

Article

Driving the Hydrogen Energy Economy toward Carbon Neutrality: A Financial and Accounting Perspective on Cost, Risk, and Financing

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Abstract: Against the backdrop of global carbon neutrality, the hydrogen energy industry serves as a critical pillar in the low-carbon energy transition. However, it faces prominent financial and accounting challenges, including incomplete cost accounting systems, high financial risks, difficult financing, and immature carbon accounting mechanisms. This study starts from the perspective of finance and accounting, identifies key constraints in cost management, risk control, financing models, and carbon accounting of hydrogen energy enterprises. We adopt annual panel data from representative hydrogen energy firms collected from corporate annual reports and the Wind database, and apply the two-way fixed effects model for regression analysis. Combined with the volatility characteristics of the US Hydrogen Index, this paper carries out empirical examinations to verify the interrelations between core variables. This study constructs a unified financial accounting analysis framework for the hydrogen energy industry, integrates industry volatility and green hydrogen features to revise traditional accounting logic, and provides targeted solutions. The conclusions can help enterprises reduce costs, mitigate risks, improve financial management, and provide a theoretical and empirical basis for industrial policy formulation.

Keywords: hydrogen energy industry; financial management; cost accounting; financial risk; carbon accounting; financing strategy

1. Introduction

In the context of global efforts to address climate change and promote energy transition, hydrogen energy, as a clean, efficient and renewable secondary energy source, has received widespread attention from countries all over the world [1]. Unlike traditional fossil fuels, hydrogen does not produce direct greenhouse gas emissions during its usage. If produced through renewable energy pathways, its entire value chain has almost no carbon emissions. It is an important support for achieving carbon neutrality goals in sectors such as steel, chemicals, and heavy transportation, which are difficult to reduce emissions [2]. According to data from the International Energy Agency (IEA), to achieve the global net-zero emissions target, the demand for low-carbon hydrogen will reach 1.5 billion tons by 2030, and over 1 trillion US dollars of investment will be needed for production, infrastructure, and the construction of end-use facilities [3]. However, the hydrogen energy industry is still in its early stage of industrialization, and its development is constrained by many factors. Among them, financial management and accounting are the key links [4].

The hydrogen energy industry has the characteristics of high initial investment, long investment recovery period, strong technical uncertainty and strong policy interconnection, which makes its financial and accounting



work more complex compared to traditional industries [5]. From the perspective of cost management, the production, storage, transportation and application of hydrogen involve multiple links, and the cost composition is complex. Currently, there is no unified cost accounting standard within the industry, which leads to an unclear direction for enterprises to control costs [6]. From the perspective of financial risks, fluctuations in raw material prices (such as natural gas and renewable electricity), uncertainties in technological iterations, and changes in policy support and policies all pose significant financial risks for hydrogen energy enterprise [7]. From the perspective of financing, the high investment intensity and long recovery period make it difficult for hydrogen energy enterprises to obtain financing and the financing costs are relatively high [8]. Furthermore, with the continuous deepening of global carbon accounting and carbon trading, how to conduct carbon accounting and reflect the carbon reduction value of hydrogen energy in financial statements has become an important issue faced by hydrogen energy enterprises [9].

Finance and accounting, as the core of enterprise management, play a significant role in optimizing resource allocation, controlling costs, mitigating risks, and supporting decision-making [10]. For the hydrogen energy industry, strengthening financial and accounting management can not only help enterprises reduce operating costs and enhance economic benefits, but also assist them in attracting investments and promoting the industrialization process [11]. At present, there are relatively few studies on the integration of the hydrogen energy industry and financial accounting. Most of the research focuses on the technical and policy aspects of hydrogen energy, while neglecting the significant role of financial accounting in the development of this industry [12]. Therefore, based on the core knowledge of finance and accounting, studying the financial accounting management issues in the hydrogen energy industry holds significant theoretical and practical importance for promoting the healthy development of the hydrogen energy industry.

The research framework of this article is shown in Figure 1.

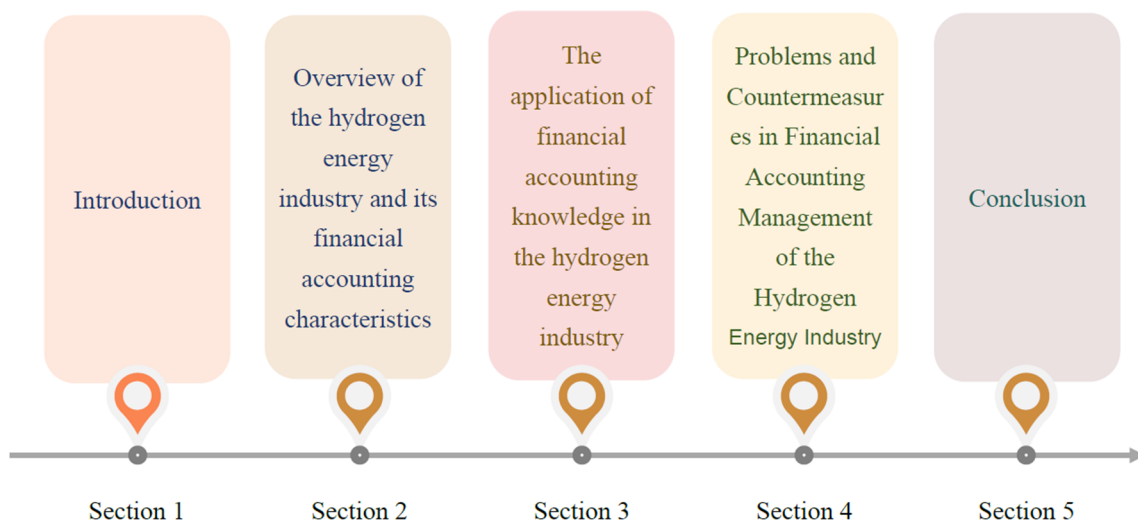


Figure 1. Research framework.

Based on the theoretical analysis and industry practical background of the hydrogen energy industry, this study proposes the following research hypotheses:

- H1: The standardization of cost accounting is significantly negatively correlated with the operating costs of hydrogen energy enterprises.
- H2: The improvement of financial risk management mechanisms is significantly negatively correlated with the financial risk level of hydrogen energy enterprises.
- H3: The diversification and optimization of financing models can significantly improve the financing availability and efficiency of hydrogen energy enterprises.
- H4: The improvement of carbon accounting and carbon asset management systems is significantly positively correlated with the market value and investment attractiveness of hydrogen energy enterprises.

Existing literature mostly focuses on the technical routes, policy formulation and macro industrial layout of the hydrogen energy sector, while rarely quantifies how accounting standardization affects corporate cost control. This study fills the gap by testing Hypothesis 1 to verify the practical value of unified cost accounting rules. For financial risk management, prior studies mainly conduct qualitative analysis on industry risks, lacking empirical evidence on the effect of risk management mechanisms, which makes Hypothesis 2 a necessary supplement to

relevant research. In terms of enterprise financing, few scholars link financing diversification to financing efficiency of hydrogen firms, so Hypothesis 3 further enriches the research on industrial financing. Additionally, carbon accounting has become a hot topic in green finance, but its impact on corporate market value is seldom discussed for hydrogen energy enterprises, and Hypothesis 4 addresses this research deficiency.

These hypotheses clarify the correlation relationship between core financial and accounting variables and enterprise operational performance, forming a clear theoretical logical chain for this paper.

2. Overview of the Hydrogen Energy Industry and Its Financial Accounting Characteristics

2.1. The Current Situation of Hydrogen Energy Industry Development

In recent years, various countries around the world have successively introduced policies to support the development of the hydrogen energy industry, and the global hydrogen energy industry has shown a rapid development trend.

As shown in Table 1, From the perspective of production technology, hydrogen production can be classified into three types: gray hydrogen, blue hydrogen, and green hydrogen: Gray hydrogen is produced through the steam reforming of natural gas, which has a high degree of technological maturity and low production costs, and is currently the mainstream method for obtaining hydrogen in the industrial sector. However, during the production process, a large amount of greenhouse gas emissions is generated, resulting in a relatively high carbon emission level, which is in conflict with the low-carbon development orientation under the carbon neutrality goal. Blue hydrogen is produced through the reforming of natural gas combined with carbon capture, utilization, and storage (CCUS) technology, and the captured and stored carbon dioxide from the production process can achieve significant reduction in carbon emissions. To a certain extent, it balances the economic efficiency of traditional hydrogen production technologies and their low-carbon attributes. As the global pressure for carbon reduction continues to increase, blue hydrogen, as a transitional low-carbon hydrogen source, is rapidly expanding its production scale. Green hydrogen is produced through electrolysis of water using renewable energy sources (such as wind energy and solar energy), and is the most environmentally valuable zero-carbon hydrogen. The entire production process does not generate any carbon emissions, making it the core energy carrier for achieving deep decarbonization. Although the current production cost of green hydrogen is still relatively high and the technology is still in iterative optimization, under the strong promotion of countries' carbon neutrality goals and the continuous decline in the cost of renewable energy, its production scale is also showing a rapid expansion trend, and is regarded as the core development direction of the future hydrogen industry. Currently, gray hydrogen accounts for the highest proportion of global hydrogen production, but as the carbon neutrality goal progresses, the production scale of green hydrogen and blue hydrogen is rapidly expanding.

Table 1. Classification and feature comparison of hydrogen production technologies.

Type of Hydrogen Production	Production Technology Path	Carbon Emission Characteristics	Industry Status
Grey hydrogen	Natural gas steam reforming method	High carbon emissions	Currently, it has the highest global production share.
Blue hydrogen	Natural gas reforming + Carbon capture, utilization and storage (CCUS)	Significant reduction in carbon emissions	The production scale has rapidly expanded.
Green hydrogen	Renewable energy (wind power, solar power) electrolysis of water	Zero carbon emissions, the highest environmental value	The production scale has rapidly expanded.

As shown in Table 2, From the perspective of the industrial chain layout, the hydrogen energy industry chain consists of three major sections: the upstream hydrogen production, the middle section of storage and transportation, and the downstream application. The upstream hydrogen production section serves as the foundation for the entire hydrogen energy industry, and it plays a core role in providing hydrogen supply. Its typical feature is high investment intensity and high technical requirements. On one hand, whether it is traditional fossil energy hydrogen production or hydrogen production through electrolysis of water using renewable energy, significant investment is required in equipment, factory construction, and technological research and development, especially for green hydrogen projects, where the investment demand for electrolyzers and renewable energy power stations is more prominent. On the other hand, the selection of hydrogen production technology routes, process optimization, and efficiency improvement all rely on high-level research and engineering capabilities, and the technical barriers are relatively high. Currently, the most prominent problem in this section is high production costs, especially for green hydrogen, which is affected by factors such as the cost of electrolyzers and the electricity

price of renewable energy, and still lacks economic advantages compared to traditional fossil energy hydrogen production. This, to a certain extent, restricts the large-scale promotion and application of hydrogen energy.

Table 2. Comparison of the components and development characteristics of the hydrogen energy industry chain.

Supply Chain Link	Core Positioning	Main Features	Current Problems
Upstream: Hydrogen production	Industrial development foundation	High investment intensity and high technical requirements	High production costs
Midstream: Storage and Transportation	Industrial connection hub	Due to the constraints of technology and cost, there are many bottlenecks.	Inadequate infrastructure
Downstream: Application	Industrial value end point	It has a wide range of applications and huge market potential.	The market demand is unclear.

The middle section of storage and transportation, as the industrial connection hub connecting the upstream production and the downstream application, is crucial for ensuring the stable circulation of hydrogen. Its core feature is constrained by technology and cost, and there are many bottlenecks. Currently, hydrogen storage and transportation mainly face multiple technical paths such as high-pressure gaseous storage and transportation, low-temperature liquid storage and transportation, solid-state hydrogen storage, and pipeline hydrogen transportation. However, each path has obvious shortcomings: high-pressure gaseous storage and transportation have low energy density and limited transportation radius. low-temperature liquid storage and transportation have high energy consumption and expensive equipment costs. solid-state hydrogen storage and pipeline hydrogen transportation are still in the stage of technological iteration or demonstration, and have not yet achieved large-scale application. This dual constraint of technology and cost directly leads to the lack of complete infrastructure in this section, and the national hydrogen storage and transportation network has not yet been formed, becoming the core bottleneck restricting the cross-regional collaborative development of the industry.

Downstream, as the terminal for realizing the value of hydrogen energy, demonstrates significant advantages in terms of extensive application fields and huge market potential in its application scenarios. Its application scenarios have covered multiple fields such as transportation (fuel cell vehicles, ships, aviation), industry (steel production, chemical raw materials), and power generation (distributed power generation, peak-load power supply), and it is the core carrier for promoting hydrogen energy from the energy production end to the consumption end. However, at present, this aspect is facing a challenge of unclear market demand: On one hand, the commercialization model of hydrogen energy terminal applications is not yet mature, and users' awareness and acceptance of hydrogen energy still need to be enhanced. on the other hand, the infrastructure such as hydrogen refueling stations and fuel cell systems is insufficient, and the price of hydrogen lacks competitiveness, resulting in the actual market demand not being fully released and it is difficult to form an effective pull on the upstream hydrogen production and midstream storage and transportation.

However, the current hydrogen energy industry still faces problems such as high production costs, incomplete infrastructure, and unclear market demand, which restrict its large-scale development.

As shown in Table 3, from a financial perspective, the global hydrogen energy industry exhibits distinct characteristics in terms of capital investment, market performance, and corporate profitability. These characteristics collectively indicate that the industry is still in the early stage of industrialization and is facing financial challenges.

(1) Investment distribution: Capital concentration coexists with structural imbalance

In recent years, driven by the global carbon neutrality goals and energy transition policies, the hydrogen energy industry has become a hot area of attention in the capital market, attracting a large amount of capital inflow. However, the distribution of investments shows a significant structural imbalance: Funding is heavily concentrated in the upstream hydrogen production segment. Both capacity expansion for conventional fossil-fuel-based hydrogen production and research, development, and deployment of green hydrogen technologies have attracted substantial investment from venture capital, industrial investors, and government-guided funds. In contrast, midstream storage and downstream transportation—critical enablers of the hydrogen value chain—have received comparatively limited capital inflows. This imbalance stems from several structural challenges, including relatively low technological maturity, extended investment payback periods, and uncertain commercialization pathways. Consequently, the prevailing “production-first, infrastructure-lagging” investment pattern has exacerbated vertical imbalances across the hydrogen supply chain and hindered the large-scale, cost-effective delivery of hydrogen from production sites to end-use applications.

(2) Market Volatility: High Uncertainty in the Financial Market

This study further conducts a volatility analysis based on the daily data of the US Hydrogen Index (865,169) from 2 to 23 March 2026. The index fluctuates violently between 371.361 and 407.209, with a maximum increase of 5.75% and a maximum decrease of 6.19%. The obvious volatility reveals that the hydrogen energy market is highly sensitive to policy adjustments, technological iteration expectations, and capital market sentiment, which directly brings greater uncertainty to the cost management, financial risk and investment return of hydrogen energy enterprises. This volatility characteristic is fully considered in the data regression analysis of this paper, so as to ensure that the empirical results and research conclusions can better fit the real operation situation of the hydrogen energy industry.

(3) Enterprise Profitability: Initial Losses and High Dependence on Policies

The overall profitability of current hydrogen energy enterprises is generally weak, which is a typical manifestation of the development stage of the industry. Most enterprises are still in the early stages of development and need to bear high fixed asset investment, technological research and development expenditures, and market expansion costs. Coupled with the high production costs of hydrogen and the insufficient release of terminal market demand, these factors have led these enterprises to generally be in a loss state during the commercialization stage. To maintain operations and technological iteration, these enterprises highly rely on policy support such as government subsidies and tax incentives, and have not yet formed an independent and sustainable market-based profit model. This “policy-driven” financial characteristic provides necessary support for the initial development of the industry, but also indicates that the commercialization maturity of the hydrogen energy industry still requires a long period of cultivation.

Overall, the financial characteristics of the hydrogen energy industry essentially reflect its inherent “high investment, long cycle, high risk, and high potential” development attributes. How to optimize the investment structure, stabilize market expectations, and accelerate commercialization implementation is the core direction for resolving the current financial difficulties and promoting the healthy development of the industry.

Table 3. Financial characteristics and market performance of the hydrogen energy industry.

Financial Analysis Dimension	Specific Characteristics
Investment Distribution	In recent years, the global hydrogen energy industry has attracted a large amount of investment, However, the investment is mainly concentrated in the upstream hydrogen production stage, while investment in the middle and upper stages is relatively insufficient.
Market volatility (US Hydrogen Index 865,169)	From 2 March 2026 to 23 March 2026, this index fluctuated between 371.361 and 407.209, with the maximum increase of 5.75% and the maximum decrease of 6.19%, reflecting the high volatility and uncertainty of the industrial financial market.
Enterprise profitability	The profitability of hydrogen energy enterprises is generally weak. Most of these enterprises were in a loss-making state during their early stages of development and relied on policy subsidies to maintain their operations.

2.2. The Financial Accounting Characteristics of the Hydrogen Energy Industry

As shown in Figure 2, Compared with traditional industries, the hydrogen energy industry has distinct particularities in terms of financial and accounting work, which mainly manifest in the following aspects:

First, the cost composition is complex and the accounting process is challenging. The costs of hydrogen energy enterprises cover multiple aspects such as raw materials, equipment, energy, technological research and development, storage, and transportation. For instance, the production cost of green hydrogen includes costs from renewable energy, depreciation of electrolyzer equipment, water consumption, etc., while the production cost of blue hydrogen includes costs from natural gas and CCUS technology, etc. Moreover, the cost of hydrogen technology research and development is relatively high. How to reasonably allocate research and development expenses has become a key issue in cost accounting. Currently, the hydrogen energy industry has not yet established a unified cost accounting standard, resulting in inconsistent cost accounting methods among enterprises and making it difficult to compare cost data.

Second, the financial risks are high and diverse. The hydrogen energy industry faces multiple financial risks including market risk, technological risk, policy risk, and operational risk: Market risk is mainly reflected in the fluctuations of raw material prices and hydrogen product prices. Technological risk is manifested in the uncertainty of technological iteration, which may lead to depreciation of existing equipment and an increase in investment

risk. Policy risk is reflected in changes in government support policies, subsidies, and carbon emission policies, which have a significant impact on the operation of the enterprise. Operational risk is reflected in the high requirements for equipment operation and safety management in the hydrogen energy industry, and any operational error may cause huge economic losses. A study by the Oxford Institute of Energy Economics pointed out that the lack of stable long-term purchase contracts and price fluctuations are the main factors affecting the financial risks of hydrogen energy projects.

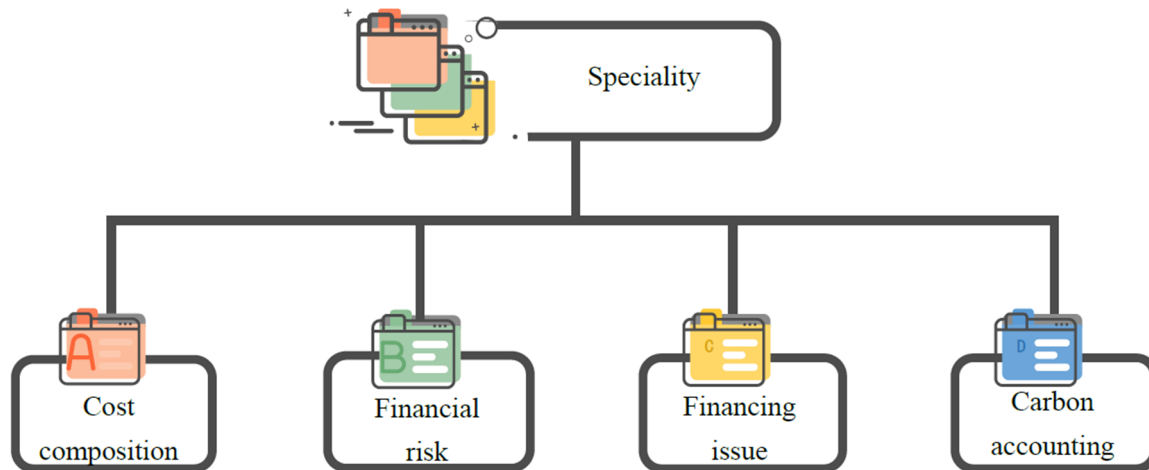


Figure 2. Aspect of manifestation of uniqueness.

Thirdly, the financing process is difficult and the financing structure is monotonous. The hydrogen energy industry has the characteristics of high investment intensity, long recovery period and high risks, which makes it difficult for enterprises to obtain traditional financing methods such as bank loans. Currently, the financing of hydrogen energy enterprises mainly relies on government subsidies and equity financing, with the proportion of debt financing being relatively low. The Organization for Economic Cooperation and Development (OECD) pointed out that high capital costs and the lack of reliable underwriters are the main factors restricting the financing of green hydrogen projects in emerging economies and developing economies. In addition, the financing costs of hydrogen energy enterprises are relatively high, increasing the financial burden of enterprises.

Fourth, carbon accounting has become an important component of financial accounting. Hydrogen energy, as a clean energy source, has significant advantages in carbon reduction. With the development of carbon accounting and carbon trading systems, hydrogen energy enterprises need to conduct carbon accounting, measure carbon emissions and carbon reduction amounts, and reflect the value of carbon assets in financial statements. However, the current carbon accounting standards for the hydrogen energy industry are not perfect. There are issues such as inconsistent measurement methods and difficulties in confirming carbon assets. For example, the US Inflation Reduction Act (IRA) provides tax credits for low-carbon hydrogen production, and these credits are linked to the greenhouse gas emission intensity throughout the hydrogen production process, making carbon accounting even more important for hydrogen energy enterprises.

3. The Application of Financial Accounting Knowledge in the Hydrogen Energy Industry

3.1. Cost Accounting and Control in the Hydrogen Energy Industry

Cost accounting is the foundation of financial management. Scientific cost accounting and control can help hydrogen energy enterprises reduce operating costs and enhance economic benefits. For the hydrogen energy industry, a cost accounting system that suits its industry characteristics needs to be established, clearly defining the cost composition and accounting standards of each link, and achieving refined cost management.

As shown in Table 4, In terms of cost composition, the costs of hydrogen energy enterprises can be classified into four categories: production costs, storage and transportation costs, research and development costs, and operating costs. The production cost is the core cost, including raw material costs, equipment depreciation costs, energy consumption costs, and labor costs, etc. For example, in green hydrogen production, the cost of renewable energy (such as wind power and solar power) accounts for a very high proportion, and enterprises need to reasonably calculate the cost of renewable energy based on actual power consumption, storage and transportation costs include storage equipment costs, transportation vehicle costs, pipeline construction costs, etc., which are

greatly affected by storage and transportation technologies and distances, research and development costs include research and development costs, equipment renovation costs, patent application costs, etc.

In terms of cost control, hydrogen energy enterprises can take the following measures: First, optimize production processes to enhance efficiency and reduce raw material and energy consumption. For instance, by improving the efficiency of electrolyzers and lowering hydrogen production energy consumption, the production costs can be reduced, second, strengthen supply chain management and optimize raw material procurement channels. Through bulk purchasing and long-term cooperation, the cost of raw materials can be lowered, third, reasonably allocate research and development investment, focus on core technology research, and avoid blind investment, fourth, strengthen management of storage and transportation links, optimize storage and transportation routes, and reduce transportation costs. In addition, enterprises can utilize the H2FAST (Hydrogen Financial Analysis Scenario Tool) developed by the National Renewable Energy Laboratory of the United States for in-depth financial analysis. By simulating different cost scenarios, it can provide support for cost control decisions [13].

Table 4. Core classification table of cost composition for hydrogen energy enterprises.

Cost Type	Core Composition Content
Production cost	Raw materials, equipment depreciation, energy consumption, labor cost
Storage and transportation costs	Storage equipment, transportation vehicles, pipeline construction
Research and development costs	Technology research and development, equipment renovation, patent application
Operating costs	Equipment maintenance, safety management, personnel training

3.2. Financial Risk Assessment and Mitigation in the Hydrogen Energy Industry

The high financial risks in the hydrogen energy industry require enterprises to establish sound mechanisms for financial risk assessment and mitigation, promptly identify potential risks, and take targeted measures to reduce the impact of these risks.

As shown in Table 5, In terms of financial risk assessment, hydrogen energy enterprises can utilize financial indicators such as the debt-to-asset ratio, current ratio, return on assets, and cash flow ratio to evaluate the debt-paying ability, profitability, and operational capability of the enterprise, and identify potential financial risks. At the same time, enterprises also need to pay attention to non-financial indicators such as technological maturity, policy support, market demand, and industry competition to comprehensively assess the level of financial risks. For example, through net present value (NPV) sensitivity analysis and internal rate of return (IRR) sensitivity analysis, the impact of key variables (such as natural gas prices) on the project's profitability can be evaluated, in addition, enterprises can utilize risk assessment models such as Monte Carlo simulation to simulate the impact of various risk factors on the enterprise's operations, providing a basis for risk management decisions.

Table 5. Core methods and indicators for assessing financial risks of hydrogen energy enterprises.

Evaluation Dimension	Core Indicators
Financial indicator assessment	Debt-to-asset ratio, current ratio, return on assets, cash flow ratio
Non-financial indicator assessment	Technology maturity, policy support, market demand, industry competition intensity
Project Sensitivity Analysis	Net Present Value (NPV) sensitivity analysis, Internal Rate of Return (IRR) sensitivity analysis
Comprehensive risk simulation	Monte Carlo simulation and other risk assessment models

In terms of risk mitigation, hydrogen energy enterprises can take the following measures: First, diversify their operations to spread risks. For instance, they can expand the application fields of hydrogen energy, reduce reliance on a single market, or enter into joint ventures or partnerships with other enterprises to share investment risks [14]. Second, strengthen market risk management and establish a price monitoring mechanism. Lock in the prices of raw materials and products through long-term contracts to reduce the impact of price fluctuations. For example, green hydrogen producers can sign hydrogen purchase agreements (HPA) with industrial customers to ensure long-term demand and stable prices, thereby enhancing the project's financing feasibility [15]. Thirdly, enhance technological research and development, increase technological maturity, and reduce technological risks. Enterprises can increase their investment in research and development, collaborate with research institutions, and accelerate the iteration and application of core technologies [16]. Fourthly, closely monitor policy changes, actively respond to policy adjustments, and strive for policy support. For example, apply for government subsidies,

tax incentives, etc., to reduce financial burdens [17]. Fifthly, establish and improve an internal control system, strengthen the management of financial activities, and prevent operational risks and financial fraud [18].

3.3. Financing Model Optimization in the Hydrogen Energy Industry

A sound financing model is the key to solving the financing difficulties of the hydrogen energy industry and promoting the industrialization process. Hydrogen energy enterprises need to innovate financing models, expand financing channels, and optimize the financing structure to reduce financing costs and improve financing efficiency.

First, give full play to the role of government guidance and increase policy support. The government can increase financial subsidies for the hydrogen energy industry, establish a special fund for hydrogen energy, and provide guarantees for the financing of enterprises. At the same time, the government can introduce preferential tax policies, such as reducing the corporate income tax and value-added tax of hydrogen energy enterprises, to reduce the financial burden of enterprises. For example, the US government has invested billions of dollars in hydrogen hubs and provided tax credits for clean hydrogen production to promote the development of the industry.

Second, expand equity financing channels. Hydrogen energy enterprises can attract investment from venture capital, private equity, and other institutions through listing, equity transfer, and other methods, and expand the source of funds. At the same time, enterprises can carry out employee stock ownership plans to mobilize the enthusiasm of employees and improve the cohesion of enterprises. In addition, the government can encourage the establishment of hydrogen energy industry investment funds to provide capital support for the development of the industry.

Third, develop debt financing tools. Hydrogen energy enterprises can issue corporate bonds, convertible bonds, and other debt financing tools to raise funds. At the same time, enterprises can strengthen cooperation with banks, financial institutions, etc., obtain bank loans, and improve the proportion of debt financing. For example, banks can launch special loan products for the hydrogen energy industry, reduce the loan threshold, and reduce the loan interest rate. In addition, enterprises can use asset securitization to securitize the future cash flow of hydrogen energy projects and raise funds through the capital market.

Fourth, carry out green financing. As a clean energy industry, the hydrogen energy industry is in line with the development direction of green finance. Enterprises can issue green bonds, green loans, and other green financing tools to attract green investment. At the same time, enterprises can actively participate in carbon trading, obtain carbon emission reduction benefits, and improve the ability of financing. For example, the carbon emission reduction of green hydrogen can be converted into carbon credits, which can be traded in the carbon market to bring additional income to enterprises.

3.4. Carbon Accounting and Carbon Asset Management in the Hydrogen Energy Industry

With the deepening of global carbon neutrality goals, carbon accounting has become an important part of the financial accounting of hydrogen energy enterprises. Carbon accounting refers to the measurement, recording, and disclosure of carbon emissions and carbon emission reductions of enterprises, and the management of carbon assets.

In terms of carbon accounting, hydrogen energy enterprises need to establish a carbon accounting system, clarify the scope of carbon accounting, and adopt scientific measurement methods to calculate carbon emissions and carbon emission reductions. The scope of carbon accounting includes direct carbon emissions (such as carbon emissions from fuel combustion in the production process) and indirect carbon emissions (such as carbon emissions from the purchase of electricity and heat). For green hydrogen production, the carbon emissions are mainly indirect carbon emissions from the purchase of renewable energy. Enterprises need to track the carbon emission intensity of renewable energy and calculate the carbon emission reduction volume of green hydrogen compared with gray hydrogen. A study published in Nature pointed out that the carbon emission intensity of blue hydrogen varies significantly according to the source of natural gas, which requires enterprises to carry out supply-chain specific life-cycle assessments in carbon accounting. In addition, enterprises can refer to the carbon accounting standards issued by international organizations and countries, such as the Greenhouse Gas Protocol, to ensure the accuracy and comparability of carbon accounting data.

In terms of carbon asset management, hydrogen energy enterprises can recognize carbon emission reductions as carbon assets and reflect them in financial statements. Carbon assets include carbon credits, carbon emission rights, and other assets, which can be traded in the carbon market to bring economic benefits to enterprises. Enterprises can formulate carbon asset management strategies, actively participate in carbon trading, and maximize the value of carbon assets. At the same time, enterprises can disclose carbon accounting information in the annual report, improve the transparency of information, and enhance the trust of investors and the public. A study by MIT found that different carbon accounting rules have a significant impact on the financial performance

of hydrogen projects, and enterprises need to choose appropriate accounting rules according to policy requirements and their own development needs.

4. Research Design and Empirical Analysis

This chapter presents the empirical design and hypothesis testing. We introduce the research sample, data sources, variable definitions and econometric model, and then report and interpret the regression results. In terms of the design of the research model, this paper is based on panel data and uses the twoway fixed effect method for analysis. In the model, individual differences and time variations are fully controlled to accurately identify the relationships between core variables. This method can effectively eliminate external interference, enhance the credibility of regression results, and make the analysis conclusions more in line with the actual operating conditions of hydrogen energy enterprises.

This study selects 6 representative enterprises covering the whole industrial chain of hydrogen production, storage, transportation and application in the hydrogen energy industry as research samples. The selected samples cover all core links of the industrial chain, and can reflect the overall operation status of domestic and foreign hydrogen energy enterprises, thus possessing good representativeness. The research period ranges from 2021 to 2026, a stage when the global hydrogen energy industry develops rapidly and relevant financial and accounting problems become prominent, so the selected time span is appropriate for this research. We adopt annual panel data in this study. All raw data are obtained from official corporate annual reports, public industry statistical reports and the Wind financial database. The data sources are publicly available, standardized and highly credible. We construct a balanced panel dataset with a total of 36 observations. Before regression analysis, all continuous variables are treated with 1% winsorization to eliminate the interference of extreme outliers and guarantee data quality.

In terms of variable selection, this paper constructs an index system from multiple dimensions. The explained variables are operating costs, financial risks, financing efficiency, and enterprise value, which are used to measure the core operating conditions of the enterprises. Among them, operating costs are measured by the ratio of operating costs to total assets, financial risks are measured by the debttoasset ratio, financing efficiency is the ratio of debt financing scale to total assets, and enterprise value is measured by the Tobin Q value. The core explanatory variables include the degree of standardization of cost accounting, the level of risk management improvement, the degree of financing diversification, and the soundness of the carbon accounting system, all of which are quantified using a 15 point scoring system to correspond to the four research hypotheses proposed in this paper. At the same time, to ensure the robustness of the results, this paper also incorporates control variables such as enterprise size, enterprise age, growth potential, and cash flow, to eliminate the influence of other factors on the regression results. Among them, enterprise size is represented by the natural logarithm of total assets, growth potential is the growth rate of operating income, and cash flow is the ratio of net operating cash flow to total assets.

In terms of data sources and sample selection, this paper selects 6 representative enterprises in the hydrogen energy industry and constructs a balanced panel sample using data from 2021 to 2026. The sample covers the entire hydrogen production, storage and transportation, and application value chain, with a total of 36 observations. The data mainly come from the annual reports of enterprises, public industry statistics, and data calculation from the Wind database. Before analysis, continuous variables are trimmed by 1% to reduce the influence of outliers on the results and ensure the quality of the data.

In the analysis of empirical results, this paper employs a twoway fixed effects model for regression, and the results are shown in Table 6. The regression results indicate that the influence directions of all core variables are consistent with expectations, and all have passed the significance tests. Specifically, the regression coefficient of the cost accounting standardization is 0.091, which is significantly negative at the 1% level, indicating that the more standardized the cost accounting system is, the lower the operating costs of hydrogen energy enterprises will be; the regression coefficient of the completeness of risk management is 0.132, which is significantly negative at the 1% level, suggesting that the more complete the risk control mechanism is, the lower the financial risks of the enterprises will be; the regression coefficient of financing diversification is 0.072, which is significantly positive at the 1% level, indicating that the more diversified the financing channels are, the higher the availability and efficiency of financing for the enterprises will be; the regression coefficient of the soundness of the carbon accounting system is 0.110, which is significantly positive at the 1% level, suggesting that the more complete the carbon accounting and information disclosure are, the stronger the market value and investment attractiveness of the enterprises will be. Regarding the control variables, enterprise size, years of operation, growth rate, and cash flow all show expected significant influences. Both individual and time fixed effects are controlled. The R^2 distribution of the model is between 0.768 and 0.826, and the F values are all significant at the 1% level. The

overall model fitting effect is good and the explanatory power is strong, indicating that all the four research hypotheses set by this paper have been effectively verified.

Table 6. Baseline regression results.

Variable	H1 Operating Cost	H2 Financial Risk	H3 Financing Efficiency	H4 Enterprise Value
Cost Accounting Standardization	0.091 ($p < 0.01$)	—	—	—
Risk Management Perfection	—	0.132 ($p < 0.01$)	—	—
Financing Diversification	—	—	0.072 ($p < 0.01$)	—
Carbon Accounting Perfection	—	—	—	0.110 ($p < 0.01$)
Size	0.026 ($p < 0.01$)	0.040 ($p < 0.01$)	0.021 ($p < 0.01$)	0.045 ($p < 0.01$)
Age	0.004 ($p < 0.01$)	0.006 ($p < 0.01$)	0.003 ($p < 0.01$)	0.007 ($p < 0.01$)
Growth	0.059 ($p < 0.01$)	0.078 ($p < 0.01$)	0.044 ($p < 0.01$)	0.087 ($p < 0.01$)
Cashflow	0.128 ($p < 0.01$)	0.101 ($p < 0.01$)	0.080 ($p < 0.01$)	0.119 ($p < 0.01$)
Individual/Time Fixed Effects	Controlled	Controlled	Controlled	Controlled
R^2	0.802	0.826	0.768	0.821
F-statistic	35.12 ($p < 0.01$)	41.36 ($p < 0.01$)	30.75 ($p < 0.01$)	39.48 ($p < 0.01$)
Observations N	36	36	36	36

Notes: $p < 0.01$, $p < 0.05$, $p < 0.1$. All coefficients are statistically significant at the 1% level.

To further ensure the reliability of the conclusions, this paper also conducts robustness tests. These tests include replacing core independent variables with standardized indicators, adopting 1% and 5% winsorization, and using one-period lagged independent variables to alleviate potential endogeneity. The results show that the influence direction and significance of core variables remain unchanged, indicating that the research results are stable and reliable, and the conclusions are authentic and credible.

5. Challenges and Strategic Responses in Financial Accounting Management within the Hydrogen Energy Industry

5.1. Existing Problems

Currently, the financial accounting management in the hydrogen energy industry still faces numerous problems, mainly manifested in the following aspects:

First, the cost accounting system is not complete. The hydrogen energy industry lacks a unified cost accounting standard, and the cost accounting methods of enterprises are inconsistent, resulting in unclear cost composition, high difficulty in cost control, and inability to compare cost data among enterprises. At the same time, the amortization of research and development expenses and the accounting of storage and transportation costs are not standardized, which affects the accuracy of cost accounting.

Second, the financial risk management mechanism is not sound. Most hydrogen energy enterprises lack a complete financial risk assessment and mitigation mechanism, have weak risk awareness, are unable to promptly identify potential financial risks, and lack effective risk mitigation measures, leading to high financial risks for enterprises.

Third, the financing channels are narrow, and the financing structure is unreasonable. The financing of hydrogen energy enterprises mainly relies on government subsidies and equity financing, with a low proportion of debt financing. The financing cost is high, and the financing difficulty is large, which restricts the development of enterprises.

Fourth, the carbon accounting system is not mature. The carbon accounting standards in the hydrogen energy industry are not complete, the measurement methods are inconsistent, and the confirmation and measurement of carbon assets are difficult, at the same time, the disclosure of carbon accounting information is not standardized, which affects the assessment of the carbon reduction value of enterprises.

Fifth, the professional quality of financial accountants is not high. The hydrogen energy industry involves multiple fields such as energy, technology, and finance, requiring financial accountants to have comprehensive knowledge reserves. However, at present, most financial accountants in the hydrogen energy industry lack expertise in the hydrogen energy industry, which affects the quality of financial accounting management.

5.2. Solutions and Suggestions

In response to the above issues, this article proposes the following countermeasures and suggestions to enhance the financial accounting management level of the hydrogen energy industry:

First, improve the cost accounting system. The government and industry associations should formulate unified cost accounting standards for the hydrogen energy industry, clearly define the cost composition, accounting methods, and amortization standards for each link, and standardize the cost accounting behavior of enterprises.

Enterprises should establish a refined cost management system, strengthen cost control in each link, improve the accuracy and comparability of cost data, and reasonably amortize research and development expenses, and standardize the accounting of storage and transportation costs.

Second, establish a sound financial risk management mechanism. Hydrogen energy enterprises should establish a complete financial risk assessment system, adopt scientific risk assessment methods to identify and assess potential financial risks, and formulate targeted risk mitigation measures, strengthen market risk, technical risk, policy risk, and operation risk management, establish a risk warning mechanism, and respond to risks in a timely manner, in addition, strengthen internal control and enhance financial management level to prevent financial risks.

Third, optimize financing models and expand financing channels. The government should increase policy support, improve the fiscal subsidy system, and provide guarantees for enterprise financing, enterprises should innovate financing models, expand equity financing and debt financing channels, and increase the proportion of debt financing, actively carry out green financing, issue green bonds and green loans, attract green investment, strengthen cooperation with financial institutions, establish long-term cooperative relationships, and reduce financing costs.

Fourth, improve the carbon accounting system. The government should formulate clear hydrogen energy industry carbon accounting standards, unify the measurement methods for carbon emissions and carbon reduction, and standardize the confirmation and measurement of carbon assets, enterprises should establish a carbon accounting system, strengthen carbon asset management, actively participate in carbon trading, standardize carbon accounting information disclosure, enhance information transparency, and strengthen the trust of investors and the public, in addition, professional carbon accounting tools can be utilized to improve the efficiency and accuracy of carbon accounting.

Fifth, enhance the professional quality of financial accountants. Enterprises should strengthen the training of financial accountants, improve their professional knowledge and skills, and enable them to master knowledge related to hydrogen energy industry, finance, and accounting, introduce high-quality financial accountants with comprehensive knowledge reserves to enhance the financial accounting management level, in addition, industry associations can conduct training and exchange activities to promote the exchange and learning among financial accountants within the industry.

6. Conclusions

The hydrogen energy industry is at a critical stage of industrialization, facing prominent financial and accounting challenges in cost control, risk prevention, financing support, and carbon value realization. From the financial and accounting perspective, this study proposes research hypotheses regarding the relationships between the standardization of cost accounting, the improvement of risk management, the diversification of financing models, the enhancement of carbon accounting systems, and enterprise operational performance. Combining the high volatility characteristics of the hydrogen energy market reflected by the US Hydrogen Index, this study adopts data regression to conduct empirical tests and obtains clear and robust research conclusions.

First, the standardization of cost accounting can significantly reduce the operating costs of hydrogen energy enterprises. The empirical results show that a unified and standardized cost accounting system helps enterprises clarify cost composition, optimize resource allocation, and strictly control various expenditures. It is especially effective for cost collection and allocation of different hydrogen production routes such as green hydrogen and blue hydrogen, serving as an important institutional foundation for achieving cost reduction and efficiency improvement in the hydrogen energy industry.

Second, the improvement of financial risk management mechanisms can effectively restrain the financial risks of enterprises. A sound system of risk identification, assessment and response can significantly alleviate the uncertainties caused by raw material price fluctuations, hydrogen price volatility, policy changes and technological iteration, reduce financial pressure and debt repayment risks, and enhance operational stability.

Third, the diversification of financing models can significantly improve the financing availability and efficiency of hydrogen energy enterprises. Broadening diversified financing channels including equity financing, debt financing, green finance and policy funds helps alleviate financing constraints caused by large investment, long cycle and slow returns in the hydrogen energy industry, improve corporate cash flow, and support continuous project investment and large-scale development.

Fourth, the improvement of carbon accounting systems can significantly enhance the market value and investment attractiveness of hydrogen energy enterprises. Complete carbon emission accounting, carbon emission reduction measurement and carbon information disclosure can fully demonstrate the low-carbon and zero-carbon

advantages of hydrogen energy, strengthen recognition in the capital market, improve corporate valuation and competitiveness, and effectively convert carbon emission reduction value into economic benefits for enterprises.

Fifth, the high volatility of the hydrogen energy industry exerts a significant impact on the effectiveness of financial decision-making. The volatility analysis of the US Hydrogen Index shows that the hydrogen market is highly sensitive to policies, technologies and capital sentiments. This feature must be fully considered in cost control, risk early warning and investment and financing arrangements, and traditional financial and accounting methods need to be adapted and improved in accordance with industry characteristics.

The theoretical contribution of this study is to break through the limitation of existing literature that overemphasizes technology and policies, construct an integrated financial and accounting analysis framework covering cost, risk, financing and carbon accounting, and integrate the industry's high volatility, large investment and long-cycle characteristics into the theoretical logic, enriching the theoretical system of financial research on the hydrogen energy industry. The practical contribution is reflected in the targeted and operable countermeasures, including unifying industry-caliber cost accounting, establishing a risk early warning mechanism integrating financial and non-financial indicators, innovating diversified green financing schemes, and improving the full-life cycle carbon accounting system.

In summary, scientific financial and accounting management is a critical support for hydrogen energy enterprises to reduce costs, control risks, improve efficiency and realize carbon asset value, as well as an important guarantee for promoting the hydrogen energy industry from policy-driven to market-oriented and large-scale sustainable development. In the future, with the continuous improvement of the hydrogen energy industrial chain and the gradual improvement of relevant policies and standards, enterprises should continuously strengthen the construction of financial and accounting systems and promote refined management. Governments and industry organizations should speed up the unification of cost accounting and carbon accounting standards, and improve financial support and risk-sharing mechanisms. Follow-up studies can further conduct in-depth discussions on refined cost accounting of green hydrogen, dynamic risk early warning under price fluctuations, and financing models of cross-regional storage and transportation projects, so as to provide more accurate and systematic theoretical references and decision-making basis for the high-quality development of the hydrogen energy industry.

Author Contributions

H.W. and X.R.: Conceptualization; S.Y., H.W. and X.R.: methodology, software; H.W. and X.R.: validation; H.W. and X.R.: writing—original draft preparation; X.R. and S.Y.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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