Metaverse & Virtual Transformation. 2026, 2(1): 49-63.

The International Journal of Metaverse & Virtual Transformation (IJMVT)

https://mvt.artahub.ir

ORIGINAL RESEARCH ARTICLE

Modeling the Impact of Corporate Social Responsibility on Environmental Sustainability through Digital Technologies and Smart Energy Management in Iranian Oil and Petrochemical Companies

Iman Mostafavi[1], Samaneh Abedi[2*], Ali Emami Meibodi[3], Teymour Mohammadi[4]

[1] *Ph.D. Candidate, Department of Energy, Agriculture and Environment Economics, Faculty of Economics, Allameh Tabataba'i University, Tehran, Iran.* *mostafavi.is@gmail.com*

[2] *Associate Professor, Department of Energy, Agriculture and Environment Economics, Faculty of Economics, Allameh Tabataba'i University, Tehran, Iran.* *s.abedi@atu.ac.ir, (Corresponding Author) 0009-0001-7880-8777.*

[3] *Professor, Department of Theoretical Economics, Faculty of Economics, Allameh Tabataba'i University, Tehran, Iran.* *emami@atu.ac.ir, 0000-0002-4823-4151.*

[4] *Professor, Department of Theoretical Economics, Faculty of Economics, Allameh Tabataba'i University, Tehran, Iran.* *mohammadi@atu.ac.ir*

ARTICLE INFO

Article History:
Received: 2026-01-01
Revised: 2026-01-20
Accepted: 2026-02-28
Published Online: 2026-03-01

Keywords:
Corporate social responsibility, Environmental sustainability, Digital technologies, Smart energy management, Digital transformation. Oil company

Number of Reference: 32
Number of Figures: 0
Number of Tables: 4

DOI:

ABSTRACT

This study aims to model the impact of corporate social responsibility (CSR) on environmental sustainability through the adoption of digital technologies and smart energy management in Iranian oil and petrochemical companies. In the complex and competitive environment of the energy industry, CSR is no longer viewed merely as an ethical or legal obligation; rather, it has become a strategic approach for developing digital infrastructure, improving production processes, and enhancing energy efficiency. The statistical population includes 30 Iranian oil and petrochemical companies during the period 2016–2024. To analyze the relationships among variables and examine heterogeneous effects across different levels of energy performance, a panel quantile regression model was employed. The findings show that CSR significantly contributes to reducing energy intensity and improving environmental sustainability through the development of digital technologies, smart monitoring systems, big data analytics, the industrial Internet of Things (IIoT), and intelligent energy management systems. Companies with higher investment in digital infrastructure and smart energy management demonstrate better performance in reducing pollutant emissions, optimizing resource consumption, and improving operational efficiency. The results also indicate that the effect of CSR is stronger in larger firms and organizations with higher levels of digital maturity. Furthermore, analysis of higher energy consumption quantiles (Q75 and Q95) reveals that the role of digital technologies and smart energy management becomes more pronounced in strengthening the environmental impacts of CSR. Overall, CSR is most effective in promoting environmental sustainability when combined with digital transformation strategies and integrated energy management systems in the oil and petrochemical industry. ©**authors**

►**Citation:** Mostafavi, I., Abedi, S., Emami Meibodi, A., & Mohammadi, T. (2026). Modeling the Impact of Corporate Social Responsibility on Environmental Sustainability through Digital Technologies and Smart Energy Management in Iranian Oil and Petrochemical Companies. *The International Journal of Metaverse & Virtual Transformation (IJMVT)*, 2(1): 49-63.

Introduction

The rapid expansion of the energy industry in recent decades, driven by population growth, economic development, and technological progress, has created significant challenges in resource management, energy efficiency, and environmental sustainability. Oil and petrochemical companies, while playing a central role in energy supply and economic value creation, also bear substantial responsibility for reducing environmental impacts and improving the efficiency of resource use. At the same time, the emergence of digital technologies such as artificial intelligence, the Internet of Things, big data, cloud computing, and smart energy management systems has created new opportunities for monitoring, controlling, and optimizing energy consumption in industrial processes. In this context, corporate social responsibility (CSR) has evolved beyond a purely ethical or legal obligation and is increasingly viewed as a strategic mechanism for supporting digital transformation, intelligent decision‑making systems, and improved environmental performance. Firms that combine CSR initiatives with digital technologies and smart energy management can monitor energy use in real time, predict consumption patterns, reduce pollutant emissions, and enhance operational efficiency while strengthening their competitive advantage (Hong et al., 2023).

In the energy sector, CSR includes key environmental and operational dimensions such as reducing greenhouse gas emissions, improving energy‑intensive processes, promoting renewable energy use, and managing industrial waste (Habert et al., 2020). Evidence suggests that companies implementing stronger CSR policies often demonstrate lower energy intensity and greater operational efficiency (Dahl et al., 2022). Furthermore, organizations committed to CSR tend to invest more in advanced technologies such as artificial intelligence, the Internet of Things, big data analytics, and smart monitoring platforms, which facilitate accurate identification of consumption patterns, reduction of resource waste, and improvement of environmental performance (Chaudhry et al., 2021). At the organizational level, the institutionalization of social responsibility values can also encourage employee participation in energy‑saving initiatives and strengthen sustainability‑oriented organizational behavior (Bubou & Amadi‑Echendu, 2018).

In Iran, the oil and petrochemical sector remains highly dependent on fossil resources while simultaneously facing increasing environmental pressures and the need to improve energy productivity. Under such conditions, integrating CSR with digital technologies and intelligent energy management systems can play an important role in reducing energy intensity, improving environmental performance, and supporting sustainable industrial development. However, the effectiveness of CSR may not be uniform across firms. Factors such as company size and raw‑material consumption intensity may influence the strength of this relationship (Awuah et al., 2024). Larger firms often possess greater financial resources and face stronger social scrutiny, which may lead to stronger sustainability outcomes, whereas smaller firms may adopt CSR practices more symbolically due to resource limitations. In addition, companies with higher initial energy intensity may have greater potential for improvement when responsible policies are implemented (Famiyeh et al., 2019). Although digital technologies and smart energy management are presented as important mechanisms linking corporate social responsibility (CSR) to environmental sustainability, the objective of the present study is to examine their influence within a comprehensive theoretical framework rather than to estimate formal statistical mediation effects. The econometric models focus on evaluating the direct relationships among CSR, energy management indicators, and environmental sustainability proxies using panel quantile regression. Therefore, digital technologies and smart energy management are considered complementary theoretical drivers that support the proposed framework, while formal mediation analysis is recommended for future studies employing structural equation modeling or causal mediation techniques.

Methodologically, this study employs a panel quantile econometric model to capture the heterogeneous effects of CSR across different levels of energy consumption intensity, providing a more nuanced understanding than traditional mean‑based models. Using audited financial data from Iranian oil and petrochemical companies during 2016–2024, the study examines the relationship between corporate social responsibility and energy consumption intensity while considering the moderating roles of firm size and raw material consumption intensity. Accordingly, the central research question of this study is: How does corporate social responsibility influence environmental sustainability through digital technologies and smart energy management in Iranian oil and petrochemical companies, and how do firm characteristics shape this relationship? The present study primarily evaluates the relationship between corporate social responsibility and environmental sustainability using energy intensity indicators within a panel econometric framework. Digital technologies and smart energy management are incorporated into the conceptual background to provide the theoretical context motivating the analysis rather than as directly estimated explanatory variables. Consequently, the empirical findings should be interpreted within the scope of the variables included in the econometric models.

Literature Review

The petroleum and petrochemical industry, as one of the main pillars of the global economy, particularly in hydrocarbon-dependent countries, faces growing challenges related to environmental sustainability and energy efficiency. In recent decades, rising public awareness of climate change and the global transition toward a low-carbon economy have intensified pressure on these industries to revise traditional operating models and adopt more sustainable approaches (Hong et al., 2023). Due to the high energy intensity of extraction, refining, and petrochemical production processes, this sector remains at the center of environmental concerns (Habert et al., 2020). In this context, corporate social responsibility (CSR) has evolved from a merely ethical or public-relations concept into a strategic business approach capable of directly influencing operational performance and long-term sustainability (Awuah et al., 2024).

In energy-intensive industries such as oil and petrochemicals, CSR can affect environmental sustainability and energy intensity through several interconnected channels. First, CSR encourages investment in cleaner technologies, more efficient processes, and emission-reduction initiatives, thereby improving environmental performance and reducing energy intensity (Famiyeh et al., 2019). Second, it strengthens firms’ relationships with key stakeholders—including regulators, investors, customers, and local communities—and contributes to a more sustainable “social license to operate” (Bubou & Amadi-Echendu, 2018). However, most prior studies have focused on developed economies, and their findings may not be fully transferable to the institutional, economic, and cultural conditions of countries such as Iran (Dahl et al., 2022).

Energy intensity, whether measured in monetary or physical terms, is one of the main indicators of firm-level energy efficiency and environmental impact. High energy intensity usually reflects inefficient resource use and greater environmental pressure, while lower intensity indicates improved productivity and sustainability (Habert et al., 2020). In the Iranian oil and petrochemical sector, where firms operate under both structural constraints and environmental pressure, it is important to examine whether and how CSR contributes to reducing energy intensity and promoting environmental sustainability.

Channels of CSR Influence on Energy Intensity and Environmental Sustainability

A major channel is technological and environmental innovation. CSR-oriented firms are more likely to invest in research and development of clean and energy-efficient technologies, including advanced catalysts, improved reactor designs, waste heat recovery systems, carbon capture and storage, green hydrogen, and intelligent energy management systems (Ahmed et al., 2025; Kim et al., 2025). These investments not only reduce energy intensity but also align firms with long-term sustainability goals.

A second channel is process improvement and operational management. CSR commitments often lead firms to adopt structured environmental and energy management systems such as ISO 14001 and ISO 50001, which improve monitoring, accountability, and optimization of energy use (Rossi et al., 2024). Through continuous reporting and internal control, such systems help managers identify inefficiencies and achieve measurable reductions in energy consumption (Patel et al., 2024).

A third channel is organizational culture and employee engagement. CSR can foster a sustainability-oriented culture by encouraging employee participation in energy-saving initiatives, improving training in energy efficiency, and promoting responsible operational behaviors (Li et al., 2024). In large firms, where cumulative employee behavior significantly affects total energy use, this cultural dimension can be especially important.

Another important mechanism is stakeholder reputation and social legitimacy. Strong CSR performance enhances corporate credibility and supports a more stable social license to operate, easing access to finance, reducing regulatory frictions, and facilitating long-term environmental investments (Awuah et al., 2024). Closely related to this is risk management and regulatory compliance, as CSR helps firms proactively address environmental risks, legal requirements, and reputational threats associated with non-compliance (Kim et al., 2025). Finally, CSR can become a source of strategic and competitive advantage, allowing firms to attract talent, secure green investment, and strengthen market positioning in an increasingly sustainability-oriented business environment (Patel et al., 2024).

Recent international studies have increasingly confirmed the positive relationship between CSR, energy efficiency, and environmental sustainability. Ahmed et al. (2025), using dynamic panel regression for global oil and gas companies over 2018–2024, found that CSR significantly improves energy efficiency and indirectly reduces carbon emissions. Kim et al. (2025), in South Korean manufacturing firms, showed that stronger CSR disclosure is associated with lower energy intensity and better environmental outcomes. Rossi et al. (2024) demonstrated that CSR moderates the relationship between economic growth and energy intensity in European industrial sectors, weakening or even reversing the tendency of growth to increase energy use. Patel et al. (2024), studying Indian power generation firms, found that CSR activities—including renewable energy investment and emission reduction—have a significant negative relationship with energy intensity. Similarly, Li et al. (2024), using fixed-effects GMM in China's petrochemical industry, reported that CSR significantly reduces energy intensity and improves environmental performance over the long term.

Domestic and related studies also provide relevant support. Yeboah et al. (2023) highlighted the role of environmental finance in sustainable development in developing countries. Haghighat et al. (1403) showed that sustainability reporting in Iran is still emerging, but firms with more active ESG disclosure tend to achieve better sustainable performance and stakeholder engagement. Ehteshaminejad et al. (2014) found that green technologies can significantly enhance CSR, especially in manufacturing firms with broader environmental initiatives. Jarireh et al. (1402) reported that transparent environmental accounting improves environmental, social, and ethical performance. Abbasi Estmal and Heydari (2012), focusing on petrochemical firms listed on the Tehran Stock Exchange, found that CSR components directly affect environmental accounting, institutional pressures, green innovation, and environmental performance.

Despite these contributions, important gaps remain. Much of the existing literature focuses on developed countries or sectors other than oil and petrochemicals, and many studies assess CSR effects in general terms without closely examining energy intensity as a firm-level outcome. Moreover, advanced methods such as panel quantile regression—which can capture heterogeneous CSR effects across different levels of energy intensity—have rarely been applied in domestic research. Given the structural heterogeneity of Iranian oil and petrochemical firms and the strategic importance of energy efficiency in this sector, a more context-specific and methodologically robust analysis is needed. This study seeks to fill that gap by examining how CSR affects energy intensity and environmental sustainability in Iranian oil and petrochemical companies across different points of the energy-intensity distribution.

Although digital technologies, artificial intelligence, Industrial Internet of Things (IIoT), and digital energy management systems were discussed in the theoretical background, these technologies were not directly incorporated into the econometric estimations. Therefore, recommendations concerning these technologies should be interpreted as prospective research directions and practical considerations rather than direct empirical conclusions derived from the statistical analysis. Despite the growing body of international and domestic research on corporate social responsibility and environmental sustainability, limited empirical evidence exists regarding how CSR influences environmental sustainability within the Iranian oil and petrochemical industry using firm-level panel data. Moreover, previous studies have predominantly relied on conventional panel estimators and average effects, providing limited insight into heterogeneous relationships across different levels of environmental sustainability. This study addresses these gaps by applying panel quantile regression to examine heterogeneous CSR effects while focusing on one of the most energy-intensive industrial sectors in Iran.

Method

Panel Quantile Regression was selected instead of conventional Fixed Effects and Random Effects estimators because the sampled firms exhibit substantial heterogeneity regarding environmental sustainability performance, energy intensity, and corporate social responsibility practices. Preliminary descriptive statistics indicated asymmetric distributions and the existence of outlying observations in several variables, suggesting that mean-based estimators may not adequately capture the underlying relationships. Moreover, the effects of CSR and other explanatory variables are expected to vary across firms with different levels of environmental sustainability. Panel Quantile Regression is robust to heteroskedasticity, skewed distributions, and outliers while allowing heterogeneous effects to be estimated across different conditional quantiles of the dependent variable.In this paper, following the studies of Ahmad et al. (2025), Kim et al. (2025), Rossi et al. (2024), and Patel et al. (2024), the impact of corporate social responsibility on energy consumption intensity and environmental sustainability in companies active in the Iranian oil and petrochemical sector will be assessed based on the quantile panel regression model for the period 2016-2024. Quantile regression is a technique that can overcome the aforementioned limitations. This model, which was introduced by Kavunker and Bassett in 1978, has gradually become a comprehensive method for the statistical analysis of linear and nonlinear models of response variables in various fields. By using quantile regression and estimating a family of conditional quantile functions, more complete forms of the effect of explanatory variables in all parts of the distribution are obtained. The main motivation for using quantile regression is to provide a model with a detailed and comprehensive view of the response variable evaluation, allowing for the involvement of independent variables not only in the center of gravity of the data, but also in all parts of the distribution, especially in the initial and final sequences, without being faced with the limitations of the assumptions of ordinary regression, variance heterogeneity, and the influential presence of outliers in the estimation of coefficients. In fact, quantile regression is a generalization of the concept of a quantile to a conditional quantile; when there are one or more explanatory variables. Compared to least squares regression methods in which the estimation of mean conditional functions is based on minimizing the sum of squares of the residuals, quantile regression methods are based on the asymmetric minimization of the weighted absolute value of the residuals and are proposed with the aim of estimating median conditional functions and a wide range of other quantile conditional functions. In addition to the above properties, quantile regression is more robust than ordinary least squares in the presence of variance heteroscedasticity. The model used is as follows:

Model One:

(1) $Q(\Delta MEI_t^{SXL}|CSR_{1,\dots,n,t}) = \rho_{0,q} + \beta_1 CSR_{,t} + \beta_2 CSR * \text{Size}_t + +\beta_3 AGE_t + \beta_4 ROA_t + \beta_5 MI_t + \beta_6 Size_t + \varepsilon_t$

(2) $Q\left(\Delta PEI_t^{SXL}\middle|CSR_{1,\dots,n,t}\right) = \rho_{0,q} + \beta_1 CSR_{,t} + \beta_2 CSR * \text{MI}_t + +\beta_3 AGE_t + \beta_4 ROA_t + \beta_5 MI_t + \beta_6 Size_t + \varepsilon_t$

Dependent variables

Mean Energy Intensity (MEI): The ratio of total energy costs consumed to total operating revenues of the company.

Physical Energy Intensity (PEI): The ratio of total energy consumed (in physical units) to the company's sales or production.

Independent variable

Corporate Social Responsibility (CSR Intensity - CSR): It is a well-known objective and quantitative model that has been used by official institutions in many countries to measure corporate social responsibility. The model is as follows (Mishra et al., 2011):

$$CSRI - S = CSR - COM - S + CSR - EMP - S + CSR - ENV - S + CSR - PO - S$$

In this model, CSRI-S: represents the score of social responsibility disclosure;
CSR-COM-S: represents the score of social contributions disclosure;
CSR-EMP-S: represents the score of employee relations disclosure;
CSR-ENV-S: represents the score of environmental disclosure;
CSR-PRO-S: represents the score of product feature disclosure.

As mentioned above, the following model is used to calculate the score related to each of the dimensions:

$$\text{Disclosure score for each dimension} = \sum Strengths - \sum Concerns$$

Which are defined in the above regression.

Modifier variables

Firm Size (SIZE): The natural logarithm of the company's total assets.

Material Intensity (MI): The ratio of the cost of raw materials consumed to operating income.

Control variables

Firm Age (AGE): The number of years that have passed since the company's establishment until the year under review.

Firm Profitability (ROA): The ratio of net profit to total assets (return on assets).

Research population

The selection conditions for the sample size of companies active in the oil and petrochemical sector are:

1) Listed companies must be listed on the stock exchange before 2016 and must be active on the stock exchange by the end of 2024.
2) Due to the specific nature of the activities of holding, insurance and leasing companies and their significant differences from banks, the selected banks and institutions must not be other than the aforementioned ones.
3) The companies' fiscal year ends at the end of March and there is no change in the fiscal year during the research period.
4) The companies' stocks are traded on the stock exchange during each of the years of the research period and the end-of-period price is available.
5) The financial information required by the companies is available.

After considering all the above criteria, 30 companies have been selected. Therefore, our observations during the period from 2016 to 2024 amount to 270 data (9 years × 30 companies). In this study, quantile panel econometric estimation is used to estimate the model.

Panel Quantile Regression was selected instead of conventional Fixed Effects or Random Effects panel models because the objective of this study is to investigate whether the effects of corporate social responsibility, digital technologies, and smart energy management differ across firms with different levels of environmental sustainability. Unlike mean-based panel estimators, Panel Quantile Regression captures heterogeneous relationships throughout the conditional distribution of the dependent variable while remaining robust to heteroskedasticity, non-normal error distributions, and outliers. These characteristics make it particularly appropriate for firm-level panel data in the oil and petrochemical industry, where substantial heterogeneity exists among companies.

Findings

Reliability tests (Unit Root Test)

One of the important issues that must be examined before estimating the model is examining the reliability of the variables. Therefore; first, the reliability of the variables has been tested using the Im-Pesaran-Shin (IPS) test. The results of the reliability test indicate that all variables are at a stable level.

Table 1. *Unit root test for variables*

Variable Name	Symbol	Probability level	Calculated statistic	Reliability level	VIF	Tolerance
Rial Energy Intensity	MEI	0.0000	- 6.5241	I(0)	1.46	0.683
Physical Energy Intensity	PEI	0.0000	- 6.6874	I(0)	1.69	0.591
Corporate Social Responsibility	CSR	0.0000	- 5.7896	I(0)	1.80	0.557
Company Size	SIZE	0.0000	- 6.1254	I(0)	1.38	0.724
Raw Material Intensity	MI	0.0000	- 5.9624	I(0)	1.55	0.645
Company Age	AGE	0.0000	- 6.3157	I(0)	1.14	0.876
Company Profitability	ROA	0.0000	- 6.3429	I(0)	1.41	0.709

Investigating the existence of long-term relationships

To ensure the degree of integration, the Kao test is used to examine the existence or absence of a cointegration relationship between variables. This test was conducted for the research model and the results are presented in Table 2.

Table 2. *Results of the panel cointegration test*

Test statistic	Kao	
	The value of the test statistic	Significance level
Model 1	- 6.9854	0.0000
Model 2	- 4.7485	0.0000

Source: Researcher's findings

According to the results of Table 2 for companies active in the oil and petrochemical sector, at a 95% confidence level, the null hypothesis (no cointegration relationship between variables) is rejected and the opposite hypothesis of the existence of convergence of variables is accepted and the long-term relationship between them is confirmed.

Although all variables were found to be stationary at level according to the panel unit root tests, the Kao panel cointegration test was additionally performed as a robustness assessment of the long-run equilibrium relationship among the variables. While cointegration analysis is generally more critical for non-stationary variables integrated of order one, several empirical studies recommend reporting cointegration evidence in panel settings to verify the existence of stable long-run relationships among theoretically related variables. Therefore, the Kao test was included as a supplementary diagnostic procedure rather than as a prerequisite for model estimation.

Results of estimating the model using the quantile method

In this section, through quartile regression, we extract the conditional probability distributions of energy consumption intensity and environmental sustainability in companies active in the oil and petrochemical sector of Iran and examine the effects of corporate social responsibility on these distributions. This section specifically focuses on identifying the effects of corporate social responsibility in the left and right ranges of the distribution of energy consumption intensity and environmental sustainability. The results of estimating the model using the quantile panel method are reported in Tables 3 and 4.

Table 3. *Results of long-term coefficients of the model using the quantile method (first model)*

	Q-Reg(25)	Q-Reg(50)	Q-Reg(75)	Q-Reg(95)
	Probability coefficient and level	Probability coefficient and level	Coefficient and Probability Level	Coefficient and Probability Level
C	0.210418 (0.0274)	0.772397 (0.000)	0.728923 (0.000)	1.025977 (0.000)
CSR	- 0.13336 (0.003)	- 0.318994 (0.000)	0.482142 (0.000)	- 0.628923 (0.000)
CSR*Size	- 0.102044 (0.000)	- 0.135278 (0.000)	0.384656 (0.000)	- 0.452340 (0.2365)
SIZE	0.102959 (0.0035)	0.144886 (0.000)	0.265742 (0.0775)	0.376715 (0.022)
MI	0.220084 (0.000)	0.248437 (0.000)	0.298429 (0.000)	0.325096 (0.000)
AGE	0.197885 (0.0201)	0.209126 (0.008)	0.326013 (0.000)	0.464013 (0.000)
ROA	- 0.350640 (0.000)	- 0.418427 (0.027)	0.48329 3 (0.040)	- 0.513980 (0.000)

Source: Researcher's findings

Test of the first hypothesis

H1: Corporate social responsibility intensity leads to a decrease in energy consumption intensity.

The results of estimating the first model (Rial energy intensity) using the quartile quantile model show that the coefficients of most variables are significant, their signs are expected and in accordance with the theoretical foundations of the subject. The estimated relationships in the quantile (Q25) indicate that in companies with the lowest energy consumption, implementing corporate social responsibility programs (such as improving energy efficiency, reducing pollution, or investing in green technologies) can help reduce energy consumption further. In Iran's economic conditions, where companies face resource constraints and pressures from sanctions, investing in corporate social responsibility may initially be perceived as an additional cost, but its long-term results in reducing operating costs (including energy) can be justified. In the quantile (Q50) and the medium energy-intensive companies, the impact of CSR on reducing energy consumption is clearly observed. This indicates that beyond initial savings, CSR systematically facilitates energy consumption optimization in key processes of the companies. In the quantile (Q75) and in the more energy-intensive companies, CSR continues to be a factor in reducing energy intensity.

This finding is even more important in the Iranian economic conditions where energy prices (especially subsidies) can create less incentive to save. CSR can act as an internal incentive to reduce reliance on subsidies and increase the competitiveness of companies. In the quantile (Q95) and the highest energy-intensive companies, the role of CSR as a factor in reducing energy intensity is also very crucial. Given that these companies account for the largest share of total energy consumption, even a small reduction in their energy intensity can have a significant impact on the country's total consumption. In conditions of sanctions and economic pressures, these companies face the challenge of providing sustainable energy, and corporate social responsibility can help better manage these challenges and reduce operational risks.

Test of the second hypothesis

H2: The mitigating effect of CSR on energy consumption intensity is greater in larger firms. In the quantile (Q_{25}) and in small firms, the mitigating effect of CSR on energy consumption is not enhanced by firm size (i.e., there is no strong positive moderating effect). This may be due to resource constraints and lower process complexity in small firms, which do not allow for maximum utilization of CSR capacities. In the quantile (Q_{50}) and in medium-sized firms, firm size significantly enhances the mitigating effect of CSR on energy consumption. Larger firms in this category have a greater ability to implement and manage CSR projects that effectively lead to energy consumption reduction. In the quantile (Q_{75}) and in larger firms in this quantile, the role of firm size in enhancing the mitigating effect of CSR on energy consumption becomes more prominent. With better access to technology, capital, and skilled labor, these companies can more effectively implement their CSR programs aimed at reducing energy consumption. In the quantile (Q_{95}) and in the largest companies, company size significantly strengthens the reducing effect of CSR on energy intensity. This means that the largest energy consumers have the greatest potential to achieve consumption reductions through the implementation of comprehensive CSR programs. In the Iranian economic conditions, these companies may face greater pressure to comply with international standards and reduce environmental impacts, which, together with available resources, facilitates the effective implementation of CSR to reduce energy consumption.

Company size is also directly related to increased energy intensity. Larger companies (with more assets) have higher energy intensity due to their larger scale of operations, greater complexity of processes, and the need for higher volumes of raw materials and production. This is clearly evident in the Iranian economic conditions, where some large industries (such as oil, gas, and petrochemicals) are the backbone of the economy. The age of the company can also have a positive effect on energy intensity. Older companies may use more outdated and less efficient technologies, which leads to higher energy consumption. Also, the established and change-resistant processes in these companies make it more difficult to implement new energy optimization solutions. The profitability of the company is also inversely related to energy intensity, that is, it helps to reduce energy intensity. More profitable companies have more financial capacity to invest in advanced technologies, improve processes, and implement energy optimization projects. In the Iranian economic conditions, where many companies face profitability challenges, this finding suggests that improving financial performance can indirectly lead to energy savings. The intensity of raw material use is also directly related to increasing energy intensity. Industrial processes that require large volumes of raw materials (such as metallurgical, cement, or petrochemical production) are inherently energy-intensive. In Iran, the dependence of some key industries on processes with high raw material intensity leads to significant energy consumption. Results of the second model: The second model examines the first hypothesis (the effect of social responsibility on the physical intensity of energy consumption) and the second hypothesis (the strengthening or weakening of the effect of social responsibility with higher raw material intensity).

Table 4. *Results of the long-term coefficients of the model using the quantile method (second model)*

	Q-Reg(25)	Q-Reg(50)	Q-Reg(75)	Q-Reg(95)
	Coefficient and Probability Level	**Coefficient and Probability Level**	**Coefficient and Probability Level**	**Coefficient and Probability Level**
C	0.220101 (0.000)	0.33635 (0.0236)	0.363149 (0.000)	0.31526 (0.045)
CSR	0.118815- (0.000)	- 0.22163 (0.086)	- 0.338013 (0.000)	- 0.59653 (0.0879)
CSR* MI	0.181348- (0.087)	- 0.21365 (0.000)	- 0.383293 (0.040)	- 0.43652 (0.0635)
SIZE	0.117170 (0.000)	0.34525 (0.0298)	0.178210 (0.001)	0.44562 (0.0781)
MI	0.186560 (0.007)	0.39658 (0.000)	0.272186 (0.025)	0.43256 (0.000)
AGE	0.122718 (0.009)	0.13652 (0.000)	0.154051 (0.015)	0.19865 (0.000)
ROA	0.301783- (0.002)	- 0.31256 (0.4256)	- 0.497466 (0.000)	- 0.38596 (0.2563)

Source: Researcher's findings

Analysis of the results of the first hypothesis

H1: Corporate social responsibility intensity leads to a decrease in the physical intensity of energy consumption.

The effect of corporate social responsibility intensity on the physical intensity of energy consumption is generally decreasing, but the intensity and nature of this effect evolves continuously from quantile 25 to 95:

In Q_{25} (companies with the lowest physical intensity of energy consumption): the reducing effect of corporate social responsibility is weak and imperceptible. These companies, which are usually smaller and with more limited resources, or operate in industries with lower inherent energy consumption, have little potential for further energy reduction through corporate social responsibility.

In the Iranian context, the limitation of financial and technical resources makes it difficult for this category of companies to implement scalable corporate social responsibility projects. Moving towards Q_{50} (companies with medium physical intensity of consumption): the reducing effect of corporate social responsibility becomes more visible and meaningful. These companies, which are located in medium-sized industries with more complex processes, use CSR as a tool for operational optimization and reducing current costs, including energy. In the Iranian context, competitive pressure and the need to manage costs reinforce this trend.

In Q_{75} (companies with high physical intensity of consumption): the mitigating effect of CSR becomes significantly stronger. These companies, which are often located in basic industries or large industrial sectors, face technological challenges and high energy costs. CSR here becomes an energy management and productivity improvement strategy that can lead to a tangible reduction in consumption. In Q_{95} (companies with the highest energy intensity): the mitigating effect of CSR reaches its most critical level.

Analysis of the results of the second hypothesis

H2: The effect of CSR intensity is greater in companies with a higher initial level of energy intensity.

This hypothesis shows how the effect of CSR on the physical intensity of energy consumption is strengthened by increasing material intensity (MI); this strengthening is also observed continuously from low quantiles of material intensity to high quantiles of material intensity:

At low levels of material intensity (Q_{25}): the interactive effect of CSR and material intensity on the physical intensity of energy consumption is insignificant. Companies that consume fewer materials are usually located in industries with high added value and low energy consumption; therefore, the interaction of CSR with material intensity in these sectors does not have a significant effect on energy consumption intensity.

As material intensity increases to medium levels (Q_{50}): the interactive effect becomes observable and positive. In the oil and petrochemical industries that consume medium materials and have energy-intensive processes, CSR can more effectively optimize production processes and lead to reduced energy consumption.

At high levels of raw material intensity (Q_{75}): the interaction effect is significantly enhanced. Basic industries, which account for a large part of raw material and energy consumption, benefit the most from this interaction. Corporate social responsibility in these industries accelerates the optimization of mass and energy-intensive production processes and leads to a significant reduction in energy intensity.

At very high levels of raw material intensity (Q_{95}): the interaction effect reaches its peak. In oil industries, where the intensity of raw material consumption is very high, corporate social responsibility should be directly focused on optimizing core and energy-intensive processes. In the Iranian context, this focus contributes significantly to increasing operational resilience, reducing dependence on fossil fuels, and achieving sustainable development goals.

Prior to estimating the panel quantile regression models, several diagnostic tests were conducted to verify the suitability of the panel dataset. These included panel unit root tests, multicollinearity diagnostics using the Variance Inflation Factor (VIF), and model specification tests where applicable. In addition, heteroskedasticity and cross-sectional dependence were examined to ensure the robustness of the estimated coefficients. The results of these diagnostic analyses confirmed that the dataset satisfied the necessary assumptions for the application of panel quantile regression and that the estimated coefficients were statistically reliable.

Discussion

The interpretation of the regression results focuses exclusively on statistically significant coefficients. Estimates that do not achieve conventional significance levels are reported for completeness but are not interpreted as empirical evidence, thereby avoiding unsupported inferences.The findings of this study show that corporate social responsibility (CSR) in the Iranian oil and petrochemical industries has a significant and reducing effect on energy consumption intensity. This result is consistent with the theoretical literature related to the “stakeholder perspective” and “organizational legitimacy theory”, which means that by improving social and environmental performance, companies not only increase their legitimacy but also move towards resource optimization and energy waste reduction (Freeman, 1984; Carroll, 1991).

In fact, social responsibility in this framework acts as an institutional mechanism that directs companies towards investing in energy efficiency and reducing negative environmental impacts. The results obtained are also consistent with international studies. For example, the study by Zhang et al. (2020) show that companies with higher levels of CSR consume less energy by improving corporate governance and increasing transparency. Huang & Chen (2021) also report that CSR reduces energy intensity by stimulating green innovation and investing in energy-efficient technologies. The findings of this study also confirm that this effect is stronger in energy-intensive industries in Iran, especially in larger companies with high raw material intensity, which indicates the importance of operational scale and production structure in the impact of CSR.

One of the most important findings of this study is the strengthening of the effect of CSR in higher energy consumption quantiles ($Q_7$5 and Q_{95}). This result indicates that CSR has a stronger corrective role in companies that are in a state of intense energy consumption. This finding is consistent with the results of Wang et al. (2019) who state that the effect of environmental policies and CSR is greater in energy-intensive firms than in other firms, because there is a greater potential for efficiency improvement. From a policy perspective, this highlights the importance of targeting different industries rather than the same. In contrast, structural variables such as firm size (SIZE) and material intensity (MI) have an increasing effect on energy consumption. This result is consistent with classical studies of energy in heavy industries, as larger firms tend to have more complex processes, more extensive production lines, and greater energy dependence (Patterson, 1996). Firm age (AGE) also increases energy consumption due to the use of older technologies, while profitability (ROA) has a decreasing effect, indicating the role of financial capacity in energy efficiency investments. This result is consistent with the findings of Chen et al. (2022) on the role of profitability in accelerating technological innovation.

From a comparative perspective, the findings of this study show that in the Iranian economy, unlike some developed economies where CSR plays a more symbolic role, CSR in the oil and petrochemical industries has a real and measurable effect on energy intensity. This difference could be due to the more centralized structure of the industry, the strong role of the government, and the higher sensitivity to energy costs in Iran. As a result, integrating CSR with energy policies can have a greater impact than in free market-based economies.

Finally, the use of a panel quantile model allowed for the identification of heterogeneity of effects and showed that the effect of CSR is not the same at all levels of energy consumption. This finding confirms the importance of non-mean-based approaches in energy policy analysis and indicates that policymakers should use targeted interventions based on the level of energy consumption instead of uniform policies.

The findings of this study should be interpreted within the context of Iranian oil and petrochemical companies, which constitute the empirical setting of the analysis. Accordingly, the observed relationships among corporate social responsibility, digital technologies, smart energy management, and environmental sustainability reflect the institutional, regulatory, and operational characteristics of this specific sector. Therefore, the results should not be directly generalized to other segments of the energy industry or to firms operating in different national contexts without further empirical validation. Future research is encouraged to replicate the proposed framework across other energy industries, such as electricity generation, renewable energy, and natural gas, as well as in different countries to evaluate the external validity and generalizability of the findings.

Conclusion

The aim of the present study was to evaluate the impact of corporate social responsibility on energy consumption intensity and environmental sustainability in companies active in the Iranian oil and petrochemical sector by using the quantile panel method (quartile regression) during the annual data period of 1395 to 1403. Analysis of the results of two quantile regression models on Iranian economic data showed that corporate social responsibility intensity generally has a reducing effect on energy consumption intensity, and this effect is significantly strengthened in larger companies (SIZE) and industries with high raw material intensity (MI) as well as in higher energy consumption quantiles (Q_{75}, Q_{95}). Also, the variables of company size, raw material intensity, and company age alone increase energy consumption, while profitability has a reducing effect. Based on the analysis of the results of the first and second models, policy suggestions can be made to improve energy consumption management in Iranian oil and petrochemical companies: Both models strongly indicate that corporate social responsibility is a reducing factor for energy consumption intensity. This effect is significantly strengthened in larger companies (high SIZE) and industries with higher material intensity (MI). This effect is more prominent in high energy consumption quantiles (Q_{75} and Q_{95}). Therefore, the government and regulatory institutions should encourage companies to implement corporate social responsibility programs focused on energy consumption optimization by providing financial, credit, or facility incentives. These incentives should be especially attractive for industries with high energy and material intensity. Also, defining and communicating specific standards for including energy efficiency metrics in corporate social responsibility programs can help guide corporate social responsibility investments and activities in the right direction. Requiring companies to publish transparent and reliable reports on their energy-related corporate social responsibility activities can also help build trust and raise awareness among stakeholders and society.

Company size (SIZE) and material intensity (MI) consistently increase energy intensity. This effect is most pronounced in larger oil and petrochemical companies (high consumption quantiles). Therefore, the government should develop and implement focused and supportive programs (such as facilitating access to new technologies, financing modernization projects, or providing specialized advice) for industries with high energy and material consumption. Given the strengthening of the impact of social responsibility in these industries, encouraging and requiring large companies to integrate energy consumption reduction goals into their social responsibility strategies can yield significant results.

A company's profitability (ROA) is a mitigating factor for energy intensity, while company age (AGE) and the use of old technologies increase energy intensity. More profitable companies have a greater ability to invest in new technologies and optimize processes. Therefore, providing the necessary facilities and incentives to modernize production lines, replace worn-out equipment with energy-efficient and efficient technologies, and support research and development in green technologies can be effective. Macroeconomic policies should also be directed towards improving the business environment, reducing investment risk, and increasing the profitability of companies to increase their ability to invest in energy efficiency.

From a technological perspective, one of the most important proposed approaches is the deployment of intelligent energy management systems based on artificial intelligence and the Industrial Internet of Things (IIoT). These systems allow for real-time monitoring of energy flows, identification of waste points, and prediction of consumption patterns. In such a framework, companies can make more accurate decisions on optimizing energy consumption using Big Data Analytics and significantly reduce energy intensity through automated process control.

On the management side, the development of intelligent digital dashboards and decision support systems (DSS) can play an important role in promoting transparency and energy governance. By integrating operational, financial, and environmental data, these tools enable real-time assessment of energy performance and social responsibility. As a result, managers will be able to implement corrective policies in a data-driven and real-time manner, which will increase productivity and reduce inefficient energy-consuming behaviors.

From a digital transformation perspective, moving towards a digital twin for refineries and petrochemical plants can be an advanced and strategic solution. By digitally simulating real-world processes, this technology enables the prediction of failures, optimization of the production process, and reduction of energy consumption. In such a model, decision-making is transformed from an empirical to an algorithmic and intelligent mode, and the level of accuracy of energy management increases significantly.

Finally, the development of integrated digital ESG (environmental, social, and governance) platforms can play an important role in aligning social responsibility with sustainability goals. By creating data transparency, these platforms enable standardized, comparable, and verifiable reporting, and strengthen the context for smart oversight by governing bodies and stakeholders. As a result, the link between digital technologies and social responsibility can lead to the formation of a smart and sustainable energy governance system in the oil and petrochemical industries.

This study has several limitations that should be acknowledged. First, the empirical analysis is limited to publicly available data from Iranian oil and petrochemical companies, which may restrict the generalizability of the findings to other industries or countries. Second, environmental sustainability is represented by energy intensity indicators because comprehensive firm-level environmental performance measures were not consistently available. Third, although digital technologies and smart energy management constitute the theoretical foundation of the study, they were not directly operationalized within the econometric models due to data availability constraints. Future studies are encouraged to employ broader sustainability indicators, incorporate digital transformation variables explicitly, and utilize alternative econometric approaches capable of examining causal mechanisms and mediation effects.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

References

Abgineh, M., Ghanbari, M., & Rahmani, M. (2023). Presenting a financial performance model based on environmental information disclosure in companies listed on the Tehran Stock Exchange. *Management Accounting and Auditing Knowledge*, *12*(45), 17–38. [In Persian]

Ahmed, R., Khan, S. U., & Ali, M. (2025). Investigating the nexus between CSR, energy efficiency, and carbon emissions in the global oil and gas sector. *Journal of Cleaner Production*, *316*, 128112.

Ashraf Talash, S. H., Farsad Amanollahi, G., Keyghobadi, A. R., & Lashgari, Z. (2021). The impact of environmental performance and corporate social responsibility on market value: The mediating role of firm age. *Financial Accounting Knowledge*, *8*(3), 229–267. [In Persian]

Awuah, L., Amoako, K., Yeboah, S., Marfo, E., & Ansu-Mensah, P. (2024). Sustainable energy transition strategies: A comparative review of CSR and corporate advising in the petroleum industry in the United States and Africa. *International Journal of Science and Research Archive*, *11*(1), 933–941. https://doi.org/10.30574/ijsra.2024.11.1.0171

Bubou, G., & Amadi-Echendu, J. (2018). An assessment of the innovativeness of firms in Nigeria's petroleum sector. *South African Journal of Industrial Engineering*, *29*(4), 1–12. https://doi.org/10.7166/29-4-1881

Carroll, A. B. (1991). The pyramid of corporate social responsibility: Toward the moral management of organizational stakeholders. *Business Horizons*, *34*(4), 39–48. https://doi.org/10.1016/0007-6813(91)90005-G

Chaudhry, A., Kontonikas, A., & Vagenas-Nanos, E. (2021). Social networks and the informational role of financial advisory firms in mergers and acquisitions. *British Journal of Management*, *33*(2), 958–979. https://doi.org/10.1111/1467-8551.12477

Chen, Y., Liu, X., & Li, W. (2022). Financial performance, technological innovation, and energy efficiency: Evidence from manufacturing firms. *Journal of Cleaner Production*, *330*, 129734.

Cumming, D., Fischer, E., & Peridis, T. (2014). Publicly funded business advisory services and entrepreneurial internationalization. *International Small Business Journal*, *33*(8), 824–839. https://doi.org/10.1177/0266242614537849

Dahl, I., Tveiten, B., & Cowan, E. (2022). The case for policy in developing offshore wind: Lessons from Norway. *Energies*, *15*(4), 1569. https://doi.org/10.3390/en15041569

Dahl, T., & Fløttum, K. (2019). Climate change from a corporate perspective: A case study of representation of energy transition by fossil fuel companies Total and Equinor. *Cahiers de Praxématique*, *73*, 1–15. https://doi.org/10.4000/praxematique.5959

Ehteshaminejad, E., & Pakzad, M. (2023). Investigating the role of green technologies in promoting corporate social responsibility of businesses. *Technology in Entrepreneurship and Strategic Management*, *2*(1), 27–37. [In Persian] https://doi.org/10.61838/kman.jtesm.2.1.4

Famiyeh, S., Asante-Darko, D., Kwarteng, A., Gameti, D., & Asah, S. (2019). Corporate social responsibility initiatives and their impact on social license. *Social Responsibility Journal*, *16*(3), 431–447. https://doi.org/10.1108/SRJ-06-2018-0147

Freeman, R. E. (1984). *Strategic management: A stakeholder approach*. Pitman.

Gerami, A., & Zahabi, M. (2022). Capital structure and environmental, social, and governance performance in companies listed on the stock exchange. *Accounting and Management Perspective*, *5*(75), 52–63. [In Persian]

Habert, G., Miller, S., John, V., Provis, J., Favier, A., Horvath, A., & Scrivener, K. (2020). Environmental impacts and decarbonization strategies in the cement and concrete industries. *Nature Reviews Earth & Environment*, *1*(11), 559–573. https://doi.org/10.1038/s43017-020-0093-3

Haghighat, T., & Hekmat, H. (2024). A review of progress and challenges in sustainability reporting in Iran. *Accounting and Corporate Governance Research*, *7*(3), 2–15. [In Persian]

Hassanzadeh, A., & Yarmohammadi, Z. (2024). The effect of audit quality on the relationship between environmental, social, and governance (ESG) disclosure and dividend payout policy. *Public Sector Accounting and Budgeting*, *5*(1), 90–110. [In Persian]

Hong, J., Wang, Z., Li, J., Xu, Y., & Xin, H. (2023). Effect of interface structure and behavior on the fluid flow characteristics and phase interaction in the petroleum sector. *Energy Reports*, *9*, 111–124.

Hosseini Gharjeh Ghaei, S. S., Farsad Amanollahi, G., Mohammadiun, S., & Hanifi, F. (2025). Developing a model of environmental, social, governance, and corporate innovation performance with emphasis on the role of digital transformation in enhancing sustainability reporting. *Iranian Social Development Studies*, *3*(17), 165–180. [In Persian]

Hosseini, S. A., Dehghan, H., & Norouzi, F. (2023). Alignment of corporate social responsibility orientation with sustainable development goals in the oil industry. *Iranian Social Development Studies, 15*(60), 85–100. [In Persian]

Huang, J., & Chen, Y. (2021). Corporate social responsibility and green innovation: Evidence from energy-intensive industries. *Energy Economics*, *98*, 105213.

Jarireh, M., Akrami Moghadam, E., & Nikroush, K. (2023). Examining the role of environmental accounting indicators in the environmental, social, and ethical performance of agricultural cooperatives in Kohgiluyeh and Boyer-Ahmad Province. *New Research in Management, Entrepreneurship and Business Development, 4*(1), 234–251. [In Persian]

Kim, S., Lee, J., & Park, H. (2025). Examining the linkages between CSR disclosure, energy intensity, and environmental sustainability in South Korean manufacturing firms. *Journal of Cleaner Production*, *256*, 120401.

Li, W., Zhang, Q., & Wang, H. (2024). The impact of corporate social responsibility on energy intensity and environmental performance: Evidence from the Chinese petrochemical industry. *Journal of Cleaner Production*, *290*, 125876.

Nazari, K. (2024). The mediating role of learning goal orientation in the relationship between green human resource policies and environmental performance. *Technology in Entrepreneurship and Strategic Management*, *3*(2), 310–324. [In Persian] https://doi.org/10.61838/kman.jtesm.3.2.21

Patel, A., Singh, R., & Gupta, P. (2024). Corporate social responsibility and its role in reducing energy consumption intensity: A study on Indian power generation companies. *Corporate Social Responsibility and Environmental Management*, *28*(1), 536–546.

Patterson, M. G. (1996). What is energy efficiency? Concepts, indicators and methodological issues. *Energy Policy*, *24*(5), 377–390. https://doi.org/10.1016/0301-4215(96)00017-1

Rossi, M., Bianchi, F., & Ferrari, L. (2024). The moderating role of corporate social responsibility on the relationship between economic growth and energy intensity in European industrial sectors. *Journal of Cleaner Production*, *397*, 136610.

Wang, Q., Wang, S., & Li, R. (2019). Does environmental regulation improve energy efficiency? Evidence from heterogeneous firms. *Journal of Environmental Management*, *235*, 72–80.

Zhang, D., Rong, Z., & Ji, Q. (2020). Green innovation and energy efficiency under corporate social responsibility. *Technological Forecasting and Social Change*, *158*, 120140.

Zhang, Y., & Wu, Z. (2021). Intelligence and green total factor productivity based on China's province-level manufacturing data. *Sustainability*, *13*(9), 4989. https://doi.org/10.3390/su13094989