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Article

Investigating the Influence of Green Technology Innovations on Energy Consumption and Corporate Value: Empirical Evidence from Chemical Industries of China

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Abstract: This study investigates the impact of green technology innovation on energy consumption and corporate value in China's chemical industries, utilizing data from 133 A-share listed enterprises over the period of 2013-2022. Data on green technology innovation are sourced from the Chinese Research Data Services (CNRDS) Platform, while energy consumption data are obtained from listed companies' annual reports, social responsibility reports, and websites. Corporate ESG data is sourced from Huazheng ESG rating, and other data are obtained from China Stock Market & Accounting Research Database (CSMAR) and the National Statistics Bureau. Employing a two-way fixed effects model, this finds that green technology innovation mitigates energy consumption, and boosts corporate value of Chinese A-share listed enterprises of chemical industries. The study ensures the robustness of its findings through 2SLS analysis, using green patent applications as instrumental variables. The moderating effects of ESG disclosure are found significant to strengthen the influence of green technology innovation on energy consumption and corporate value. These findings offer valuable insights for policymakers and stakeholders in shaping strategies to promote sustainability and competitiveness in the chemical industry.

Keywords: green technology innovation; energy consumption; corporate value; ESG disclosure; chemical industries

1. Introduction

In last few years, China's unstoppable economic development has led it to ascent to the world's second largest GDP, trailing only the United States. However, this economic development is came with significant challenges such as environmental pollution and energy consumption [1]. The chemical industries of China are ranked as the second largest emitters of carbon emissions and have utilized excessive volume of resources. The resources such as water, coal, electricity, and other are largely consumed in these industries. In 2020, the chemical industry consumed almost 567.23 million tons of standard coal, which is almost 11.38% of total energy consumption of China [2]. In response to the excessive use of resources in chemical industries, China's government has played an active role to provide grants and subsidies to move toward green innovation

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solutions. The Asian Development Bank (ADBP) approved $100 million to help China reduce energy consumption, phasing out mercury use, and reduce greenhouse gas and toxic emissions in chemical industry [3]. The prevailing industrial development has led China to enter in a cycle of environmental pollution-economic development, and to break from this cycle, the adoption of green technology innovation is crucial.

Braun and Wield [4] proposed concept of green technology as a broader category including technologies, products, or products focused toward reducing the environmental emissions and minimizing energy and raw material consumption. They underscored the importance of green technology innovation policies to promote innovation aimed at curbing environmental impacts, and thus improving the use of energy resources. Green technology innovation is dedicated to foster mutually beneficial relationship between the economy and environment. Its pursuit is crucial to achieve sustainable development in every sector, especially chemical sector [5]. Green technology innovation includes both negative externalities and positive externalities. Positive externalities arise from technology innovation, require government support through funding policies, and negative externalities arising from environmental resource utilization, and necessitate regulatory interventions. Effective environmental regulations, coupled with government subsidies and grants for green technology research and development, lead to create win-win scenario via fostering innovation while protecting the environment [6].

Green technology innovation falls under the realm of technology innovation, including management and technology innovations aiming to ensure environmental protection [7]. In exploring new methods for green chemistry and emissions reduction, employing efficient technologies is essential [8,9]. While some interventions can enhance productivity, but on the other side they ignore environmental externalities such as technology innovations prioritize boosting output in energy-intensive sectors. Consequently, various sectors adapt green principles, increasingly focused on both environmental concerns and economic growth [10,11]. In the pursuit of green chemistry and emissions reduction, innovative sensing technologies play a pivotal role. Deng et al. developed a Ge-core/a-Si-shell nanowire field-effect transistor, providing a sensitive detection solution for terahertz frequencies [12]. Additionally, they enhanced detection efficiency and precision with a surface plasmon polariton graphene mid-infrared photodetector utilizing multifrequency resonance [13]. These advancements not only improve environmental monitoring capabilities but also significantly aid corporate efforts in energy conservation and pollution reduction. Green technology adheres to ecological laws of ecological economy, emphasizing energy and resource conservation in the innovation process while diminish pollution and ecological damage. It aims for minimal negative ecological impact in technology innovation process. Green technology innovation fosters long-term sustainable development, deliver economic, social, and environmental benefits via conserving resources, energy, and minimizing the environmental damages [14,15]. The substantial influence of green technology innovation is examined previous researchers, and found its significant impact to reduce the environmental emissions. Green technology innovation may also escalate enterprises' production costs, necessitating greater consideration of enhancing energy consumption efficiency. Therefore, investigating the influence of green technology innovation on energy consumption is imperative in chemical sector of China. Hence, this study delves into the influence of green technology innovation on energy consumption in chemical industries of China.

Currently, China is in a phase of transition, committed to steer its energy system toward green practices to get a "new normal", where transition could balance the economic and ecological goals [16]. In corporate sector, it is critically important to remain profitable while being sustainable, so compromise could not do any of these both concerns as per the stakeholder theory. China's transition is underscored by the implementation of environmental regulations and a growing societal emphasis on sustainable development, elevating the importance of green technology innovation in the eyes of businesses, government, and the market. This transition is positioned as a catalyst for sustainable progress, green technology innovation facilitates a harmonious balance between economic advancement and environmental preservation [17, 18]. However, its impact on enterprises in terms of corporate value is remained ambiguous as some studies found positive effects of green innovation on businesses [7, 19], other suggested that investments in environmental endeavors could potentially rise enterprise productivity, raise concerns over the cost recovery of green investments [20,21]. As

per the stakeholder theory, there should have been balance in meeting the interests of wide range of interests, and thus green technology innovation is expected to deploy for balancing the energy and economic benefits of enterprises [22]. Drawing on this theory, this paper empirically explores the influence of green technology innovation on corporate value in chemical industries of China.

The impact of green technology innovation on energy consumption and corporate value is constituted by various mechanisms but the most important one is Environmental, Social, and Governance (ESG) performance. In recent years, there has been a notable shift in corporate objectives, shifting from short-term profit maximization to sustainable ESG performance [23, 24]. Stakeholder theory posits that ESG emphasizes the synchronized advancement of the economy, environment, and society, advocating for long-term goal orientation, and the pursuit of social value maximization by enterprises [25]. This approach could foster trust in uncertain environments, and push enterprises to adopt sustainability practices, augmenting their investments and foster ESG advantages, which can encourage positive business development. Empirical research in this realm has primarily focused on two key areas: the economic ramification of corporate ESG and multitude of factors that influence ESG performance. Several studies show that ESG is a crucial source of corporate risk directly or indirectly influence company's financial performance [26 – 28]. It is also shown by empirical literature that better ESG performance has led the enterprises to get easier access to financial resources at a lower cost [29].

Research indicates a growing market interest in the transparency of firms' ESG performance as it allows to develop a better enterprise credibility [30]. Despite the findings of numerous studies to investigate the influence of ESG on different aspects of firms, existing literature does not provide a conclusive answer [31 – 33]. This paper aims to investigate the moderating role of ESG disclosure on the nexus of green technology innovation with energy consumption and corporate value. By extending stakeholder theory, this paper explains that how firms derive corporate value from ESG disclosure when investing on green technology innovation. Instead of tradition view of maximizing shareholders' wealth, stakeholder theory states that other parties such as customers, employees, suppliers, banks, communities, banks, and regulatory agents, are integral stakeholders. Drawing on these all discussion, it can be argued that ESG disclosures may appeal more to both investors and financial institutes to gain high credibility, and thus the impact of green technology innovation on energy consumption and corporate value can be moderated by ESG disclosure.

By utilizing the data of 133 chemical industries' A-share listed enterprises of China, this study employs two-way fixed effects model to analyze the influence of green technology innovation on energy consumption and corporate value. Additionally, it incorporates the moderating effects of ESG disclosure to examine its influence on the nexus of green technology innovation on energy consumption and corporate value. The findings of this study shows that green technology innovation significantly reduces the energy resources' consumption and increases the corporate value. The moderating effects of ESG disclosure are found positive for the nexus of green technology innovation with energy consumption and corporate value.

Remaining of this paper is structured as follow; Section (2) presents theoretical and empirical literatures and develop hypothesis to show the links between independent, dependent, and moderating variables, Section (3) covers methodology and data sources of study, Section (4) presents the empirical results with their interpretations, Section (5) concludes the paper with policy implications of findings.

2. Literature Review and Hypotheses Development

With the global population experiencing rise, living spaces and resources are shrinking. Conventional manufacturing, production, and business models are struggling to keep pace with the economic development, and leading to deplete natural resources and escalate environmental damages [34]. In response to these damages, countries are prioritizing green technology innovation to conserve energy, resources, and mitigate ecological degradation. This shift leads to achieve sustainable development that could create balance between economic and ecological benefits [35, 36]. Green technological innovation is the optimal solution that facilitates the allocation and optimization of natural resources, and it can enhance the efficiency of raw material and energy utilization to promote energy-saving products [37]. It fosters the transition from the "three high and one low" production model to the "three low and one high" paradigm, and it can foster low-carbon economic growth, and

stimulate development. The relationship between green technology innovation and resource utilization efficiency is explored by numerous researchers and found the positive connection [38,39].

Resources are mandatory for national economic and social development [40], and their efficient use is crucial to maximize their utility and achieve high output. Industrialization has led to increase demand and extensive exploitation of resources, and thus resulting in degradation and depletion [41]. Low utilization efficiency could pose significant challenges to the economic development [42], and there could be substantial benefits achieve through green technology innovation for energy conservation, emission reduction, and promoting sustainable resource utilization [43, 44]. The emergence of the technology revolution offers both opportunities and challenges of the global green development. Technological innovations are imperative to promote natural resource utilization efficiency and green technology innovation can address the economic and environmental dilemmas of low-carbon development, and has crucial role for all, including industries and enterprises. Amore and Bennedsen [45] stated that ineffective corporate governance hinders the potential benefits of green technology innovation. Bi, et al. [46] proposed analytical framework for low-carbon technology innovations within the global value chain, and Albort-Morant, et al. [47] underscored the importance of efficient green innovation to enhance corporate performance.

As per the "new normal" transition of China, current production and energy consumption models prioritize environmental quality improvement and innovation [48]. The multifaceted nature of factors influences natural resource efficiency and thus necessitates comprehensive analysis, including technology systems and energy consumption-related factors [49]. Despite extensive literature, research gaps exist in understanding the nexus between green technology innovation and energy consumption efficiency [50]. As per the "Porter Hypothesis", green technology innovation improves the energy efficiency and reduce energy consumption in manufacturing operations [51]. This theory suggests that stringent environmental regulations drive innovation, and thus resulting in cleaner production processes that lead to improve the economic competitiveness while also reducing the environmental impact. Drawing on this theory, and findings of previous empirical literature, we can postulate this hypothesis:

Hypothesis 1: Green technology innovation mitigates the energy consumption in chemical industries' enterprises of China.

Green technology innovation includes advancements which aims at environmental protection and preservation. Chen, et al. [52] states that green technology innovations in both software and hardware, relates the development of green products and processes. Due to the greater governmental and societal attention toward environmental issues and resources scarcity, sustainable development has become crucial for every sector. Enterprises also increasingly prioritize green innovations to align with market preferences and achieve competitive advantages. They are positioned to conduct for sustainable development, and create a win-win scenario through balancing profitability with environmental preservation [17, 18]. The drivers of green innovation are categorized into internal and external factors [53]. External drivers primarily sourced by government interventions and stakeholder influences. Governmental environmental regulations and environmental awareness significantly foster enterprise innovation, and lead to gain green patents [54,55]. R&D tax credits serve as the incentives and they foster green production innovation investments, while emission taxes positively impact green innovation [56]. Moreover, environmental disclosures foster green innovation [57], as consumer preferences have been shifted toward green products, which are pushing enterprises to meet the rising environmental demands [58]. Collaborations with environmentally friendly suppliers with increase foreign stakeholder ownership is found a significant factor to promote green innovation in state-owned enterprises [59]. Additionally, employee proficiency in green practices promote positive impacts of enterprise green innovation [60]. Enterprise characteristics such as firm size, firm age, and firm nature significantly influence green innovation capabilities, such as larger firms face high stakeholder pressure, and thus necessitating green innovation to maintain strong competitiveness [61].

Previous research studies show that green innovation stimulates environmental, financial, and social performance [62], and thus facilitating access to government financial support and green credit loans, and thus alleviate enterprise financing constraints [63]. Notably, green innovation promotes enterprise performance

metrics such as competitive advantage, benefit, labor productivity, and ecological reputation [19, 64]. Some studies report that green innovation increases operational costs (de Oliveira et al., 2018), and underscoring the importance of simultaneously enhancing environmental performance and resource efficiency to gain better financial goals [65]. Existing studies focus on factors such as corporate social responsibility, firm size, sales growth, stakeholder wealth maximization, and profitability when examining corporate value [66]. Notably, sustainability-related disclosures positively influence corporate value [67], with efficient firms enjoying greater market valuation than their competitors. Moreover, engagement in environmental responsibility and management increases corporate value [68]. However, there are conflicting views regarding the impact of environmental and sustainable investments on enterprise costs and productivity [69]. Overall, few studies examine the relationship between green innovation and corporate value, and this scenario is not explored in case of the chemical industries of China. Drawing on these views presented by previous studies, we postulate this hypothesis:

Hypothesis 2: Green technology innovation positively influences corporate value in China's chemical industries' enterprises.

Enterprises' commitment towards environmental, social, and governance responsibilities entails significant opportunities and challenges, influencing investors' decisions based on ESG rating [70,71]. Enterprises having ample production resources could attain higher revenues and rapid short-term development with minimal external investor demand. Firms with scare resources may not able to meet their ESG commitments, and thus could not achieve the potential benefits. Enterprises adopt crude production model are characterized by high consumption, input, pollution, and low technological sophistical, incur substantial environmental management costs [72]. Enterprises operating in regions with low resource abundance and dependency could rely on internal capital allocation, resource accumulation, technological innovation, and organizational change to create opportunities can intensify competition. The current landscape emphasizes low-carbon development and environment, and enterprises can actively meet their social and environmental responsibilities at achieve competitive advantage in the market. Consequently, the increasing dependence of enterprises on resources can impede the fulfilment of integrated ESG performance.

Previous studies on the nexus between ESG information disclosure and firm value has been remained primarily focused on specific environmental, governance, social, and ethical events. For instance, Blacconiere and Patten [73] argued that investors are less reactive to companies with comprehensive environmental information during the industrial crisis. Recent research presented a scope to include both broader ESG disclosure cases. Richardson and Welker [74] stated that unexpected negative links between ESG disclosure and market value among Canadian companies, present positive association [75]. The positive synergy theory states that firms with better ESG practices can attract more investors which create higher value for them [76]. It can be argued that ESG transparency increases the credibility of firms in eyes of the institutions and investors which lead to create high value for them in long run. Additionally, the affordability theory presents reverse casualty, wherein financial performance also drives ESG practices and performance. Enterprises which are aspired to engage in sustainable practices, could e able to attract wide range of stakeholders. The delegation social responsibility of firms leads to create a positive sense about the firms, and thus help them to create high value for them. Drawing on these views regarding the role of ESG disclosure for energy consumption and corporate value, we postulate this hypothesis:

Hypothesis 3: ESG disclosure moderates the influences of green technology innovation on energy consumption and corporate value in chemical industries' enterprises of China.

3. Empirical Strategy and Data Sources

3.1. Data Sources

This paper employs empirical strategy and uses data of 133 Chinese A-share listed enterprises of chemical industries to examine the influence of green technology innovation on energy consumption and corporate value over the period of 2012–2022. The data of green technology innovation is sourced from database of the Chinese

Research Data Services (CNRDS) Platform. The data sources of energy consumption include listed companies' annual reports, social responsibility reports, and company website. The corporate ESG (Environmental, Social, and Governance) data is sourced from Huazheng ESG rating, while other data are obtained from China Stock Market & Accounting Research Database (CSMAR), and the National Statistics Bureau. Before conducting empirical analysis, the sample is screened and processed to make it balanced for analysis. This includes excluding companies with missing ESG scores, energy consumption data, and/or green technology innovation data, ST (special treatment) or PT (partial treatment) companies in chemical industries of China. The final sample size is 133 Chinese A-share listed enterprises of chemical industries, and sample period is 2013–2022.

3.2. Model and Variables

3.2.1. Econometric Model

Two-way fixed effects model is employed in this study with fixed effects of firm and year. The model is constructed as follows:

$$En\_Cons_{it} = \alpha + \beta_1 \mathrm{TGTI}_{it} + \beta_j \mathrm{X}_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

where i is the listed enterprises, t is the time, β is the regression coefficient of the associated variable, En_Cons_{it} is the energy consumption of firm i in year t, TGTI_{it} is the green technology innovation of firm i in year t, X is the control variable, μ_i and δ_t are the firm and time-fixed effects, and ε is the standard error term. In this model, we will add P/B_{it} as the corporate value of firm i in year t, and now model will be reshaped as:

$$P/B_{it} = \alpha + \beta_1 \mathrm{TGTI}_{it} + \beta_j \mathrm{X}_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

Further, we will incorporate moderating variable ESG in both baseline models (1) and (2), and interaction term will be retrieved. With the interaction term, our models will be framed as:

$$En\_Cons_{it} = \alpha + \beta_1 \mathrm{TGTI} * \mathrm{ESG}_{it} + \beta_j \mathrm{X}_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

$$P/B_{it} = \alpha + \beta_1 \mathrm{TGTI} * \mathrm{ESG}_{it} + \beta_j \mathrm{X}_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

where $TGTI * ESG_{it}$ is the moderating variable to examine the influence of ESG disclosure on the nexus of green technology innovation with energy consumption and corporate value.

3.2.2. Variables of Study

Independent Variable: Enterprise green technology innovation [77], total green innovation [78]: number of green invention patent applications + number of green utility model applications + 1, take the natural logarithm

Dependent Variables: Energy consumption [79] is calculated a s: Energy Consumption (EN_Cons) = water consumption × 0.0002429 + electricity consumption × 1.229 + coal consumption × 0.7143 + natural gas consumption × 13.3 + gasoline consumption × 1.4714 + diesel consumption × 1.4571 + district heating × 0.03412,

The conversion coefficients are sourced from the official website of the Energy Bureau of China.

Price to book value (P/B) is calculated as Market value of the stock / book value of stock

Moderator: ESG disclosure is the average of Huazheng ESG rating for environment, social, and governance score.

Control Variables: The control variables of this study include return on assets (ROA), Research and Development Expense ratio (RD), Cash ratio (Cash), Debt to Equity ratio (D/E), and firm size (natural log of Total Assets: TA). These variables are selected based on their relevance to the model of this study.

4. Empirical Results

4.1. Descriptive Statistics

The variables of this study and their descriptive statistics are shown in Table 1. It can be seemed that green technology innovation (TGTI) has mean value of 0.932749, and standard deviation of only 1.037471, reflecting the normal distribution of data. It is shown that its minimum and maximum range is also not so high, showing that there are companies which are moderately, lower, and highly level of influenced by the green technology

innovation in chemical industries of China. The energy consumption (EN_Cons) has mean value of 7.316465, and standard deviation is 0.171909, showing that companies have normally distributed data of this variable as well. Price to book ratio (P/B) has presented the range of 0-67.0272 for the minimum and maximum values, and moreover the mean value is 2.879905, showing that most of the companies are priced at higher value than their actual book value in chemical sector of China. Moderator, ESG disclosure has mean value of 72.8626, showing a good level of ESG disclosure in our sample. The descriptive statistics of the control variables are also in a normal range, and there could not have been high level of deviation in these variables except D/E. Additionally, Figure 1 shows the scatter charts for the green technology innovation, energy consumption, price to book ratio, and ESG disclosure for the period of 2013–2022.

Table 1. Descriptive statistics.

Type	Variable	Symbol	Obs	Mean	Std. dev.	Min	Max
Independent	Green technology innovation	TGTI	1330	0.932749	1.037471	0	5.273
Dependent	Energy Consumption	En_Cons	1330	7.316465	0.171909	6.95046	7.64032
	Price to Book Ratio	P/B	1330	2.879905	3.310807	0	67.0272
Moderator	ESG Disclosure	ESG	1330	72.8626	6.029958	48.9	87.46
Control	Return on Assets	ROA	1330	0.049415	0.129446	-3.3237	0.721492
	Research and Development Expense Ratio	RD	1330	0.014223	0.019875	0	0.233228
	Cash Ratio	Cash	1330	0.586413	0.929422	0.001117	7.91184
	Debt to Equity ratio	D/E	1330	1.177692	6.183203	-151.933	95.5314
	Natural log of Total Assets	TA	1330	22.35915	1.058444	19.6592	26.6165

4.2. Correlation Analysis

Table 2 presents the results of the correlation analysis of all variables of this study. It can be seemed that TGTI has negative association with the En_Cons, reflected by the correlation value of -0.1651. It can be argued that with the increased green technology innovation there could have been lower energy consumption in chemical industries of China. TGTI has presented a positive relationship with P/B, reflected by the value of 0.0824. This relationship shows that green technology innovation allows the enterprises in China's chemical industries to have the greater corporate value with better green innovation. Moreover, ESG has shown positive association with TGTI and P/B, while negative with En_Cons. This association shows that when there will be increased ESG ratings, there will be greater level of the green technology innovation. Moreover, improved ESG ratings direct to achieve greater corporate value, and with better ESG ratings there is reduction in energy consumption. It can be simply said that ESG has significant links with the independent and dependent variables, so there could have been direct influence of this variable on the nexus of independent with the dependent variables. The moderating effects can strengthen and weaken the nexus of green technology innovation with energy consumption and corporate value.

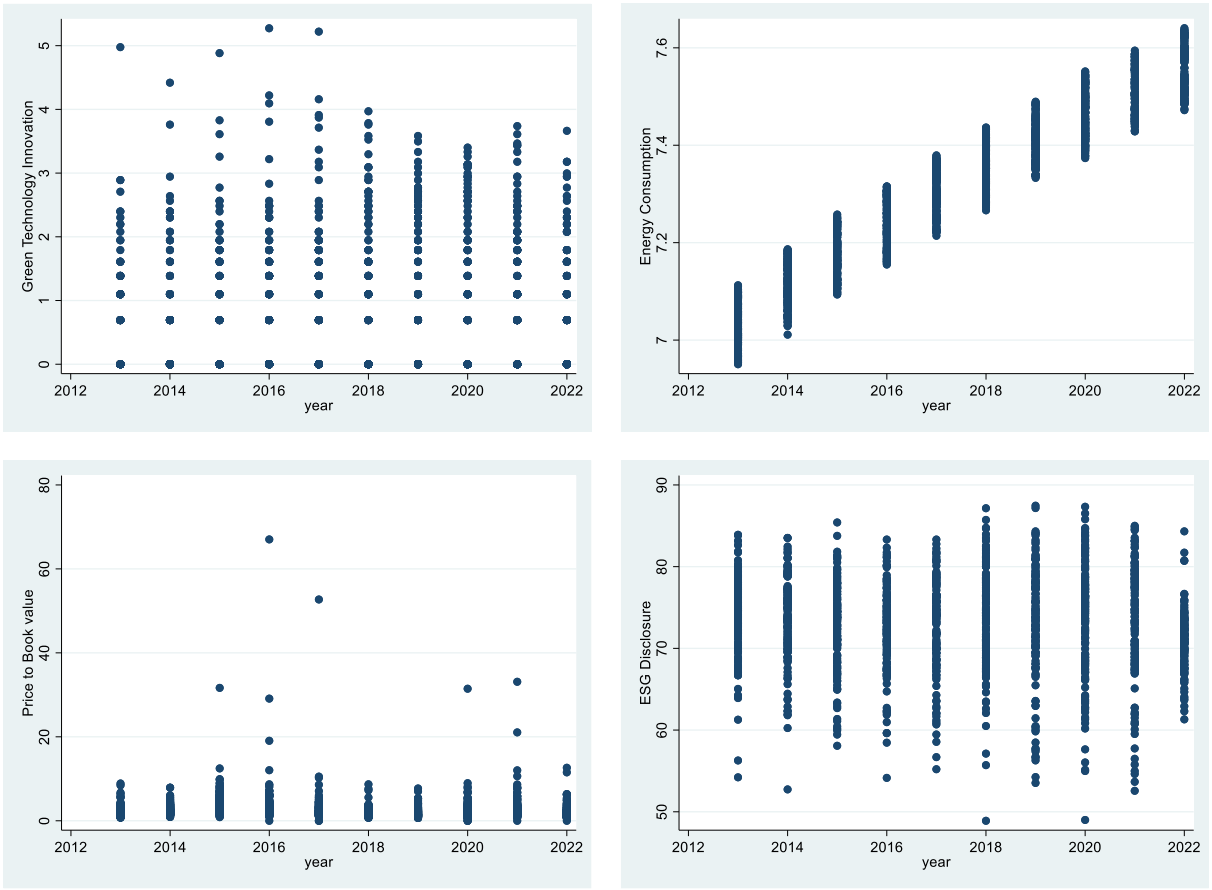

Figure 1. Scatter charts for TGTI, En_Cons, P/B, and ESG disclosure.

Table 2. Correlation analysis.

	En_Cons	P/B	TGTI	ESG	ROA	RD	Cash	D/E	TA
En_Cons	1								
P/B	-0.0652***	1							
	(0.0174)								
TGTI	-0.1651***	0.0824***	1						
	(0.00)	(0.0026)							
ESG	-0.0699***	0.1161***	0.1272***	1					
	(0.0108)	(0.00)	(0.00)						
ROA	-0.0115	-0.0528**	0.0707***	0.2148***	1				
	(0.6753)	(0.0544)	(0.0099)	(0.00)					
RD	0.6225***	-0.0554**	0.0966***	0.0554**	-0.0057	1			
	(0.00)	(0.0435)	(0.0004)	(0.0435)	(0.8343)				
Cash	0.0236	0.0209	-0.1641***	0.0315	0.0473*	0.0107	1		
	(0.3901)	(0.4465)	(0.00)	(0.2515)	(0.0844)	(0.6961)			
D/E	0.0108	0.5069***	0.0525**	-0.0654**	0.0064	0.007	-0.0685***	1	
	(0.6951)	(0.00)	0.0556	(0.0171)	(0.8144)	(0.7997)	(0.0125)		
TA	0.2383***	-0.2215***	0.4517***	0.0816***	0.1295***	0.0743***	-0.3308***	0.0821***	1
	(0.00)	(0.00)	(0.00)	(0.0029)	(0.00)	(0.0067)	(0.00)	(0.00)	

Note: ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

4.3. Baseline Regression Results

Table 3 presents the baseline regression results of this study for model (1) and model (2). Results of model (1) are reported in column (1), and results of model (2) are reported in column (2). It can be seemed in column (1) that regression coefficient for TGTI for En_Cons is -0.0153, showing that with improved green technology innovation there is reduction in energy consumption. Specifically, with one unit increase in green technology innovation, there will be reduction of 0.0153 in energy consumption chemical enterprises of China, and it accepts our hypothesis 1. The negative impact of green technology innovation on energy consumption shows that when a company moves toward green technology solutions, it gets the potential to utilize less resources and thus achieves resource efficiency, these results support the findings of previous studies [38,80].

Table 3. Baseline regression results.

	(1)	(2)
Variables	**En_Cons**	**P/B**
TGTI	-0.0153***	0.0940***
	(-3.23)	(2.95)
ROA	-0.0484*	0.4864
	(-1.71)	(0.82)
RD	5.1379***	-10.1899**
	(23.74)	(-2.25)
Cash	0.0302***	-0.3870***
	(5.50)	(-3.36)
D/E	-0.000272	0.2821***
	(-0.00)	(24.43)
TA	0.1216***	-0.7414***
	(13.17)	(-3.84)
Constant	4.4948***	19.3841***
	(22.01)	(4.54)
Firm & Year FE	Yes	Yes
R-Squared	0.5697	0.3492
Obs.	1,330	1,330

Note：The values in parentheses are the t-statistics; ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

As per the results, reported in column (2), TGTI has regression coefficient of 0.0940, which is significant at 1%. This result indicates that improved green technology innovation boosts the price/book ratio of Chinese A-share listed enterprises of chemical industries. In numeric terms, if there is one unit increase in TGTI, the value of P/B will be increased by 0.0940, so this finding leads us to accept hypothesis 2. The positive impact of green technology innovation on corporate value reflects that chemical industry firms having greater focus on adapting the green technologies, can attract more investors, thereby resulting a greater P/B ratio, and this finding is also in line with the previous literature [81].

4.4. Checking Robustness of Baseline Results Using 2SLS

To further confirm the robustness of baseline findings, this study employs two-stage least squares (2SLS) model to assess the impact of green technology innovation on energy consumption and corporate value in Chinese A-share listed enterprises of chemical industries. By following previous studies [82], we used green patent applications (GPT_Ap) as the instrumental variable to address potential endogeneity concerns. By

employing 2sls, we can mitigate biases arising from unobserved reverse causality and heterogeneity, thereby providing additional insights in the relationship between green technology innovation, energy consumption, and corporate value. This approach enhances the rigor and reliability of the analysis [83], contributing to a more comprehensive understanding of dynamics at place within context of Chinese chemical industries.

The results of 2SLS model are reported in columns (1) to (4) of Table 4. We have reported results of first stage and second stage for both of baseline models of this study. It can be seemed in column (1) that GTP_Ap has regression coefficient of 0.60896 for TGTI, indicating the fitness of this instrumental variable to influence the green technology innovation. Column (2) reports the results of second stage regression, and shows that the impact of TGTI even in 2sls model is negative as indicated by the regression value of -0.01159. It can be argued that there is robust impact of green technology innovation on energy consumption. Column (3) of Table 4 reports first stage regression results and shows that impact of GPT_Ap is like the results reported in column (1) because the instrumental variable is similar. The second stage results are shown in column (4) of Table 4, indicating that with the increased green technology innovation there will be greater corporate value. It can be said that P/B ratio is positive influenced even when used instrumental variable approach. Based on the results of Table 4, w can claim that baseline results are still unchanged and the impact of green technology innovation on energy consumption is negative, and on corporate value is positive.

Table 4. Checking robustness of baseline results with 2SLS.

	(1)	**(2)**	**(3)**	**(4)**
	First stage	Second stage	First stage	Second stage
Variable	TGTI	En_Cons	TGTI	P/B
GPT_Ap	0.60896***		0.60896***	
	(26.24)		(26.24)	
TGTI		-0.01159***		0.0332***
		(-2.96)		(3.02)
ROA	0.04884	-0.05379*	0.04884	-0.65579
	(0.30)	(-2.13)	(0.30)	(-1.07)
RD	-1.14483	4.38197***	-1.14483	-10.48333**
	(-1.07)	(26.45)	(-1.07)	(-2.61)
Cash	0.00843	0.01993***	0.00843	-0.12801
	(0.34)	(5.12)	(0.34)	(-1.36)
D/E	-0.006	-0.007	-0.006	0.28227***
	(-0.02)	(-0.13)	(-0.02)	(22.55)
TA	0.18707***	0.02741***	0.18707***	-0.89425***
	(7.86)	(6.44)	(7.86)	(-8.67)
Constant	-3.78330***	6.64448***	-3.78330***	22.91260***
	(-7.16)	(71.78)	(-7.16)	(10.21)
R-Squared	0.4984	0.4131	0.4984	0.3403
Obs.	1,197	1,197	1,197	1,197

Note: The values in parentheses are the t-statistics; ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

4.5. Moderating Effects of ESG Disclosure

This study considers the moderating effects of ESG disclosure as it is found a factor which can posit pressure on firms to move toward green processes and products. The moderating effects of ESG disclosure are inspected by creating an interaction term with TGTI, and running the model 3 and 4. The results of these models

are reported in column (1) and (2) of Table 5 respectively. It is shown that TGTI*ESG has regression coefficient of -0.02026, which is greater than regression coefficient of TGTI reported in baseline results (in column 1 of Table 3). It can be said when ESG disclosure significantly strengthens the influence of green technology innovation on energy consumption in A-share listed enterprises of Chinese chemical industries. The results of model (4) are reported in column (2) of Table 5, showing the regression coefficient of 0.11558. It can be claimed that with the ESG moderating effects, the influence of TGTI on P/B has become stronger.

Table 5. Moderating effects of ESG disclosures.

	(1)	**(2)**
Variables	En_Cons	P/B
TGTI*ESG	-0.02026***	0.11558***
	(-3.37)	(3.02)
ROA	-0.0489517*	0.4836511
	(-1.73)	(0.82)
RD	5.1395***	-10.1844**
	(23.74)	(-2.25)
Cash	0.03032***	-0.3872***
	(5.51)	(-3.36)
D/E	0.000808	0.2822***
	(0.01)	(24.44)
TA	0.1217***	-0.7451***
	(13.17)	(-3.86)
Constant	4.4934***	19.4614***
	(21.99)	(4.55)
Firm & Year FE	Yes	Yes
R-Squared	0.5696	0.3492
Obs.	1,330	1,330

Note: The values in parentheses are the t-statistics; ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively.

These findings state that when there are improved ESG ratings, the impact of green technology innovation on corporate value becomes greater. Overall, results reported in Table 5 accept the moderating effects of ESG disclosures, and accept hypothesis 3.

5. Conclusion and Policy Implications

Using data of 133 Chinese A-share listed enterprises of chemical industries of China for the period of 2013-2022, this study employs two-way fixed effects model to investigate the effects of green technology innovation on energy consumption and corporate value. Additionally, this study incorporates the moderating effects of ESG disclosures to show its influence on the nexus of green technology innovation with energy consumption and corporate value. The results of this study show that green technology innovation significantly reduces the energy consumption of the chemical enterprises of China. The impact of green technology innovation on corporate value is also found positive and significant, indicating the value addition done by the green innovations for chemical enterprises. The results of 2sls model shows that baseline results are robust. Moreover, the moderating effects of ESG disclosure are found significant to strengthen the influence of green technology innovation on energy consumption and corporate value.

Thera are numerous policy implications directed by the findings of this study. First, policymakers in

chemical enterprises can increase the volume of investments on green technology innovations to gain the resource efficiency, and thus reducing the overall costs of their operations. Second, there can be use of green technology innovations to attract investors, and thus garnering better market value. Third, green technology innovations could have been focused to achieve the competitive advantage in chemical industry, and gaining a better image in eyes of stakeholders. Fourth, there can be enhanced level of focus on ESG disclosures to get better ratings, and thus firms can be able to strengthen the effects of green technology innovations to achieve high market valuation and boost energy efficiency.

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The authors declare no conflict of interest.

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