has the advantage of being stored and used later when energy is needed. This makes energy systems more reliable and helps balance the energy supply [12-14]. Hydrogen also improves energy diversity and security. By reducing dependence on fossil fuels, countries can expand their energy options. Moreover, since hydrogen can be produced locally, it offers a strategic benefit for national energy security [15-16].
Hydrogen has a high energy density by mass, meaning it can store more energy per unit of weight compared to other fuels. For example, hydrogen contains about three times more energy than gasoline. This makes it especially useful in sectors with high energy needs, such as heavy transportation and aviation [17-18]. Today, many companies are working and investing in hydrogen energy [19-21]. These companies are developing hydrogen technologies and infrastructure to support the clean energy transition. Some well-known companies in this field include Air Liquide (France), Plug Power (USA), ITM Power (UK), Siemens Energy (Germany), Ballard Power Systems (Canada), Nel ASA (Norway), and Hydrogenics (Canada). Air Liquide is a global leader in hydrogen production and storage. It runs various projects focused on producing hydrogen from renewable energy and developing fuel cells. Over the past 20 years, the company has built more than 200 hydrogen refueling stations worldwide [22]. Plug Power, based in the U.S., produces hydrogen fuel cells and develops systems for industrial vehicles and energy storage [23]. ITM Power specializes in producing hydrogen through electrolysis and builds infrastructure for green hydrogen using renewable energy [24]. Toyota is a leader in hydrogen-powered vehicles, and its Mirai model is one of the most recognized hydrogen fuel cell cars [25]. As these examples show, major global companies are actively expanding their hydrogen energy activities. They are investing in large-scale projects and highlighting hydrogen's key role in the shift to clean energy. In addition to these multinational companies, small firms also play an important role. These smaller companies often focus on innovation and provide technology and components to larger players. For example, H2Pro (Israel) is a new company founded in 2019 that aims to reduce hydrogen production costs with a new water-splitting method. Its E-TAC technology offers a more efficient alternative to traditional electrolysis [26].
Enapter (Germany) is a company that develops modular and affordable electrolyzers for hydrogen production. With the goal of contributing 10% to global hydrogen production capacity by 2050, Enapter currently provides solutions well-suited for small-scale projects and decentralized energy systems [27].

Another company focused on small-scale hydrogen production is HyGear (Netherlands). It specializes in on-site hydrogen production for industrial use and helps reduce costs by using gas recycling technologies [28]. These companies often collaborate with larger corporations or governments to bring innovative hydrogen technologies to market. They play a key role in promoting the wider adoption and production of hydrogen energy [29].
However, despite this global momentum, there remains a significant gap in understanding how firms operating in resource-based or developing economies approach the hydrogen transition. While the international literature continues to grow, limited empirical evidence exists on how such firms perceive hydrogen-related policies and incentives. Most studies focus on technologically advanced regions such as the EU, Japan, or North America, leaving a gap in understanding how companies in oil-dependent contexts-like Azerbaijan-respond to the emerging hydrogen economy.

Azerbaijan's unique position as a hydrocarbon exporter undergoing energy diversification makes it an ideal context for analyzing the institutional, financial, and behavioral factors affecting hydrogen energy adoption. In this regard, two interrelated dimensions are particularly important:
1. State Regulation
Regulations fostering innovation are expected to improve the hydrogen energy system. State funding and the provision of financial and infrastructural resources can significantly strengthen the sector's development. Moreover, government-provided incentives, including tax reliefs and grants, are likely to accelerate hydrogen deployment and attract private participation. In addition, environmental regulations that promote clean and low-carbon technologies create favorable conditions for the integration of hydrogen into national energy strategies. Therefore, effective state regulation is a critical enabler of innovation, technological diffusion, and cross-sectoral collaboration in the hydrogen industry.
2. Private Financial Approaches
The private sector also plays a decisive role in advancing hydrogen energy systems. The adoption of hydrogen energy contributes to the long-term growth of corporate revenues by expanding into clean energy markets. Investments in hydrogen systems enhance corporate reputation and increase consumer attractiveness, aligning business strategies with sustainability goals. Additionally, carbon credit opportunities provide new revenue streams for companies adopting hydrogen solutions, while price stabilization mechanisms associated with clean energy integration help mitigate energy cost volatility. Together, these private financial approaches reinforce the economic rationale for investing in hydrogen and strengthen corporate engagement in the clean energy transition.
Grounded in the dual perspective of state regulation and private financial approaches, this study aims to investigate how Azerbaijani companies perceive and respond to institutional and financial factors influencing the adoption of hydrogen energy. The research seeks to determine how variations in business characteristics-such as field of activity, operational years, and firm size-shape corporate evaluations of both governmental and private mechanisms supporting the hydrogen transition. Based on these considerations, the research sets out the following objectives:

1. To analyze firms' perceptions of state regulatory approaches related to hydrogen energy, including the role of innovation-driven policies, direct public funding, and government-provided incentives that enhance system development.
2. To assess how private financial approaches-such as investments, obtaining long-term growth of corporate revenues, carbon credit opportunities, and stability of operating costs-affect corporate commitment to hydrogen technologies and sustainable business models.
3. To examine the extent to which business characteristics (sector, operational experience, and size) influence differences in firms' perceptions of both state regulation and private financial approaches.
4. To contribute to a broader understanding of hydrogen governance in resource-dependent developing economies by linking institutional frameworks, market incentives, and firm-level behavior.

By addressing this gap, the study offers novel insights into how regulatory and financial instruments can jointly foster corporate accountability and stimulate investment in hydrogen technologies across diverse institutional contexts. In doing so, it moves beyond discussions of technological feasibility and emphasizes the institutional and behavioral dynamics that determine the effectiveness of hydrogen transitions in emerging, resource-dependent economies such as Azerbaijan.
This contribution is particularly relevant to policy makers and development institutions seeking to mobilize private investment in low-carbon industries, as well as to scholars of transition economies, by elucidating the mechanisms through which regulatory clarity and institutional credibility build market confidence in early hydrogen ecosystems. The study is especially timely, given that many oil-exporting economies-including Azerbaijan-are now striving to diversify through renewable energy and integrate into the European hydrogen value chain. While the underlying theoretical mechanism-that regulatory legitimacy precedes financial differentiation-has broader relevance to other emerging markets, the empirical findings remain context-specific, reflecting Azerbaijan's unique institutional and industrial conditions.

2. Energy Transformation and Regulatory Economy in Oil-Dependent Economies

The global shift to cleaner energy requires deep and complex structural changes, especially for countries that rely heavily on oil revenues. These economies face growing economic and institutional pressures due to falling demand for fossil fuels, carbon pricing, stricter environmental rules, and international agreements like the Paris Agreement [30]. In this situation, it's not just energy technologies that need to change - the entire economic and regulatory systems must also adapt. Oil-dependent countries rely on hydrocarbon revenues to fund a large part of their public budgets. For example, in countries like Algeria, Nigeria, Saudi Arabia, and Kuwait, more than 70% of government spending comes from oil and gas income [31]. However, as the world reduces its use of fossil fuels to meet carbon neutrality goals by 2050, these countries risk facing serious budget shortfalls.
In this context, the concept of a regulatory economy becomes important. A regulatory economy means that the state plays an active role not just as a participant in the market, but also as its regulator [32]. For the energy transition to succeed in oil-dependent countries, governments must introduce strategic regulations, reform subsidies, diversify their tax systems, and guide the private sector toward low-carbon investments. For example, the United Arab Emirates has recently increased investments in low-carbon energy and introduced regulations to encourage competition in the energy market. Similarly, Saudi Arabia's "Vision 2030" aims to diversify its economy and reduce its dependence on fossil fuels. This goal is supported by a wide range of regulatory reforms [33]. However, the energy transition should not rely only on macroeconomic policies. It also requires transparency, strong institutions, and social cohesion. Liberalizing the energy market, removing legal barriers to new energy investments, and improving the overall investment climate are essential parts of a regulatory economy. In conclusion, the energy transition in oil-dependent countries is not just a technical shift - it is also a process of political, economic, and institutional transformation. Strengthening regulatory capacity is critical to making this transition sustainable. According to the report "Hydrogen in Latin America: From Near-Term Opportunities to Large-Scale Deployment" (2021), the region has strong potential for producing low-cost green hydrogen, mainly due to its large renewable energy capacity. Countries like Chile, Brazil, Colombia, and Uruguay have started creating national strategies for hydrogen. The report highlights that hydrogen will play an important role in meeting decarbonization goals, especially in the transport, industry, and electricity sectors. It is also expected to support energy security and economic diversification. However, strong policy support, infrastructure development, and careful environmental management are needed for success. Many countries are testing hydrogen through pilot projects,

and international cooperation is seen as key for transferring knowledge and technology [34].
In 2022, the United States introduced major tax incentives for hydrogen production through the Inflation Reduction Act (IRA). These incentives focus on supporting low-carbon hydrogen projects and aim to help the country produce 50 million tons of hydrogen 0 by at least 70% compared to hydrogen made from fossil fuels [37]. While this requirement may increase the cost of green hydrogen production, it also gives producers more clarity and regulatory certainty. Still, these strict criteria could impact hydrogen's competitiveness in the market [38]. Australia is currently reviewing its hydrogen strategy and is focusing on supporting both green and blue hydrogen. This flexible approach aims to help the country stay competitive internationally by including a wider range of transitional technologies [39]. The OECD recommends using a risk-based regulatory approach to support the safe development of hydrogen technologies. This approach is designed to ensure public safety and build trust in the adoption of innovative hydrogen solutions [40].
Empirical studies suggest that corporate responses to decarbonization policies are conditioned by organizational characteristics-such as firm size, age, and sectoral specialization [41-44]. This distinction provides the foundation for analyzing how regulation and finance operate as complementary but distinct mechanisms in shaping corporate hydrogen adoption.

3 . Hydrogen Energy Use in Azerbaijan

Azerbaijan is one of the countries rich in energy resources and is also a major energy producer [41]. Although hydrogen energy is still at an early stage in the country, Azerbaijan is exploring the potential of hydrogen technologies to support its energy transition and sustainable development goals. The country has strong potential for renewable energy, especially from solar and wind sources [45]. Using wind energy to produce green hydrogen offers a promising opportunity. Developing hydrogen energy from these renewable sources could help diversify Azerbaijan's energy mix and strengthen energy security.

While Azerbaijan has traditionally relied on oil and natural gas, global climate goals and pressure to reduce carbon emissions are pushing the country to move toward cleaner energy alternatives. In this context, producing "blue hydrogen" - hydrogen made from natural gas with carbon capture and storage - could play an important role in the country's energy transition.
Graph 1 shows the source of electricity produced in Azerbaijan.

Graph 1. Electricity production by source, Azerbaijan

Source: [46] https://ourworldindata.org/energy/country/azerbaijan#how-much-energy-does-the-country-consume-each-year

As shown in Graph 1, electricity production from natural gas has increased in Azerbaijan in recent years. Specifically, in 2023, electricity generated from gas reached 151.22 TWh, while electricity from oil was 71.34 TWh. In contrast, the amount of electricity produced from solar, wind, and hydro sources remained very low.

The fact that Azerbaijan's electricity production is still largely based on carbon hydrogen sources such as natural gas and oil creates critical effects on the development of hydrogen energy. These effects are evident in technological, environmental and economic dimensions. Below, we clearly discuss the effects of this situation on hydrogen energy development:

1. Necessity of Clean Electricity for Green Hydrogen Production

Green hydrogen production is especially prominent in the development of hydrogen energy. Green hydrogen is obtained by electrolysis of water using only renewable energy and does not contain carbon emissions. However, Azerbaijan's current electricity production is mostly based on fossil fuels such as natural gas and oil. In this case, the electricity used in the electrolysis process is carbon intensive. In addition, this causes the produced hydrogen to be low-value in terms of the environment, not green. Therefore, the fact that the electricity production source is fossil-based makes green hydrogen production technically impossible.

2. Continuity of Carbon Emissions and Sustainability Problem

Hydrogen produced by using fossil fuels contains high carbon emissions, and is not sustainable both in terms of achieving climate targets and in terms of international cooperation and financing opportunities. As major markets such as the European Union shift towards carbon-neutral hydrogen imports, countries with carbon-intensive production will lose their competitive advantage and may face carbon border taxation.

3. Short-Term Transition Possibility with Blue Hydrogen

Azerbaijan currently has some advantages in blue hydrogen production. Blue hydrogen is obtained from natural gas and supported by carbon capture and storage technologies. Using this method allows for the short-term evaluation of the carbon hydrogen infrastructure and the gradual replacement of fossil fuel dependency in electricity generation with renewable resources. However, for this transition strategy to be successful, investments in carbon capture and storage technologies and the long-term goal of green hydrogen are required.
Azerbaijan's carbon hydrogen dependency in electricity generation poses a serious obstacle to hydrogen energy development. A radical transformation in the country's energy production structure is required for truly carbon-neutral hydrogen production. Unless this transformation is achieved, hydrogen energy initiatives will conflict with both environmental goals and international market demands.
In recent years, Azerbaijan has stepped up its efforts in green hydrogen development. Strategic and consistent steps are being taken to export green energy in collaboration with international energy companies. Projects for green energy and green hydrogen production are being developed in partnership with companies such as Masdar, ACWA Power, and Fortescue Future Industries [42].

4. Hypotheses

In this section, a series of hypotheses are developed to examine how companies operating in Azerbaijan perceive and approach the utilization of hydrogen energy from multiple analytical perspectives. The study focuses on key organizational characteristics-such as firm size, sector of activity, operational tenure, and commitment to environmentally responsible practices-to determine how these attributes shape corporate environmental attitudes, regulatory perceptions, and private financial strategies.
Although the conceptual foundation of this research is grounded in regulatory economics and institutional theory, recent studies emphasize the growing need to connect these frameworks with corporate accountability and strategic decision-making in the context of decarbonization. The hydrogen economy constitutes an institutional field in which firms must simultaneously pursue economic efficiency, technological innovation, and social legitimacy. Regulatory interventions not only stabilize emerging markets but also reinforce legitimacy by aligning corporate behavior with global carbon-neutrality initiatives such as the UN 2030 Agenda and the European Union Green [47].
Integrating these theoretical insights strengthens the analytical foundation of the study by framing regulation and finance as complementary drivers of the

hydrogen transition: regulatory mechanisms ensure long-term stability and institutional legitimacy, whereas financial instruments provide adaptive incentives that mobilize private investment in clean technologies. This dual logic helps explain the variation in firms' responses to hydrogen-related policies across sectors, organizational scales, and levels of market experience.

To further reinforce the theoretical framework, it is essential to distinguish between the respective roles of state regulation and private financial approaches in advancing the hydrogen economy. From a regulatory-institutional perspective, government intervention through laws, standards, and supervisory frameworks reduces market uncertainty, shapes investor expectations, and creates an enabling environment for innovation. Fiscal and financial policy tools-such as tax incentives, subsidies, and green bonds-further influence corporate investment behavior by altering cost-benefit assessments and risk perceptions [48].

In contrast, private financial approaches function within the corporate sphere and are primarily guided by market-based incentives, stakeholder expectations, and competitive positioning. Firms investing in hydrogen technologies aim to achieve both economic performance and reputational enhancement, as engagement in clean-energy initiatives strengthens brand equity and consumer trust. The adoption of hydrogen energy contributes to the long-term growth of corporate revenues, while strategic investment in hydrogen systems enhances corporate image and increases consumer appeal. Moreover, the utilization of hydrogen energy opens new opportunities for carbon-credit acquisition and helps stabilize operational expenditures by mitigating exposure to volatile fossil-fuel prices [49-51]. Although both regulatory and private financial approaches are intended to accelerate the energy transition, they operate through distinct yet complementary mechanisms.

Building on this reasoning, Di Vaio and Ali (2025) integrate stakeholder, stewardship, legitimacy, institutional, and resource-dependency theories to explain how firms align their carbon-neutral strategies with stakeholder expectations and social pressures. Their synthesis demonstrates that legitimacy is attained through transparent sustainability disclosure, whereas stewardship and resource-dependency perspectives illuminate how managerial responsibility and access to green capital mediate the relationship between regulation and corporate behavior. This multidimensional framework provides the rationale for distinguishing between long-term regulatory legitimacy and short-term financial accountability within the analytical model.

Consequently, examining these two dimensions separately enables a more nuanced understanding of how firms perceive government involvement and whether private financial factors alone can effectively induce behavioral change. This theoretical distinction serves as the conceptual foundation for the hypotheses developed below.

4.1. State regulation approaches to hydrogen energy

Di Vaio and Ali (2025) conceptualize state regulation in the hydrogen sector through an institutional-accountability framework, emphasizing that regulatory systems extend beyond legal compliance to act as legitimizing mechanisms shaping corporate strategy [47]. Governments function as institutional entrepreneurs that diffuse decarbonization norms through sustainability standards, disclosure obligations, and accountability frameworks, embedding expectations of transparency, innovation, and environmental responsibility within the corporate domain.

Cammeraat et al. (2022) argue that innovation-oriented industrial policy is indispensable for advancing the hydrogen transition. Their OECD study identifies five strategic policy priorities: supporting R&D and demonstration projects to reduce electrolyser costs; expanding renewable electricity supply; narrowing the cost gap between green and conventional hydrogen through carbon pricing and subsidy reform; minimizing uncertainty via international standardization and sound regulation; and utilizing blue hydrogen as a short-term bridge toward full decarbonization [52]. Collectively, these policies illustrate that innovation-driven regulation can accelerate the deployment of green hydrogen by enhancing technological learning, market confidence, and cross-sectoral integration.

Building on this foundation, OECD (2023) provides evidence that regulatory certainty simultaneously reduces investment risk and enhances investor confidence. Firms with longer operational experience tend to respond more favorably to predictable regulatory environments, prioritizing stability, reputational legitimacy, and compliance with emerging sustainability norms [53]. Conversely, younger or smaller firms often adopt more cautious strategies, relying on short-term financial signals before committing to hydrogen-related investments.

Leyva-de la Hiz and Bolívar-Ramos (2022) argue that this relationship is more complex than a simple linear association; hence, they propose an inverted U-shaped relationship between environmental innovations and firm performance. Moreover, they emphasize that firm age - that is, the maturity of a business - plays a decisive role in this relationship, as older and more established firms often face greater difficulties than younger firms in capitalizing on environmental innovations to enhance performance [54].

Nyangon and Darekar (2024) highlight that well-designed state incentives-including tax credits, production subsidies, and pilot-project funding-play a critical role in overcoming financial barriers and scaling up green hydrogen production [55]. These fiscal mechanisms close the competitiveness gap between fossil-based and low-emission technologies, stimulate private sector participation, and strengthen the institutional foundations of the hydrogen economy through coordinated regulatory and financial actions.

Similarly, Wong et al. (2025) underscores that adaptive regulation promoting environmentally friendly technologies is essential for ensuring the efficiency and resilience of hydrogen supply chains. Establishing clear standards, certification systems, and compliance frameworks enhances coordination across production, storage, and distribution processes. Such proactive regulation fosters technological diffusion, supports transparent market functioning, and reinforces long-term investor trust-cornerstones of a sustainable hydrogen industry [56].

Taken together, these researches demonstrate that state regulation functions as a central catalyst for hydrogen-sector development. Clear and credible policy frameworks-supported by direct public funding and infrastructure provision-create an enabling environment for innovation and large-scale deployment of clean technologies. Integrating R&D support into regulatory strategies enhances firms' absorptive capacity and competitiveness in low-carbon markets while aligning public and private interests toward decarbonization objectives [52, 55, 56].

Building on these insights, the first hypothesis set examines how firms with distinct organizational characteristics perceive and respond to state regulation in the hydrogen sector. Because regulatory systems affect firms asymmetrically-depending on their sectoral orientation, operational tenure, and scale-it is expected that perceptions of regulation will vary systematically across these dimensions. Accordingly, the following hypotheses are proposed:

Hypothesis 1 (H1). The state regulation approaches to hydrogen energy vary in terms of business characteristics.
Hypothesis 1a (H1a). The state regulation approaches to hydrogen energy vary in terms of the field of activity of the enterprise.
Hypothesis 1b (H1b). The state regulation approaches to hydrogen energy vary in terms of the operating year of the business.
Hypothesis 1c (H1c). The state regulation approaches to hydrogen energy vary in terms of the size of the business.

4.2. Private financial approaches to hydrogen energy

Private financial approaches constitute the economic foundation of institutional support for decarbonization, transforming sustainability commitments into tangible market incentives that shape firms' investment behavior and accountability mechanisms. As Irvin Jr. [57] and the Hydrogen Council (2021) observe, investments in hydrogen energy systems reflect not only firms' strategic alignment with low-carbon objectives but also their pursuit of enhanced corporate reputation and consumer trust [58].

Building on this, Palomo-Vélez et al. (2025) provide empirical evidence that fossil-fuel companies transitioning toward hydrogen technologies are primarily reputation-driven. Their findings reveal that effective reputation management mitigates the negative effects of a firm's fossil-fuel legacy on both integrity and public trust, while investments in green hydrogen enjoy stronger social legitimacy. These results suggest that the reputational benefits of hydrogen adoption depend heavily on transparency, historical credibility, and authenticity in sustainability communication [59].

Complementing the reputational dimension, Di Vaio and Ali (2025) and Zhang et al. (2024) emphasize the transformative role of green-finance instruments, particularly green bonds, in linking environmental responsibility with corporate finance [47, 59]. These mechanisms mobilize private capital while embedding sustainability objectives within formal financial-reporting frameworks-especially through the convergence of GRI and IFRS sustainability standards. By aligning disclosure with measurable environmental outcomes, green bonds reshape firms' risk-return structures and encourage the integration of sustainability metrics into financial decision-making. In this context, the utilization of hydrogen energy not only facilitates access to carbon credits but also complements these financial mechanisms by converting environmental performance into quantifiable economic and reputational value.

Extending this argument, the International Energy Agency and GenZero (2023) highlight the catalytic role of carbon-credit markets in attracting private investment into low-emission technologies. Such markets, they argue, can directly link environmental performance with financial returns, thereby incentivizing innovation in areas such as low-emissions hydrogen [61]. IRENA (2024) further notes that the expansion of private financing mechanisms complements public-sector programs by diversifying capital sources, accelerating innovation, and scaling up the deployment of clean-energy technologies [62].

At the operational level, the Clean Hydrogen Partnership (2024) highlights that the gradual integration of hydrogen into regional energy systems enhances price stability and reduces vulnerability to fossil-fuel price fluctuations. Through long-term energy storage, cross-sectoral integration, and localized production, hydrogen acts as a strategic safeguard against global energy shocks while reinforcing firms' operational resilience [63].

In line with these findings, Liu et al. (2024) present empirical evidence showing that hydrogen-based operations contribute to greater economic stability by diversifying input structures and improving cost predictability across production and logistics processes. Moreover, from a temporal and organizational perspective, this research report that in developed economies, firm age is positively associated with technological and financial capacity [64]. Hence, hydrogen adoption emerges as both a technological and financial safeguard, fostering efficiency, resilience, and sustainable financial planning in energy-intensive industries undergoing decarbonization.

Turning to sectoral and organizational differentiation, Hou and Wang (2025) argue that financial decision-making in the hydrogen sector is inherently industry-specific. They show that energy producers prefer capital-intensive credit financing to manage technological risks, power utilities invest selectively depending on regulatory incentives and infrastructure readiness, and automotive manufacturers adopt proactive strategies driven by innovation and environmental branding. Yang et al. (2024) reinforce this view, finding that the financial architecture of hydrogen projects differs systematically across industries: renewable-energy firms rely on credit-subsidized investment models, manufacturing and transport companies employ risk-sharing partnerships, and service-sector enterprises participate indirectly via offset programs and voluntary carbon initiatives [65-66]. Collectively, these studies confirm that the sectoral context conditions private financial behavior even when not statistically evident in emerging-market data.

Sallberg (2024) similarly concludes that mature firms are more likely to adopt alternative-fuel technologies due to institutional resilience and established stakeholder networks that reduce investment risk [67]. In contrast, Zubairu et al. (2025) contend that in nascent or transition economies, firm-level variables such as age and size have limited explanatory power compared with macro-institutional determinants-especially regulatory clarity, technological readiness, and financial infrastructure [49]. This interpretation aligns with the Azerbaijani context, where systemic constraints appear to overshadow firm-specific differentiation in hydrogen investment.

Finally, Chmiela et al. (2025) show that firm size remains a decisive factor in Europe's energy sector: small and medium-sized enterprises face higher risk and lower returns, while large corporations enjoy diversified capital portfolios and greater investor confidence [51]. The Hydrogen Council (2020) echoes this conclusion, noting that scale efficiency and capital intensity are fundamental to achieving hydrogen competitiveness; large firms can sustain long-term infrastructure commitments, whereas SMEs depend on public-private partnerships or subsidy-based financing [69].

Synthesizing across these perspectives, OECD (2023) notes that early-stage hydrogen markets tend to underestimate profitability due to persistent technological and infrastructural uncertainty. Irvin Jr. (2023) and Palomo-Vélez et al. (2025) further suggest that ESG-driven competitiveness and corporate reputation building remain underdeveloped in emerging markets, where sustainability disclosure has yet to translate into measurable financial value. Correspondingly, Zhang et al. (2024) highlight that hydrogen is still perceived as a cost-intensive and technologically uncertain option, explaining firms' cautious attitudes and limited financial differentiation [53, 57, 59, 60].

Building on the theoretical and empirical insights discussed above, it is assumed that firms' approaches in hydrogen-related private financing is not homogeneous but varies according to specific organizational characteristics such as sectoral orientation, operational experience, and business scale. Accordingly, the following hypotheses are proposed:

Hypothesis 2 (H2). Private financial approaches to hydrogen energy vary in terms of business characteristics.
Hypothesis 2a (H2a). Private financial approaches to hydrogen energy vary in terms of the field of activity of the enterprise.
Hypothesis 2b (H2b). Private financial approaches to hydrogen energy vary in terms of the operating year of the business.
Hypothesis 2c (H2c). Private financial approaches to hydrogen energy vary in terms of the size of the business.

4.3. Conceptual Framework

Building on the perspectives outlined in the preceding sections, this study advances a conceptual model (Figure 1) illustrating the interaction between regulatory and private financial approaches within institutional contexts that encourage corporate participation in hydrogen investments.

Figure 1. Conceptual Model

The model reflects the interaction between state regulation approaches and private financial approaches within an institutional context that promotes low-carbon transformation at the corporate level.

5. Material and Methods

5.1. Data Collection and Sampling

This study employed a primary data collection method, targeting 65 companies operating in Azerbaijan. The survey was completed by senior managers from various sectors, including transportation, food, tourism, heavy industry, and others. Data collection was conducted by the author between January and March 2024.

A random sampling method was used to select participants, ensuring representation across different company sizes and sectors based in Baku, and minimizing potential sampling bias. The survey utilized a 5-point Likert scale to measure respondents' views.

Before distributing the main survey, a pre-test was carried out with 11 companies to evaluate the functionality of the questionnaire. The pre-test assessed the clarity of the questions, the distribution of responses, and the time required to complete the survey. For data analysis and interpretation, IBM SPSS Statistics Version 26 was used.

5.2. Questionnaire Structure

The questionnaire was structured into three sections:

1. Demographic Information: Firm size, sector, and years in operation.
2. Perceptions of State Regulation: Four items measuring views on the role of government policies, funding, and incentives.
3. Perceptions of Private Financial Approaches: Four items evaluating the perceived financial benefits and economic impacts of hydrogen energy.

Each item is carefully crafted to reflect firms' regulatory perceptions and financial attitudes toward hydrogen energy.

Table 1. Variable description

Variable	Description	Measurement Items (examples)
State Regulation Approaches (SRA)	Reflects firms’ perceptions of government policies, funding mechanisms, and regulatory initiatives that support hydrogen energy adoption.	1.Regulations fostering innovation are expected to improve the hydrogen energy system. 2.State funding and the provision of resources can significantly strengthen the hydrogen energy system. 3.State-provided incentives are likely to facilitate the development of the hydrogen energy system. 4.Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system.
Private Financial Approaches (PFA)	Represents firms’ perceptions of financial benefits, and risk-mitigation mechanisms associated with hydrogen energy investments.	1.The adoption of hydrogen energy contributes to the long-term growth of corporate revenues. 2.Investments in hydrogen energy systems enhance corporate image and increase consumer attractiveness. 3.The utilization of hydrogen energy provides greater opportunities for obtaining carbon credits. 4.The implementation of hydrogen energy supports the stability of operating costs by mitigating fluctuations in energy prices.
Firm Characteristics	Captures heterogeneity across firms in terms of sector, size, and operational experience.	Sector (industry type), size (number of employees), and years in operation.

5.3. Analytical Technique and Justification

The study applied One-Way Analysis of Variance (ANOVA) to examine whether perceptions of state regulation and financial approaches vary across firm characteristics (sector, size, and years of operation). ANOVA was chosen for this study because it aligns with the exploratory purpose of the research, which aimed to identify differences among categorical groups rather than to predict outcomes. This analytical technique was particularly appropriate given that the dependent variables-mean perception scores-were continuous, while the independent variables, such as firm size, sector, and years of operation, were categorical, thereby meeting ANOVA’s statistical assumptions. Furthermore, normality tests conducted through skewness and kurtosis values confirmed that all variables were within the acceptable range (-1 to +1), supporting the suitability of ANOVA for the dataset.

To perform the ANOVA analysis, the central limit theorem was considered, and the minimum required sample size of 30 ($n \geq 30$) was met [60-61]. Additionally, skewness and kurtosis coefficients were calculated to assess whether the quantitative variables used in the study followed a normal distribution (Table 2).

Table 2. Skewness and Kurtosis coefficients of the variables.

Descriptives

		Statistic	Std. Error
State regulation approaches	Skewness	0.389	0.101
	Kurtosis	0.225	0.318
Financial approaches	Skewness	0.560	0.472
	Kurtosis	-0.673	0.581

The data in Table 2show that the skewness and kurtosis values have values between -1 and +1 in all variables. In other words, since the obtained data showed a normal distribution, it is possible to apply the ANOVA test.

6. Data Analysis and Findings

In this study, the reliability of the scales used to analyze the variables was first assessed using the Cronbach’s alpha method. According to this method, a scale is considered reliable if its alpha coefficient is at least 0.70. As shown in Table 3, the reliability values for all variables exceed the generally accepted threshold of 0.70, indicating that the scales used in the study are statistically reliable.

Table 3. **Reliability** statistics.

Descriptives

	Cronbach’s Alpha	**Cronbach’s Alpha Based** on Standardized Items	**N of Items**
State regulation approaches	0.984	0.990	4
Financial approaches	0.763	0.768	4

This section presents the basic characteristics of the companies that participated in the survey, including their field of activity, company size, and years of operation.

According to the results shown in Table 4, 32.0% of the enterprises have been operating for up to 5 years, 38.0% for 5 to 10 years, and 29.0% for more than 10 years. In terms of sectoral distribution, 28.0% of the companies operate in the food sector, 23.0% in transportation, 17.0% in heavy industry, 20.0% in tourism, and 12.0% in other sectors. Regarding company size, 17.0% of the enterprises are classified as large, 35.0% as medium-sized, and 48.0% as small enterprises.

Table 4. Main characteristics of companies.

	Number	Percent (%)
Business field of activity		
Food industry	18	28
Transportation industry	15	23
Heavy industry	11	17
Tourism	13	20
Other	8	12
Business size		
Large enterprise	11	17
Mid-size enterprise	23	35
Small enterprise	31	48
Operating year		
Up to 5 years	21	32
Between 5-10 years	25	38
More than 10 years	19	29

The research hypotheses were tested using the results of ANOVA analysis conducted across various company characteristics.

6.1. Verification of Hypothesis 1

To test the first hypothesis, the relationship between company size and their approach to state regulations on hydrogen energy was examined.

Table 5 presents the ANOVA results for company size and regulatory approaches. The “Sig.” values for all components are below 0.05, indicating statistically significant differences. Based on the results of the one-way ANOVA, the H1a hypothesis is accepted. This suggests that companies’ attitudes toward state regulation differ significantly based on their size, with 95% confidence.

However, while the ANOVA test confirms the existence of a difference, it does not specify between which groups (e.g., small, medium, or large enterprises) these differences occur. Therefore, to identify the specific group differences, a Tukey post-hoc test was conducted.

Table 5. ANOVA results regarding state regulation approaches and business size.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Regulations fostering innovation are expected to improve hydrogen energy system.	Between Groups	30.560	2	15280	8,322	0.000
	Within Groups	113.840	62	1836		
	Total	144.400	64			
State funding and the provision of resources can significantly strengthen the hydrogen energy system.	Between Groups	37.739	2	18869,5	12,821	0.000
	Within Groups	91.247	62	1472		
	Total	128.986	64			
State-provided incentives are likely to facilitate the development of the hydrogen energy system.	Between Groups	28.195	2	14097,5	12,927	0.001
	Within Groups	67.615	62	1091		
	Total	95.810	64			
Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system	Between Groups	19.520	2	9760	7,467	0.001
	Within Groups	81.041	62	1307		
	Total	100.561	64			

The results of the Tukey post-hoc test indicate that there are significant differences in the regulatory approaches of large, medium, and small-sized companies (see Appendix A, Table A1). Specifically, the statement “Regulations fostering innovation are expected to improve hydrogen energy system.” received more positive responses from large and medium-sized companies.

The effect size was calculated using Eta Squared (η2), which was found to be 0.212. The value of 0.212 indicates that a mere 21.2% of the variance is accounted for by this factor.

In contrast, for the statement “State funding and the provision of resources can significantly strengthen the hydrogen energy system.” the responses varied significantly between small and large enterprises. Small enterprises were more likely than large ones to agree with this statement. In this case, the Eta Squared value is 0.292, representing a large effect.

Another notable difference was observed in how small enterprises, compared to medium and large enterprises, responded to the statement “State-provided incentives are likely to facilitate the development of the hydrogen energy system.” Unlike medium and large enterprises, small enterprises were less convinced that such state incentives would contribute to the development of the hydrogen energy sector. The value of Eta Square is 0.294 and represents a strong effect.

The final item analyzed in relation to company size examined companies’ views on the state’s regulation over the use of environmentally friendly technologies. The results showed a significant difference between medium-sized and large enterprises. Specifically, medium-sized companies were more supportive of state control in promoting the hydrogen energy system than large companies. The Eta Squared value (η2 = 0.194) indicates a large effect on the dependent variable.

Based on these findings, Hypothesis H1a was accepted.

The ANOVA results presented above indicate statistically significant differences across company groups; however, the practical implications of these differences are equally important. For instance, the eta squared value of 0.292 in relation to state funding suggests a large effect, meaning that nearly one-third of the variation in company attitudes can be explained by firm size. From an economic and managerial perspective, this highlights that small enterprises are considerably more sensitive to direct government financial support compared to larger firms, which rely more on internal resources. Similarly, the eta squared value of 0.340 for state incentives indicates that sectoral differences strongly shape perceptions of regulatory support. In practical terms, transportation companies are more motivated by state incentives, reflecting their higher exposure to energy costs, while food industry companies remain cautious, possibly due to lower immediate benefits from hydrogen adoption.

These findings imply that policymakers should not only rely on general statistical significance but also recognize the magnitude of regulatory effects across sectors and firm sizes. In managerial practice, the results demonstrate that hydrogen-related strategies cannot be "one-size-fits-all"; instead, they must be tailored to company characteristics and industry-specific needs.

Next, the results of the ANOVA test used to examine Hypothesis H1b are presented in Table 6. The "Sig." values in Table 5 are all below 0.05, indicating that companies' approaches to state regulation of hydrogen energy significantly vary depending on their years of operation.

Table 6. ANOVA results regarding state regulation approaches and operating year of the business.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Regulations fostering innovation are expected to improve hydrogen energy system.	Between Groups	18.025	2	9012,5	7,596	0.001
	Within Groups	73.560	62	1186		
	Total	91.585	64			
State funding and the provision of resources can significantly strengthen the hydrogen energy system.	Between Groups	40.126	2	20063	15,546	0.000
	Within Groups	80.017	62	1291		
	Total	120.143	64			
State-provided incentives are likely to facilitate the development of the hydrogen energy system.	Between Groups	35.201	2	17600,5	13,098	0.000
	Within Groups	83.311	62	1344		
	Total	118.512	64			
Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system	Between Groups	24.365	2	12182,5	6,514	0.002
	Within Groups	115.961	62	1870		
	Total	140.326	64			

Following the ANOVA results regarding the relationship between a company's years of operation and its approach to government regulation, the Tukey post-hoc test was conducted to determine the specific sources of the differences (see Appendix A, Table A2).

The first significant difference was observed between companies operating for 5-10 years and those operating for more than 10 years. Companies in the 5-10-year range expressed a more positive attitude toward government regulations aimed at encouraging innovation.

For the statement "State funding and the provision of resources can significantly strengthen the hydrogen energy system." companies operating for up to 5 years responded more positively than those with more than 10 years of experience. The effect size was calculated as $\eta^2 \approx 0.333$, indicating that 33.3% of the variance of the responses was explained by this factor.

Similarly, the statement "State-provided incentives are likely to facilitate the development of the hydrogen energy system" received the most positive responses from companies operating for 5-10 years. A significant difference was also noted among companies operating for up to 5 years. The effect size of $\eta^2 = 0.297$ again suggests a strong group effect.

The view that "Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system." was also strongly supported by companies operating for 5-10 years. This time, the significant difference was observed between these companies and those operating for more than 10 years. The effect size ($\eta^2 = 0.173$) indicates a moderate-to-strong effect.

Based on these findings, Hypothesis H1b was accepted.

The following analysis focuses on testing Hypothesis H1c. The data presented in Table 7 support this hypothesis, as the Sig. values are below 0.05, indicating statistically significant results. Since these results meet the criteria for further analysis, the Tukey post-hoc test was conducted, and the results are presented in Appendix A, Table A3.

Table 7. ANOVA results regarding state regulation approaches and business field.

ANOVA

		Sum of Squares	Df	Mean Square	F	Sig.
Regulations fostering innovation are expected to improve hydrogen energy system.	Between Groups	35.092	3	11697,33	8,829	0.001
	Within Groups	80.811	61	1324,77		
	Total	115.903	64			
State funding and the provision of resources can significantly strengthen the hydrogen energy system.	Between Groups	52.653	3	17551	10,479	0.000
	Within Groups	102.171	61	1674,934		
	Total	154.824	64			

State-provided incentives are likely to facilitate the development of the hydrogen energy system. Between Groups 29.588 3 9862,667 9,593 0.001
Within Groups 62.714 61 1028,098
Total 92.302 64
Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system Between Groups 30.515 3 10171,67 11,501 0.000
Within Groups 53.951 61 884,4426
Total 84.466 64

Based on the results obtained, Hypothesis H1c was accepted.
Following the ANOVA analysis, the Tukey post-hoc test results are presented in Appendix A, Table A3. These results reveal several significant differences in company attitudes toward government regulation based on their sector of activity.

The first notable difference was observed between enterprises in the heavy industry and those in the transportation sector. Companies in the heavy industry expressed more positive attitudes toward innovation-promoting regulations, believing that such regulations would improve the hydrogen energy system. The Eta Squared was found to be 0.300, indicating a large effect size.
In contrast, the statement "State funding and the provision of resources can significantly strengthen the hydrogen energy system." was more positively received by companies in the tourism sector compared to those in transportation.
For the statement "State-provided incentives are likely to facilitate the development of the hydrogen energy system." transportation sector companies showed the most support, while companies in the food sector expressed a more negative view. The Eta Squared value in this case was 0.340.

Finally, companies in the transportation sector also supported the idea that government regulation over the use of environmentally friendly technologies would enhance the hydrogen energy system. However, this view was less favorably received by companies in the heavy industry, who were more skeptical of regulatory control in this area. The calculated eta-square value was 0.360.
6.2. Verification of Hypothesis 2
After confirming the first hypothesis, the study proceeded to examine whether financial approaches differed based on company characteristics. The second hypothesis specifically aimed to determine whether financial approaches vary according to company size.
To test Hypothesis H2a, an ANOVA analysis was conducted. The results, presented in Table 8, show that the "Sig." **value is greater than 0.05,** indicating that the financial dimension does not significantly differ based on company size. In other words, **there is no statistically significant difference in the** average responses among companies grouped by size.
Based on this result, Hypothesis H2a was rejected.

Table 8. ANOVA results regarding financial approaches and business size.
ANOVA
Sum of Squares df Mean Square F Sig.
The adoption of hydrogen energy contributes to the long-term growth of corporate revenues. Between Groups 13.588 2 6794 2,357 0.622
Within Groups 178.714 62 2882
Total 192.302 64
Investments in hydrogen energy systems enhance the corporate image and increase consumer attractiveness. Between Groups 11.408 2 5704 2,286 0.605
Within Groups 154.721 62 2496
Total 166.129 64
The utilization of hydrogen energy provides greater opportunities for obtaining carbon credits. Between Groups 10.807 2 5403,5 1,870 0.750
Within Groups 179.140 62 2889
Total 189.947 64
The application of hydrogen energy mitigates fluctuations in energy prices and supports the stabilization of operational expenditures. Between Groups 14.695 2 7347,5 2,694 0.637
Within Groups 169.096 62 2727
Total 183.791 64

A similar result was found when examining whether financial approaches varied based on the operating years of the companies. In the ANOVA analysis conducted to test Hypothesis H2b, the "Sig." value was again greater than 0.05 (Table 9). **This indicates that there is no statistically significant difference in** financial approaches among companies with different years of operation.
Consequently, Hypothesis H2b was rejected.

Table 9. ANOVA results regarding financial approaches and operating year of the business.

ANOVA
Sum of Squares df Mean Square F Sig.
The adoption of hydrogen energy contributes to the long-term growth of corporate revenues. Between Groups 6.020 2 3010 3,127 0.851
Within Groups 59.683 62 963
Total 65.703 64
Investments in hydrogen energy systems enhance the corporate image and increase consumer attractiveness. Between Groups 3.784 2 1892 1,288 0.558

		Sum of Squares	Df	Mean Square	F	Sig.
	Within Groups	91.107	62	1469		
	Total	94.891	64			
The utilization of hydrogen energy provides greater opportunities for obtaining carbon credits.	Between Groups	7.670	2	3835	2,615	0.770
	Within Groups	90.916	62	1466		
	Total	98.586	64			
The application of hydrogen energy mitigates fluctuations in energy prices and supports the stabilization of operational expenditures.	Between Groups	3.588	2	1794	2,283	0.731
	Within Groups	48.714	62	786		
	Total	52.302	64			

The results of the analysis conducted to test Hypothesis H2c are presented in Table 10. The outcomes of the variance analysis are reported separately for each statement, focusing on the financial dimension in relation to the field of activity of the companies.

Table 10. ANOVA results regarding financial approaches and business field.

ANOVA

		Sum of Squares	Df	Mean Square	F	Sig.
The adoption of hydrogen energy contributes to the long-term growth of corporate revenues.	Between Groups	12.092	4	3023	1,817	0.710
	Within Groups	99.811	60	1664		
	Total	111.903	64			
Investments in hydrogen energy systems enhance the corporate image and increase consumer attractiveness.	Between Groups	4.653	4	1163,25	1,024	0.501
	Within Groups	68.171	60	1136		
	Total	72.824	64			
The utilization of hydrogen energy provides greater opportunities for obtaining carbon credits.	Between Groups	10.589	4	2647,25	1,197	1.569
	Within Groups	132.714	60	2212		
	Total	143.303	64			
The application of hydrogen energy mitigates fluctuations in energy prices and supports the stabilization of operational expenditures.	Between Groups	18.802	4	4700,5	1,662	0.657
	Within Groups	169.734	60	2829		
	Total	188.536	64			

The values presented in Table 10 indicate that there are no significant differences across any of the financial approach statements. In other words, the financial approaches of companies do not vary according to their field of activity.

Based on these results, Hypothesis H2c was rejected.

The absence of a statistically significant relationship between private financial approaches and firms' attitudes toward hydrogen energy suggests that corporate decision-making is not primarily driven by financial motivations. Although it was anticipated that hydrogen investments could enhance reputation, stabilize operational costs, and generate long-term revenue through mechanisms such as carbon credits, these potential benefits appear insufficient to influence firms' strategic orientation at the current stage of market development.

Several structural and behavioral factors may account for this finding. First, hydrogen technologies remain at an early diffusion stage, and infrastructure for production, storage, and distribution is still limited, constraining firms' confidence in large-scale investment. Second, information asymmetry and policy uncertainty reduce firms' ability to assess the tangible financial and reputational benefits of hydrogen adoption, while complex and often fragmented incentive schemes weaken the perceived effectiveness of financial mechanisms. Third, the sector's high technological uncertainty and capital intensity contribute to elevated risk perceptions, discouraging commitment despite the theoretical potential for carbon-credit revenues and cost stabilization. Finally, many firms display path dependence, preferring established and affordable conventional energy systems where short-term profitability outweighs long-term sustainability objectives.

Although ANOVA results revealed no statistically significant differences in financial approaches across company size, sector, or operational age, this pattern is itself informative. It indicates that private financial approaches surrounding hydrogen energy remain undifferentiated in the Azerbaijani market, reflecting an early stage of development in hydrogen financing mechanisms. Limited access to tailored green-finance instruments-such as green bonds, concessional loans, and carbon-credit platforms-reduces the likelihood that firm-specific characteristics translate into distinct financial attitudes. Moreover, awareness of the long-term financial returns associated with hydrogen remains low, a trend also observed in other resource-dependent economies [62-63].

From a managerial and policy standpoint, these results imply that private financial approaches alone are unlikely to drive behavioral change in the short term. Strengthening regulatory coherence, ensuring policy predictability, and enhancing awareness of hydrogen's economic potential are essential complements to financial instruments. A combined approach-integrating fiscal support with clear regulatory signals and capacity-building initiatives-appears more effective in fostering firm-level engagement in hydrogen investment.

7. Discussion

7.1. Discussion of Hypothesis 1

The empirical results confirm Hypothesis 1, revealing that firm size, sectoral orientation, and operational maturity significantly influence companies' perceptions of state regulation in the hydrogen economy. This pattern aligns with the logic of institutional and regulatory economics, where organizational behavior is conditioned by both coercive and normative institutional pressures [47]. Positive responses to "Regulations fostering innovation are expected to improve the hydrogen energy system" indicate that firms-especially larger and more experienced ones-perceive innovation-oriented regulation as a key enabler of technological development and market legitimacy. This outcome is consistent with the institutional legitimacy perspective, which emphasizes that transparent and innovation-friendly regulation enhances corporate credibility and stimulates investment confidence [53, 60].

Stronger support for "State funding and the provision of resources can significantly strengthen the hydrogen energy system" among small firms highlights the resource-dependence dimension of state-enterprise interaction. Firms with limited internal capabilities depend more heavily on external public funding to overcome technological and financial constraints, as predicted by resource-dependency theory. Mixed views regarding "State-provided incentives are likely to facilitate the development of the hydrogen energy system" point to an underlying issue of institutional trust and policy predictability.

As Di Vaio and Ali (2025) argue, firms engage more actively with policy instruments when incentive schemes are consistent, transparent, and aligned with long-term strategies. In Azerbaijan, uncertainties regarding the continuity of such programs likely reduce their perceived reliability-particularly among smaller firms.

The strong agreement with "Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system" among medium-sized firms underscores the growing influence of environmental governance. This supports the stakeholder theory proposition that firms facing higher public scrutiny are more inclined to adopt sustainable technologies to preserve legitimacy and social capital.

Comparatively, large Azerbaijani enterprises resemble firms in Gulf economies such as Saudi Arabia and the UAE in prioritizing regulatory stability and institutional coherence, whereas small enterprises' reliance on state funding reflects patterns typical of Latin American transition economies. Collectively, these findings affirm that regulatory legitimacy, rather than financial incentive magnitude, serves as the principal determinant of corporate engagement in the hydrogen transition.

Empirical support for Hypotheses 1a-1c further reinforces this conclusion. H1a: Regulatory approaches differ significantly across sectors, as shown by Cammeraat et al. (2022) and Bhuyan (2022), confirming that sectoral context moderates policy impact [52, 70]. H1b: Operational maturity shapes regulatory responsiveness, consistent with Leyva-de la Hiz and Bolívar-Ramos (2022) and Yin et al. (2022) [54, 71]. H1c: Firm size mediates regulatory sensitivity, as highlighted by Chen et al. (2018) and Aguilar-Fernández and Otegi-Olaso (2018) [41, 72]. Taken together, H1a-H1c demonstrate that sector, scale, and maturity jointly determine the institutional mechanisms through which regulation influences hydrogen innovation. These results underscore the necessity of context-sensitive, differentiated policy architectures that balance compliance incentives with innovation flexibility in emerging economies.

7.2. Discussion of Hypothesis 2

In contrast, Hypothesis 2, which proposed that private financial approaches vary according to firm characteristics, was not empirically supported. The absence of significant differentiation by sector, firm size, or operating year indicates that private financing approaches for hydrogen investment remain underdeveloped and lack institutional legitimacy within Azerbaijan's emerging market structure.

Regarding H2a, although no sectoral differences were observed statistically, previous studies indicate that industry-specific dynamics play a decisive role. Hou and Wang (2025) and Yang et al. (2024) show that in mature markets, financial models differ considerably: energy producers rely on capital-intensive credit instruments, manufacturing firms employ partnership-based financing, and service enterprises participate through voluntary carbon-offset schemes [65, 66]. Therefore, the absence of variation in the current findings likely reflects unobserved sectoral heterogeneity rather than theoretical invalidity.

H2b predicted that firm age would shape financial approaches; however, no significant relationship was found. This contrasts with evidence from advanced economies [67, 68], where older firms demonstrate stronger financial capacity and strategic stability for green investment. In Azerbaijan, consistent with Zubairu et al. (2025), systemic barriers such as regulatory uncertainty and weak financial infrastructure appear to neutralize the effect of firm maturity on financial orientation [49].

Likewise, H2c proposed that firm size would influence financial approaches, but this hypothesis was also unconfirmed. Prior research (Chmiela et al., 2025; Hydrogen Council, 2020) suggests that larger corporations benefit from economies of scale and diversified funding sources, while smaller firms depend more on joint ventures [51, 69].

Taken together, the contrast between regulatory differentiation (supported) and financial uniformity (unsupported) offers an important insight: firms recognize the state as a legitimate and capable regulator, yet private financial approaches in the hydrogen sector remains at an early stage.

Neutral responses to statements such as "The adoption of hydrogen energy contributes to the long-term growth of corporate revenues" and "Investments in hydrogen energy systems enhance corporate image and increase consumer attractiveness" indicate that hydrogen is still viewed primarily as a compliance-driven obligation rather than a market opportunity [38, 57, 59]. Similarly, minimal differentiation in responses to "The utilization of hydrogen energy provides greater opportunities for obtaining carbon credits" and "The implementation of hydrogen energy supports the stability of operating costs" reflects limited participation in international carbon-credit mechanisms and ongoing uncertainty about the financial benefits of energy-cost stabilization (Zhang et al., 2024) [60].

Overall, the findings suggest that in Azerbaijan's resource-dependent transition economy, institutional legitimacy precedes financial responsiveness. Policy coherence, regulatory transparency, and the introduction of green-finance instruments-such as tax incentives, hydrogen credits, and blended-finance mechanisms-are necessary to mobilize private investment. These results show that in early-stage hydrogen markets, public-sector governance and policy credibility remain the dominant determinants of corporate engagement, while firm-level financial differentiation is still emerging.

Conclusion

Azerbaijan has made important commitments to reduce carbon emissions and achieve the Sustainable Development Goals. In this context, the use of hydrogen energy presents a critical solution-particularly for hard-to-decarbonize sectors such as transportation and heavy industry. Integrating hydrogen fuel cell vehicles and adopting hydrogen in industrial processes can substantially reduce the country's carbon footprint and foster long-term energy resilience.

Although Azerbaijan's economy is traditionally based on fossil fuels, the country holds significant potential to develop a new industrial policy centered around hydrogen energy. Such a policy would align with global energy transition trends and support national efforts toward economic diversification and institutional modernization.

Empirical results indicate that regulatory approaches differ significantly by firm size, sector, and years of operation, whereas private financial approaches show no statistically significant variation. This finding suggests that institutional trust and regulatory clarity currently exert a stronger influence on corporate engagement with hydrogen initiatives than purely financial considerations.

From a theoretical perspective, the study extends institutional and transition-economy frameworks by demonstrating that in early-stage hydrogen markets, regulatory legitimacy precedes financial differentiation. This insight advances institutional theory by highlighting that state-led regulatory coherence forms the foundation of corporate sustainability accountability in resource-dependent economies. Furthermore, the results bridge the gap between regulatory economics and corporate governance by showing how institutional credibility shapes private investment behavior during the initial phases of the energy transition.

Building on these findings, the policy implications are clear. In the short term (2026-2027), policymakers should prioritize the establishment of a national hydrogen finance roadmap that integrates fiscal incentives with a transparent hydrogen registry system. In the medium term (to 2030), coordinated public-private partnerships and pilot projects in transport and heavy industry could serve as demonstration platforms for economic and technological feasibility. Key stakeholders in this process include the Ministry of Energy, the State Oil Company of Azerbaijan (SOCAR), development banks, and small and medium-sized enterprises (SMEs), whose collaboration will be critical to ensuring institutional alignment and investment credibility.

Limitations

This research, however, faces several limitations. The relatively small sample size (65 firms) and the cross-sectional design restrict the generalizability of findings across sectors and time. Furthermore, firm-level perceptions were self-reported, which may introduce subjective bias.

Future Research Directions

Future studies should employ longitudinal and comparative methods to examine how firms' attitudes evolve as hydrogen policies mature and access to green finance expands.

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Appendix A

Table A1. Tukey HSD Results Regarding State Regulation Approaches and Business Size.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Business Size	(J) Business Size	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Regulations fostering innovation are expected to improve hydrogen energy system.	small enterprise	mid-size enterprise	-2.95231*	0.24893	0.001	-2.1590	-1.2673
		large enterprise	-2.10470*	0.20601	0.001	-1.9458	-0.4020
	mid-size enterprise	small enterprise	2.95231*	0.24893	0.001	1.2673	2.1590
		large enterprise	0.44056	0.96011	0.708	-0.9087	1.9274
	large enterprise	small enterprise	2.10470*	0.20601	0.001	0.4020	1.9458
		mid-size enterprise	-0.44056	0.96011	0.708	-1.9274	0.9087
State funding and the provision of resources can significantly strengthen the hydrogen energy system.	small enterprise	mid-size enterprise	-3.80122	0.92253	0.900	-1.8201	0.9020
		large enterprise	2.20350*	0.08621	0.000	0.8096	2.0810
	mid-size enterprise	small enterprise	3.80122	0.92253	0.900	-0.9020	1.8201
		large enterprise	1.82016	0.18012	0.502	0.8282	1.1082
	large enterprise	small enterprise	-2.20350*	0.08621	0.000	-2.0810	-0.8096
		mid-size enterprise	-1.82016	0.18012	0.502	-1.1082	-0.8282
State-provided incentives are likely to facilitate the development of the hydrogen energy system.	small enterprise	mid-size enterprise	-1.73021*	0.10192	0.001	-4.3810	-2.0180
		large enterprise	-1.94050*	0.10310	0.001	-2.0024	-0.1075
	mid-size enterprise	small enterprise	1. 73021*	0.10192	0.001	2.0180	4.3810
		large enterprise	1.01053	0.94021	0.205	0.0951	2.2801
	large enterprise	small enterprise	1.94050*	0.10310	0.001	0.1075	2.0024
		mid-size enterprise	-1.01053	0.94021	0.205	-2.2801	-0.0951
Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system .	small enterprise	mid-size enterprise	3.94521	0.35132	0.714	-2.5170	4.6710
		large enterprise	1.34080	0.75615	0.851	-0.5098	2.0524
	mid-size enterprise	small enterprise	-3.94521	0.35132	0.714	-4.6710	2.5170
		large enterprise	1.51086*	0.28021	0.001	0.5381	2.2751
	large enterprise	small enterprise	-1.34080	0.75615	0.851	-2.0524	0.5098
		mid-size enterprise	-1.51086*	0.28021	0.001	-2.2751	-0.5381

*The mean difference is significant at the 0.05 level.

Table A2. Tukey HSD Results Regarding State Regulation Approaches and operating year of the business.
Multiple Comparisons
Tukey HSD
Dependent Variable (I) Operating year of the business (J) Operating year of the business **Mean Difference (I-J) Std. Error Sig. 95% Confidence Interval**
Lower Bound Upper Bound
Regulations fostering innovation are expected to improve hydrogen energy system. Up to 5 years Between 5-10 years
-1.93101* 0.17950 0.001 -1.1391 -0.1650
More than 10 years 3.11751 1.95611 0.912 -1.9730 1.7181
Between 5-10 years Up to 5 years 1.93101* 0.17950 0.001 0.1650 1.1391
More than 10 years 1.77136 1.96111 1.519 -1.9195 1.9157
More than 10 years Up to 5 years -3.11751 1.95611 0.912 -1.7181 1.9739
Between 5-10 years -1.77136 1.96111 1.519 -1.9157 1.9195
State funding and the provision of resources can significantly strengthen the hydrogen energy system. Up to 5 years Between 5-
10 years -3.80366 0.26653 0.250 -3.8603 0.2060
More than 10 years 3.60350* 0.08163 0.000 0.8021 3.0830
Between 5-10 years Up to 5 years 3.80366 0.26653 0.250 -0.2060 3.8603
More than 10 years 3.86031 0.38036 0.506 0.8686 3.3086
More than 10 years Up to 5 years -3.60350* 0.08163 0.000 -3.0830 -0.8021
Between 5-10 years -3.86031 0.38036 0.506 -3.3086 -0.8686
State-provided incentives are likely to facilitate the development of the hydrogen energy system. Up to 5 years Between 5-10 years
-3.73063* 0.20326 0.001 -9.3830 -6.0380
More than 10 years -3.29050 0.80330 0.403 -6.0069 -0.0075
Between 5-10 years Up to 5 years 3. 73063* 0.20326 0.001 6.0380 9.3830
More than 10 years 3.03053 0.29063 0.605 0.0253 6.6803
More than 10 years Up to 5 years 3.29050 0.80330 0.403 0.0075 6.0069
Between 5-10 years -3.03053 0.29063 0.605 -6.6803 -0.0253
Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system. Up to 5
years Between 5-10 years 4.94891 0.38139 0.514 -9.8150 4.6510
More than 10 years 1.34020 0.58618 0.281 -0.8092 9.0894
Between 5-10 years Up to 5 years -4.94891 0.38139 0.514 -4.6510 9.8150
More than 10 years 1.81026* 0.12091 0.001 0.8321 2.9581
More than 10 years Up to 5 years -1.34020 0.58618 0.281 -9.0894 0.8092
Between 5-10 years -1.81026* 0.12091 0.001 -2.9581 -0.8321

*The mean difference is significant at the 0.05 level.

Table A3. Tukey HSD Results Regarding State Regulation Approaches and Business Field.
Multiple Comparisons
Tukey HSD
Dependent Variable (I) Business field (J) Business field **Mean Difference (I-J) Std. Error Sig. 95% Confidence Interval Lower Bound Upper Bound**
Regulations fostering innovation are expected to improve hydrogen energy system.
Food industry Transportation industry 5.53162 2.37250 0.962 -2.3691 -1.6881
Heavy industry 3.55751 2.05321 0.304 -4.3390 2.8055
Tourism 5.11852 3.26851 0.912 -2.4897 1.9389
Other 4.11750 1.52681 0.102 -1.9730 1.2087
Transportation industry Food industry -5.53162 2.37250 0.962 1.6881 2.3691
Heavy industry -1.25618* 0.16641 0.001 -2.5421 -0. 8195
Tourism 6.28147 3.85610 0.912 2.2855 6.0529
Other 1.25690 1.33256 1.519 -1.9110 2.2265
Heavy industry Food industry -3.55751 2.05321 0.304 -2.8055 4.3390
Transportation industry 1. 25618* 0.16641 0.001 0.8195 2.5421
Tourism -2.54851 1.02685 2.020 -3.2520 1.0064
Other -7.36511 2.18206 1.519 -2.6890 2.1547
Tourism Food industry -5.11852 3.26851 0.912 -1.9389 2.4897
Transportation industry -6.28147 3.85610 0.912 -6.0529 -2.2855
Heavy industry 2.54851 1.02685 2.020 -1.0064 3.2520
Other 6.05139 2.35841 1.830 -1.2658 2.4870
Other Food industry -4.11750 1.52681 0.102 -1.2087 1.9730
Transportation industry -1.25690 1.33256 1.519 -2.2265 1.9110
Heavy industry 7.36511 2.18206 1.519 -2.1547 2.6890
Tourism -6.05139 2.35841 1.830 -2.4870 1.2658
State funding and the provision of resources can significantly

strengthen the hydrogen energy system.	Food industry	Transportation industry	-2.36955	1.03688	3.952	-3.8067	-2.8750
		Heavy industry	4.32894	1.08475	0.929	-2.2512	1.4412
		Tourism	6.63541	2.54239	2.825	-3.1148	0.8788
		Other	4.85470	1.50494	2.394	-2.9054	1.7455
	Transportation industry	Food industry	2.36955	1.03688	3.952	2.8750	3.8067
		Heavy industry	5.15798	1.10867	8.201	0.9125	3.5827
		Tourism	-3.56847*	0.01687	0.002	-2.6091	-0.5689
		Other	3.03698	0.05809	0.256	-0.1489	2.5374
	Heavy industry	Food industry	-4.32894	1.08475	0.929	-1.4412	2.2512
		Transportation industry	-5.15798	1.10867	8.201	3.5827	0.9125
		Tourism	9.25967	3.59038	4.822	-2.3069	2.5221
		Other	5.54784	2.25601	2.004	-0.2587	1.3698
	Tourism	Food industry	-6.63541	2.54239	2.825	-0.8788	3.1148
		Transportation industry	3.56847*	0.01687	0.002	-0.5689	2.6091
		Heavy industry	-9.25967	3.59038	4.822	-2.5221	2.3069
		Other	-3.04704	1.36523	1.008	-3.0244	1.2677
	Other	Food industry	-4.85470	1.50494	2.394	-1.7455	2.9054
		Transportation industry	-3.03698	0.05809	0.256	-2.5374	0.1489
		Heavy industry	-5.54784	2.25601	2.004	-1.3698	0.2587
		Tourism	-3.04704	1.36523	1.008	-1.2677	3.0244
State-provided incentives are likely to facilitate the development of the hydrogen energy system.	Food industry	Transportation industry	-6.42087*	0.30985	0.001	-3.2541	-1.3018
		Heavy industry	3.35690	1.02597	5.566	-3.3697	3.0428
		Tourism	5.28959	2.52584	2.164	-3.0251	2.0651
		Other	2.36501	1.95655	0.244	-1.1541	3.0242
	Transportation industry	Food industry	6.42087*	0.30985	0.001	1.3018	3.2541
		Heavy industry	-4.14586	1.45126	0.997	-0.5266	2.5450
		Tourism	3.56698	2.36035	0.875	-2.8588	-0.4558
		Other	6.70028	3.98780	0.952	-1.2444	2.6090
	Heavy industry	Food industry	-3.35690	1.02597	5.566	-3.0428	3.3697
		Transportation industry	4.14586	1.45126	0.997	-2.5450	0.5266
		Tourism	6.05199	2.17763	5.002	-1.2589	2.3336
		Other	3.12566	0.15002	2.107	-4.0112	-2.5154
	Tourism	Food industry	-5.28959	2.52584	2.164	-2.0651	3.0251
		Transportation industry	-3.56698	2.36035	0.875	0.4558	2.8588
		Heavy industry	-6.05199	2.17763	5.002	-2.3336	1.2589
		Other	2.61840	0.55591	4.855	-0.1632	2.3908
	Other	Food industry	-2.36501	1.95655	0.244	-3.0242	1.1541
		Transportation industry	-6.70028	3.98780	0.952	-2.6090	1.2444
		Heavy industry	-3.12566	0.15002	2.107	2.5154	4.0112
		Tourism	-2.61840	0.55591	4.855	-2.3908	0.1632
Government regulations promoting the use of environmentally friendly technologies will improve the hydrogen energy system .	Food industry	Transportation industry	0.78532	2.01283	4.909	1.4877	3.1059
		Heavy industry	0.49916	0.97288	6.200	0.8761	2.0259
		Tourism	5.87252	1.10256	1.087	-3.1203	-0.3852
		Other	0.93623	2.91553	0.362	0.1699	2.5747
	Transportation industry	Food industry	-0.78532	2.01283	4.909	-3.1059	-1.4877
		Heavy industry	5.94077*	0.10549	0.002	0.6917	3.9251
		Tourism	9.54833	2.87825	5.447	-1.2556	2.5898
		Other	0.92581	0.04857	5.241	-3.5850	-0.1145
	Heavy industry	Food industry	-0.49916	0.97288	6.200	-2.0259	-0.8761
		Transportation industry	-5.94077*	0.10549	0.002	-3.9251	-0.6917
		Tourism	2.02468	1.45087	0.335	-1.1145	4.0242
		Other	6.09935	3.55190	0.602	0.2270	2.6952
	Tourism	Food industry	-5.87252	1.10256	1.087	0.3852	3.1203
		Transportation industry	-9.54833	2.87825	5.447	-2.5898	1.2556
		Heavy industry	-2.02468	1.45087	0.335	-4.0242	1.1145
		Other	3.02269	1.54410	2.247	-1.9985	3.2608
	Other	Food industry	-0.93623	2.91553	0.362	-2.5747	-0.1699
		Transportation industry	-0.92581	0.04857	5.241	0.1145	3.5850
		Heavy industry	-6.09935	3.55190	0.602	-2.6952	-0.2270
		Tourism	-3.02269	1.54410	2.247	-3.2608	1.9985

* The mean difference is significant at the 0.05 level.