Information Management and Business Review (ISSN 2220-3796)
Vol. 16, No. 3(S), pp. 913-923, Sep 2024

Green Innovation and Firm Performance: An Empirical Study of China's Power Industry

Xiaoyuan Zhang[1,2], Shenglian Wang [1,2], Nurul Azlin Azmi[1,3], *Raja Adzrin Raja Ahmad[1,3]
[1]Faculty of Accountancy, Universiti Teknologi MARA, Johor Branch, Segamat Campus, Jalan Universiti, Jalan Muar, Segamat, Johor, Malaysia
[2]Faculty of Economics and Management, Beibu Gulf University, Qinzhou, Guangxi, China
[3]Accounting Research Institute (ARI), Universiti Teknologi MARA, Malaysia
*adzrin75@uitm.edu.my
Corresponding Author: Raja Adzrin Raja Ahmad

Abstracts: With China's goal of achieving "carbon peak and neutrality", green innovation has become an inevitable choice to accomplish the dual objective of ecological protection and economic growth. The objective of this study is to examine whether green innovation can contribute to enhancing firm performance. Specifically, this study empirically investigates the relationship between green innovation and firm performance by analyzing a sample of listed firms in China's A-share power industry from 2009 to 2022. By using panel fixed effect regression, this study found that green innovation markedly and positively enhances the firm's current performance. Furthermore, this paper tested the effect of green innovation on the firm's future performance, which is positive and greater than the effect on the current performance. Through data support spanning 14 years, this study verifies the theoretical hypothesis that green innovation can substantially enhance firm performance in the power industry. This not only deepens the understanding of how green innovation affects firm performance but also offers empirical evidence to support the further implementation and advancement of green innovation within the power industry. This study only uses a sample of a single industry, so the conclusions of this study do not have explanatory power for firms in other industries.

Keywords: *Green innovation, firm performance, power industry*

1. Introduction

Power is the basis of modern industrial production. It provides energy support for manufacturing, construction and other heavy industries. A stable and reliable supply of power not only ensures smooth industrial production but also directly affects the quality of life of the residents. It can be seen that the power industry is the core pillar of the modern economic system, which supports and promotes economic development in a variety of ways. The power sector significantly contributes to enhancing the economic and financial conditions of both the country and the area, while also promoting social progress (Zhao et al., 2023).

The power industry is widely recognized as a major source of pollution, with the primary issue arising from traditional fossil fuel-based power generation. These polluting fuels generate greenhouse gas emissions, air pollutants, and water and solid waste pollution, which enter the atmosphere and cause global warming and climate change. Furthermore, these pollutants damage the ecological environment and threaten human and animal health by entering waters and ecosystems (Ukaogo et al., 2020).

China's power industry is still undergoing industrialization, which is characterized by efficient management of resources, resulting in significant environmental protection challenges. An effective strategy is to adopt green

innovation, which provides a strong answer for balancing economic growth and ecological protection (Pancholi et al., 2024). Along with China's "carbon peak and neutral" goal, a green, innovative economic model has become an inevitable choice to accomplish the dual objective of ecological protection and economic growth. As a crucial component of China's market-oriented green innovation system, enhancing the accomplish the dual objective of ecological protection of energy-saving and environmentally friendly technologies is key for firms in China's power industry to secure a competitive edge (Abbas et al., 2024).

Green innovation is essential for achieving long-term growth and progress. Through technological and product innovation, green innovation can contribute positively to economic growth, environmental protection, and social well-being, thereby supporting sustainable development goals (Younas et al., 2023). Green innovation can develop more environmentally friendly technologies and products and promote resource conservation and environmental protection, and this aligns closely with the core objective of environmental sustainability. (Wang et al., 2022). Green innovation also contributes to environmental protection and brings new economic opportunities and markets. The growing demand for green technologies and products has driven the development of emerging industries, which aligns with the economic growth goal of sustainable development (Khan et al., 2022). Additionally, green innovation allows companies and communities to deliver products and services that are safer, improving the overall quality of life (Ning et al., 2023). Improving human life quality and social welfare is also one of the goals of sustainable development.

Recently, there has been increasing focus on the link between green innovation and company success, particularly in industries that have a substantial environmental impact. This study focuses on China's power industry, where integrating sustainable practices is increasingly seen as essential for long-term success. As environmental regulations tighten and societal expectations for firm responsibility grow, companies in this sector are pressured to innovate to reduce their environmental footprint while maintaining or enhancing their financial performance.

Due to the environmental pollution caused by the power industry, examining the impact of green innovation on firm performance is crucial. Green innovation not only enables power companies to capitalize on market opportunities and enhance financial performance but also supports their long-term sustainable development and the fulfillment of social responsibility.

This paper is structured as follows. The following section reviews the literature on green innovation and firm performance, while the next section outlines the data sources and model design. Following that, the models and findings of the study are presented. Finally, discussions and conclusions are elaborated in the final section. Recommendations are also made on the way forward for green innovation, especially in the power industry.

2. Literature Review and Hypothesis Development

Early scholars from different perspectives have defined green innovation from different perspectives (Braun & Wield, 1994; Jawahar & McLaughlin, 2001; Norberg-Bohm, 1999). Braun and Wield (1994) Were the first to define green innovation. They identify green innovation as a wide range of technologies, and products, as well

as procedures, aimed at mitigating environmental contamination and minimizing the depletion of raw materials, including non-renewable energy sources.

In addition, the Organization for Economic Co-operation and Development (OECD) defines green innovation as the introduction of new advancements or substantial improvements by companies in their goods, processes, marketing techniques, organizational structures, and institutional arrangements, resulting in better environmental performance relative to other companies in the same industry (OECD, 2009). In the study by Zhuang et al. (2022), green innovation is defined as all technologies conducive to green development and ecological civilization construction.

Building on previous research, this research defines green innovation as the creation of novel or enhanced goods, processes, and technology that are environmentally friendly and management practices (Xie et al., 2019) That enhances value for both customers and companies while significantly mitigating environmental harm (Karimi Takalo et al., 2021).

Green Innovation and Firms' Current Performance

Most research supports a positive link between green innovation and firm performance. Green innovation typically focuses on enhancing the efficiency of resource usage, such as energy and raw materials. Firms can significantly reduce operating costs by adopting energy-efficient technologies and reducing waste (Li et al., 2020; Yi et al., 2023). Additionally, green innovation involves improving waste management in the production process, and optimizing waste treatment and recycling processes not only reduces disposal costs but may also generate revenue through recycled materials (Farzaa et al., 2021; Xie et al., 2019).

Prior research has demonstrated that the use of green innovation and environmental protection measures may enhance current industrial methods to reduce negative environmental effects, which can help shape a firm's green brand image, gain consumers' trust, and enhance consumer loyalty to the brand (Chen et al., 2023; Chouaibi et al., 2022).

Furthermore, green products and services can satisfy the increasing demand for environmentally friendly offerings, and the firm can enter new market segments, providing the firm with a differentiated competitive advantage. (Abbas et al., 2024;Padilla-Lozano et al., 2024).

Through green innovation, the firm can reduce the legal risks and fines it faces for violating environmental regulations and safeguard the stability of its business operations. (Hu et al., 2021). Meanwhile, the firm can obtain national and regional subsidies and tax incentives for green innovation (Zhao et al., 2023). Moreover, green practices can boost a firm's reputation and enhance its brand value, attracting environmentally conscious consumers and investors and further bolstering its competitive advantage.

However, some scholars argue that the costs associated with green innovation cannot be offset by environmental benefits such as energy conservation, reduced consumption, and improved productivity (Khan et al., 2021; Xie et al., 2022). Aguilera-Caracuel and Ortiz-de-Mandojana (2013) employed an institutional

approach, analyzing a sample of 88 green innovative firms alongside 70 matched pairs, comparing both green and non-green innovative firms. They found that firms engaging in green innovation do not experience an immediate boost in financial performance compared to those not involved in green innovation. This result may be because the potential benefits of green innovation on financial performance often require time to become evident (Qing et al., 2022). Conversely, converting green innovation into financial gains relies on various underlying mechanisms and contingent conditions (Khan et al., 2022).

Most research supports a positive connection between green innovation and firm performance. Consequently, this study posits the following hypothesis:
H1: Green innovation is positively associated with the firm's current performance.

Green Innovation and Firms' Future Performance
Given that some aspects of a firm's green innovation may require time to transition from granted to practical application, the outcome of green innovation on the firm's performance will not have an immediate effect. However, future benefits must be accumulated and adapted for a certain period before they can be reflected by improving the firm's performance.

This lag effect is reflected in the following aspects: firstly, green innovation usually needs time for research and development, testing, and marketing. After investing resources and time in green innovation, it takes time for the firm to get feedback from the market and establish a differentiated competitive advantage, which impacts performance. (Padilla-Lozano et al., 2024). Second, green innovation is often accompanied by higher initial investment. Firms may face higher initial costs, and performance improvement may take time to achieve the break-even point from green innovation investment and gain profit (Chen et al., 2018). Finally, green innovation can enhance a firm's brand image and social responsibility, but it usually takes time to build a brand reputation and change consumer perceptions. Firms may require a period to market their products and align consumer perceptions before observing the positive effects of brand reputation on performance (Lestari & Soewarno, 2024; Przychodzen et al., 2019). Considering the time lag between the green innovation investment and firm performance, this study proposes the second hypothesis：
H2: Green innovation is positively associated with the firms' future performance.

3. Methodology

Sample Selection and Data Source
This study uses the power industry data in Chinese A-share listed firms from 2009 to 2022 inclusive. The firm performance and control variables data were gathered from the China Stock Market & Accounting Research Database (CSMAR). Meanwhile, data on green innovation were gathered from the China Research Data Service Platform (CNRDS).

The samples were screened based on the following steps. First, this study excluded ST, *ST, and PT firms.[1]

[1] In Chinese stock markets, **ST** firms are companies flagged for financial instability, typically after two years of losses, while ***ST** firms face more

Second, this study also excludes IPO-listed firms and delisted firms from 2009 to 2022. Third, this study eliminates the missing data. Then, the final sample of this study consists of 1,134 firm-year observations. Then, to deal with normality, this study winsorizes data at 1% to reduce the effect of extreme values (Abuzaid & Alkronz, 2024; Wan Ismail et al., 2024).

Measurement of variables

The explained variable is firm performance represented by Tobin's Q. Tobin's Q is calculated as the ratio of the firm's market value to its total assets (Yao et al., 2021). Tobin's Q has advantages because it is difficult for the firm's management to manipulate as the market value captures the current value. Tobin's Q ratio can predict the firm's future cash flow and long-term performance and is less sensitive to inflation (Chen & Lin, 2021).

This study uses the natural logarithm of the number of green patents granted plus 1 as the proxy variable for green innovation (Ma et al., 2021). The quantity of green patents granted refers to the number of applications ultimately granted after the examination. The granted innovation patent can directly demonstrate firms' actual innovation capability and success and can be used as an effective indicator of firms in green innovation (Yuan & Cao, 2022). As shown in Table 1, drawing on existing research, this study introduces the following control variables: firm size (Size), leverage (Lev), cash holding (Cash), firm age (Age), and total asset turnover (Turnover).

Table 1: List of variables

Type of Variables	Variable	Operationalization
Dependent Variable: Firm Performance	Tobin's Q	The proportion of market value to total assets
Independent Variable: Green Innovation	Green-Patent	Natural logarithm of (number of green patents granted + 1)
Control Variables	Firm size (Size)	Total assets' natural logarithm
	Firm leverage (Lev)	The ratio of total assets to total liabilities
	Cash holding (Cash)	The ratio of net operating cash flow to total assets
	Firm age (Age)	natural logarithm of (age + 1)
	Turnover of total assets (Turnover)	Operating income divided by total assets

Research Model

The following equation models were developed to test Hypothesis 1 and Hypothesis 2:

$$CP(\text{Tobin's Q})_{i,t} = \beta_0 + \beta_1 \text{Green-Patent}_{i,t} + \beta_2 \text{Control}_{i,t} + \text{Year} + \varepsilon_{i,t} \quad (1)$$

$$CP(\text{Tobin's Q})_{i,t} = \beta_0 + \beta_1 \text{Green-Patent}_{i,t-1} + \beta_2 \text{Control}_{i,t} + \text{Year} + \varepsilon_{i,t} \quad (2)$$

Where i denotes the ith firm, t is the TTH year, Tobin's $Q_{i,t}$ signifies firm performance, $\text{Green-Patent}_{i,t}$ represents green innovation, $\text{Control}_{i,t}$ encompasses all control variables, Year represents year fixed effect, $\varepsilon_{i,t}$ represents

severe financial issues, often with three consecutive years of losses and a higher risk of delisting. **PT** firms may refer to companies nearing delisting or suspension due to significant risks.

error term.

4. Result and Discussion

Descriptive Statistics

Table 2: Descriptive Statistics of Dependent, Independent, and Control Variables

VarName	Obs	Mean	SD	Min	Median	Max
Tobin's Q	1344	1.526	0.951	0.899	1.226	6.766
Green-Patent	1344	0.990	1.309	0.000	0.000	6.862
Size	1344	23.043	1.518	19.715	22.951	26.139
Lev	1344	0.559	0.182	0.051	0.578	0.934
Cash	1344	0.120	0.105	0.016	0.093	0.729
Age	1344	2.562	0.764	0.000	2.833	3.434
Turnover	1344	0.395	0.275	0.080	0.332	2.639

Table 2 presents the descriptive statistics for all variables. The standard deviation of Tobin's Q is 0.951, with a minimum value of 0.899, a maximum value of 6.766, and an average of 1.526, suggesting that firms in China's power industry exhibit underperformance with considerable variability. The green patent variable ranges from a minimum of 0 to a maximum of 6.862, indicating substantial differences in green innovation levels among the sample firms, with an average value of 0.990, reflecting relatively low levels of green innovation within the sector.

Regression Analysis

Table 3: Multiple Regression Results of Green Innovation and Firm Performance

	(1) Tobin's Q	(2) Tobin's Q
_cons	19.8256***	19.2695***
	(0.6656)	(0.7588)
Green-patent	0.0708***	
	(0.0183)	
Lag Green-patent		0.0914***
		(0.0194)
Size	-0.8318***	-0.7984***
	(0.0290)	(0.0320)
Lev	0.2283*	0.2032
	(0.1330)	(0.1453)
Cash	0.8200***	0.9361***
	(0.1997)	(0.2126)
Age	0.2773***	0.2058**
	(0.0623)	(0.0945)

Turnover	-0.7773***	-0.7524***
	(0.0902)	(0.0980)
Year effect	Yes	Yes
R^2	0.5151	0.4976
N	1344	1198

Notes: ***, **, and * represent significance at 1, 5, and 10 percent levels respectively (using a one-tailed test)

Column (1) of Table 3 displays the regression results regarding the effect of green innovation on firm performance. The coefficient for green patents is 0.0708, which is positive and statistically significant at the 1% level. This suggests that green innovation has a substantial positive impact on improving current firm performance. This finding also aligns with the results of Yi et al. (2023) And Chouaibi et al. (2022), indicating that the unique and scarce resources and capabilities accumulated in green innovation can improve the firm's performance. Therefore, hypothesis 1 is supported.

To examine whether green innovation exhibits a delayed effect, column (2) shows the results of the relationship between one-period lagged green patents on firm performance. The regression coefficient for lagged green patents is 0.0914, which is positive and statistically significant at the 1% level. It indicates that green innovation can enhance the firm's current performance and significantly enhance its future performance in the power industry. The results also reveal that the effect of green innovation on the firm's future performance is higher than on the current performance.

Concerning the firm characters, firm size (Size) is negatively significant on firm performance. This implies that excessive firm size leads to organizational rigidity, limits innovation and flexibility, and affects market competitiveness and performance (Salihi et al., 2024). Firm leverage (Lev) is positively significant on firm performance, suggesting that moderate debt can help firms use leverage to magnify returns (Jiang & Lan, 2022). The cash holding ratio (Cash) is positive and significant on firm performance, which indicates that an appropriate cash holding ratio can enhance the financial flexibility and stability of the firm (Xu et al., 2023). Firm age is positively significant on firm performance. This indicates that as the firm has been in business for a more extended period, it has gradually accumulated a wealth of industry experience, brand reputation, and market position, thus enhancing its performance. Total asset turnover (Turnover) is positively significant on firm performance and indicates that high turnover does not necessarily lead to improved performance (Patin et al., 2020).

5. Conclusion and Recommendations

Research Findings

This study empirically investigates the influence of green innovation on firm performance by analyzing data from Chinese A-share listed companies in the power industry between 2009 and 2022. The results reveal that green innovation positively impacts a firm's current performance. Moreover, green innovation significantly enhances a firm's future performance, with its impact on future performance surpassing its effect on current performance. The results of this paper are also consistent with Padilla-Lozano et al. (2024), Zhao et al. (2023)

And Chouaibi et al. (2022). Furthermore, the study reveals that the benefits of green innovation are more noticeable in firms that consistently invest in sustainable practices over the long term. This highlights the importance of sustained commitment to green strategies.

Research Contribution

The finding of this study contributes significantly to the policymakers and industry leaders. This is achieved by analyzing the impact of green innovation on firm performance, specifically within China's power industry, a sector vital to both economic growth and environmental sustainability. By empirically examining the relationship between sustainable practices and firm outcomes, this research contributes valuable insights into how firms can balance economic goals with environmental responsibilities. It is crucial to comprehend the strategic benefits of green innovation as China progresses towards a low-carbon economy. Furthermore, understanding the strategic advantages of green innovation is essential for firms seeking to remain competitive and compliant with increasingly stringent environmental regulations.

Recommendations

The analysis shows that green innovation can significantly enhance firms' performance. Business managers, especially in the power industry need to recognize the profit potential of green innovation for their firms, they should rationally allocate their resources to production and operations, increase R&D efforts in green innovation, and enhance their green innovation capabilities. From the investors' perspective, green innovation is about environmental protection, sustainable development, and long-term financial returns. Investors should allocate more funds to the green industry to help China's green industry transform and upgrade.

Furthermore, the government should improve policies to encourage green innovation in the power industry as soon as possible to incentivize firms to innovate green. The government could also actively advocate cultivating consumers' green consumption awareness and demand to promote firms to implement green innovation spontaneously. Besides, the government should guide financial resources and supportive policies to tilt towards green innovation industries to balance the significant investment and risk features associated with green innovation. This can promote China's economic development model from resource-consuming to sustainable development.

Research Limitations and Future Research Directions

This study uses an empirical analysis of listed firms in China's power industry. Therefore, the findings have no explanatory power for firms in other industries. They must be generalized to only some of the Chinese A-share market. Future research could extend the methodology of this study to other industries or even all listed firms to provide more comprehensive confirmation of the relationship between green innovation and firm performance.

Using patent grant data, this study differentiates green patents based on the World Intellectual Property Organization's classification criteria (Wu & Shan, 2024). It evaluates firm green innovation through the output of green innovation. Future research could consider exploring suitable proxy variables from the perspective of green innovation inputs to further broaden and deepen the scope of green innovation studies.

Nevertheless, this study provides valuable insights into the relationship between green patents and firm performance in China. By focusing on green patent outputs, it sheds light on how firms' innovative activities in the environmental sector can drive performance improvements. The findings offer a clearer understanding of the role green innovation plays in enhancing competitiveness and sustainability, particularly in industries like power generation, where environmental impact is a critical concern.

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