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Does the utilisation of new energy and waste gas resources contribute to product innovation from the perspective of a circular economy? Evidence from China

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These days energy-related enterprises started using a fancy terminology called circular economy (CE) to display their progress in opting for innovative approaches to mitigate carbon emissions and waste gas released in the enterprise during the operation. Hence, this paper examines whether there is any mediating role of innovation from a CE point of view or not in managing the waste resources and minimising the carbon emission on the innovation and quality of new energy products. For this, secondary data with a sample observation of 608 was selected from Chinese listed enterprises from 2015–2020. The empirical results revealed that the waste resource utilisation by firms is helpful to the quality of their products but does not significantly affect the innovation of their new energy products. In addition, the evidence from developing countries shows that companies' carbon reduction behaviour benefits their new energy product innovation. However, it does not significantly impact the quality of their products. Model validation analyses the existence of corporate waste resource utilisation through corporate new energy product innovation, thereby contributing to corporate product quality. Overall, this paper facilitates enterprises' new energy product development activities and fills the research gap between companies' waste gas resource utilisation and new energy product innovation.

KEYWORDS
carbon emission 1, waste gas resources2, new energy3, reduction4, circular economy5

1 Introduction

With the increase in human and economic activity, the global climate is getting deteriorated, resulting in land and sea warming, rising sea levels, degradation of glaciers, frequent extreme weather events and other acute events that cause disasters. Even the economic downturn associated with the COVID-19 outbreak has failed to contain the drivers of climate change (The Global Climate Status Report, 2020). As a result, the year 2020 remained as one of the three hottest years on record, with a global average temperature of around 1.2°C higher than temperatures observed in the pre-industrial era (1850–1900). Not only the rise in temperatures but climate change-related disasters are frequently happening in developed and developing countries. Such disasters have become the main concern for governments in developed and developing countries (Del Giudice et al., 2021). So, understanding the environmental impacts due to various initiatives have become mandatory, and at the same time, economic stability should be achieved (Bag et al., 2022).

The circular economy is a concept that has become popular in the last decade and can potentially promote economic stability and sustainable development. However, it has to be implemented only through corporate strategies; only then the true potential can be realised. Considering the energy sector, the circular economy is being promoted widely, especially in the content of waste to energy. More recently, new energy sources such as solar photovoltaics, wind energy, biomass, fuel cells and others have also gained importance in the circular economy context. At the same, new processes and technologies and integrated approaches have also evolved, focusing on net zero or near zero emissions. Such developments attracted energy and other energy-dependent sectors, for instance, iron and steel, paper, and cement. As a result, the captive power plants in the industries started expanding from an innovation point of view.

So, promoting new energy sources is one of the essential options for decarbonising and increasing fuel diversity. Furthermore, with the development of energy saving and emission reduction technologies, the advantages of new energy sources, such as low consumption and low exhaust emissions, are gaining increasing attention. Meeting environmental issues and resource efficiency requirements in manufacturing has become necessary to achieve effective production management. The circular economy aims to reduce resource consumption by slowing, closing and shrinking resource cycles (Geissdoerfer et al., 2017). Through the use of new energy sources and recycled materials, a circular economy can help reduce lifecycle greenhouse gas emissions and resource consumption (Aguilar Esteva et al., 2021). Thus, while the circular economy is inextricably linked to carbon reduction in enterprises, it also promotes product innovation for environmental protection.

The circular economy is a series of abstract concepts (Ripanti & Tjahjono, 2019), and past research has found that the circular economy can provide innovation in environmentally friendly products (Hopkinson et al., 2018) or processes that transform environmentally friendly resources into a variety of usable products and services and ultimately manifest in products or consumers (Lloret 2016). As the evolution of CE shows its multidisciplinary background, Pizzi et al., 2020 argue that approaches from various disciplines such as engineering, economics and ecology have contributed to its development. As a theoretical basis, the circular economy provides a favourable research perspective. There are many perspectives on new energy sources at this stage of research and study, often focusing on new energy products and corporate financing models and the impact of crude oil prices on new energy product innovation (He et al., 2022; Fu & Yang's 2021). Some scholars have focused on recycling within the production cycle of products and the recycling of industrial solid waste (Richa et al., 2017; Martínez-Martínez et al., 2020). However, there is less research on the study of carbon reduction and corporate waste gas resource use in new energy product innovation. So, this study seeks to explore the impact of corporate carbon reduction behaviour and waste body resource use on corporate new energy product innovation and quality. So, we formulated the following research questions; 1). Does carbon emission reduction by enterprises improve new energy product innovation and product quality?; 2). Does waste gas emission utilisation promote environmental innovation by enterprises; and 3). Does waste gas resource utilisation improve product quality through green innovation?

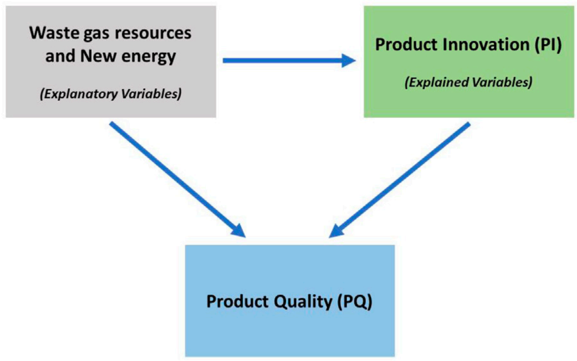

FIGURE 1
Framework highlighting the explanatory and explained variables in waste to energy.

Hence, to answer the above-raised research questions, this study aims to explore whether the enterprises' carbon and greenhouse gas emission reduction promotion is conducive to their product innovation and quality improvement. This study also attempts to analyse the mediating effect of new energy product innovation between product quality as well as waste gas emission utilisation. The past literature has suggested a higher expected return on investment for new energy products and technology innovation (He et al., 2022). This study also considers the relationship between innovation and quality of new energy products and whether there are potential

TABLE 1 Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
PI	608	6.862	19.11	0	139
CE	608	116648.8	3679198	0	3.23e + 08
GHG	608	123028.3	591434.6	1.86	3724022
Size	608	22.213	1.289	19.939	26.063
TQ	608	2.992	10.717	0.219	983.491
FirmAge	608	2.939	0.230	2.080	3.555
indep	608	0.377	0.0538	0.308	0.6
PQ	608	0.246	1.315	0	9

Note: PI, product innovation; CE, carbon emission; GHG, greenhouse gas emission; PQ, product quality; FirmAge, firm's age; Indep, independent director; TQ, tobin's Q.

channels for more linkages between new energy product innovation and the quality of products using waste gas resources. The impact of the endogeneity problem of the variables on the regression results is quite often raised in the literature, which is also addressed in this study by proposing a firm fixed effects model.

The manuscript is structured in three sections. Section 2 presents the framework and data sources. Section 3 presents the sample selection and models used for the analysis. In Section 4, the observed results are presented with a brief discussion, followed by conclusions and future work in Section 4.

2 Framework and data collection

Based on the objective, we have formulated the research framework shown in Figure 1. The framework consists of two main variables: Explanatory and explained. The explanatory variables are the waste gas resources, exhausts and any other energy type in the firm (that includes renewables too). The explained variables are the product innovation approaches used in the firm. In the below subsections, these two variables are clearly explained along with control variables, which collectively would affect the product quality in the firm.

2.1 Explanatory variables

According to Fu & Yang's (2021) research on product measures for a new energy firm, most enterprises reuse waste gas resources for industrial production. So, a firm's waste gas resource utilisation and carbon emission reductions can be the core explanatory variables. These can be measured or collected from the greenhouse gas emissions and the firm's carbon emission reduction reports. Cheng et al. (2021) also state that greenhouse gas emission reduction of enterprises can be a good standard to measure waste gas resource utilisation. The data source for greenhouse gas and carbon emission reduction is the China Industrial Enterprises Database (2015–2020).

2.2 Explained variables

The explained variable is considered to be the firm's new energy product innovation, which is measured by the firm's product-related new energy patents (Bag et al., 2022; He et al., 2022). The firm's product innovation data is obtained from the China Research Data Service (CNRDS). In addition, information on product quality is extracted from Corporate Social Responsibility (CSR) and financial data, and the Production Quality (PQ) variable is measured by the product quality score disclosed in the CSR.

2.3 Control variables

Control variables are chosen to assess the impact of carbon emission reduction and exhaust gas resources on new energy products' innovation and product quality and exclude other confounding factors. The control variables, the firm's age, size and Tobin's Q are represented by Indep, FirmAge, Size, and TQ, respectively. These variables are obtained from the firms' annual financial reports, and the firm's financial information is obtained from the China Stock Market Accounting Research Database (CSMAR).

3 Sample selection and methodology

3.1 Sample selection

The selected sample for this study is the panel data of listed enterprises in mainland China. An adequate sample size of 608 enterprises listed between 2015–2020 was obtained. For all these 608 enterprises or firms, the data related to three variables (explanatory, explained, and control) is collected using the resources mentioned in Section 2.

3.2 Model setting

For every enterprise or firm, our focus is mainly on understanding the impact of carbon emission reduction and exhaust pollutants on the innovation of new energy products from a circular economy perspective. For this, we developed the fixed effects models briefly presented below:

Model 1: Aims to explore the impact of corporate carbon emission reduction on new energy product innovation, as given in Eq. 1.

$$PI = a_0 + a_1 * GHG + FirmSize + TQ + Indep + Firmage + e_1 \quad (1)$$

where PI is the product innovation, a_0 is the intercept, a_1 is the co-efficient for GHG, GHG is the greenhouse gas emission, e_1 is the residual variance.

Model 2: Aims to explore whether greenhouse gas emission reduction promotes enterprise environmental protection innovation, as given in Eq. 2.

$$PI = a_0 + a_2 * CE + Size + TQ + Indep + Firmage + e_2 \quad (2)$$

where PI is the product innovation, a_0 is the intercept, a_2 is the co-efficient for CE, CE is the carbon emission reduction, e_2 is the residual variance.

Model 3: investigate the influence of enterprise carbon emission reduction on product quality, as given in Eq. 3.

$$PQ = a_0 + a_3 * GHG + Size + TQ + Indep + Firmage + e_3 \quad (3)$$

where PQ is the product quality, a_0 is the intercept, a_3 is the co-efficient for GHG, GHG is the greenhouse gas emission, e_3 is the residual variance.

Model 4: analyses whether greenhouse gas emission reduction can improve product quality through green innovation, as given in Eq. 4.

$$PQ = a_0 + a_4 * CR + Size + TQ + Indep + Firmage + e_4 \quad (4)$$

where PQ is the product quality, a_0 is the intercept, a_4 is the co-efficient for CE, CE is the carbon emission reduction, e_4 is the residual variance.

4 Results and discussion

This section presents the data analysis results as well as the main empirical results and the discussion. The descriptive

TABLE 2 Correlation matrix.

Variable	PQ	PI	CE	GHG	Size	TQ	FirmAge	Indep
PQ	1.000							
PI	0.041***	1.000						
CE	0.354	−0.080	1.000					
GHG	0.006	0.128***	0.994***	1.000				
Size	0.136***	0.399***	−0.015	0.072***	1.000			
TQ	−0.010	−0.047***	−0.016	-0.004	−0.400***	1.000		
Firmage	−0.006***	0.029***	−0.004***	−0.015***	−0.018	0.056***	1.000	
indep	−0.011	−0.014***	−0.021	−0.007	0.165***	−0.112***	−0.030***	1.000

Note: PI: product innovation; CE: carbon emission; GHG: greenhouse gas emission; PQ: product quality; FirmAge: firm's age; Indep: independent director; TQ: Tobin's Q.

TABLE 3 Regression results of enterprise carbon emission and greenhouse gas emission reduction on products.

Variable	(1)	(2)	Variable	(3)	(4)
PI	GHG	CE		GHG	CE
	−0.00000572	0.000000353***	PQ	0.00000198*	−1.99E-09
	(−0.57)	(11.04)		(2.34)	(−0.75)
Indep	69.56	11.80***	Indep	−21.83	−0.269
	(0.35)	(4.32)		(−1.29)	(−1.18)
FirmAge	−74.37	−4.801***	FirmAge	1.599	−0.102*
	(−1.62)	(−9.64)		(0.41)	(−2.43)
Size	17.30*	6.674***	Size	−0.947	0.200***
	(2.35)	(52.82)		(−1.51)	(18.96)
TQ	−6.949	0.304***	TQ	0.414	0.0229***
	(−0.87)	(6.06)		(0.61)	(5.46)
_cons	−177.1	−132.2***	_cons	26.94	−3.791***
	(−0.77)	(−41.10)		(1.38)	(−14.08)
N	30	15,266	N	30	14924

Note: t statistics in parentheses; *p < 0.05, **p < 0.01, ***p < 0.001.
Note: PI, product innovation; CE, carbon emission; GHG, greenhouse gas emission; PQ, product quality; FirmAge, firm's age; Indep, independent director; TQ, Tobin's Q.

TABLE 4 Sobel-goodman mediation tests.

	Coef	Std. Err	Z	P>|Z|
Sobel	−A5.826e-10	2.440e-10	−2.388	0.0169
Goodman-1 (Aroian)	−5.826e-10	2.449e-10	−2.379	0.0174
Goodman-2	−5.826e-10	2.430e-10	−2.398	0.0165
	Coef	Std Err	Z	P>|Z|
A coefficient	3.5e-07	3.2e-08	10.965	0
B coefficient	−0.001651	0.000675	−2.447	0.014
Indirect effect	−5.8e-10	2.4e-10	−2.388	0.017
Direct effect	−1.4e-09	2.7e-09	−0.530	0.596
Total effect	−2.0e-09	2.7e-09	−0.752	0.452

Note: The proportion of total effect that is mediated: 0.2922; The ratio of indirect to direct effect: 0.4128; The ratio of total to direct effect: 1.4128.

statistical analysis of the collected 608 enterprises' sample data is shown in Table 1. The observed correlations between variables are listed in Table 2.

Table 3 reveals the regression results for Models 1–4. Model 1 reported the impact of corporate GHG emission reduction on corporate new energy product innovation. The results reflect that the use of waste gas resources does not have a direct positive impact on the innovation of new energy products, with a correlation coefficient of −0,57. However, for the reduction of carbon emissions (Model 2), the adoption of carbon reduction behaviour by companies has a significant positive relationship with the innovation of new energy products, with a p-value = 0 (<0.05) and a positive correlation. Furthermore, Model 3 reveals that the use of waste resources significantly affects the quality of a company's products, with a p = 0.028 (<0.05) and a positive correlation coefficient. The results of model 4 show that carbon reduction behaviour does not effectively stimulate product quality and has a negative correlation.

The use of exhaust gas resources in enterprises' new energy innovations is insignificant because new energy product innovations generally use new energy power such as photovoltaics, wind, fuel cells and others. While the use of exhaust gas resources is generally reflected in the innovation process but the technology and systems are mainly considered old or relatively conventional. Therefore, from a technical point of view, there is limited scope to improve the number of patents granted for the use of waste gas resources. In addition, the reason why carbon reduction does not directly improve the quality of a company's products in this study is considered to be that carbon emission reduction behaviour in the production process is not related to the product quality of enterprises. So it will not have a direct impact. However, coming to the economic benefits, the past study by Xue et al. (2019) showed that carbon reductions in the circular model could generate additional revenue. Therefore, carbon reductions from this mode can have significant environmental and economic benefits. Shan et al. (2021) found that green innovation and renewable energy reduce carbon emissions when put under this approach in a given enterprise or firm, depending upon the industrial operations they perform. Thus, the model proposed in this study is further analysed to understand the relationship between corporate waste resource utilisation and corporate new energy product innovation, thereby contributing to corporate product quality. For this, a Sobel test is performed, and the results can be seen in Table 4.

Although in the previous model, corporate waste resource utilisation did not have a positive impact on new energy product innovation, the results of the Sobel test show that there is a partial mediating pathway existing for corporate waste resource utilisation through new energy innovations and thus have an impact on the quality of the firm's products. The mediating effect accounted for 29.22% of the total effect, and the ratio of indirect to direct effect was 41.28%.

5 Conclusion and future work

The circular economy is a concept promoted by policymakers and businesses worldwide (Iaquaniello et al., 2018), emphasising waste as a way to close the cycle and minimise resource use (Hollins et al., 2017). Therefore in a circular economy, in addition to using and reducing waste, there needs to be an incentive to make products that do not become waste, which is product innovation (Iaquaniello et al., 2018). The empirical results of this paper show a model of the impact of carbon emission reduction and waste resource utilisation on the innovation and quality of new energy products for Chinese listed enterprises with a total sample observation of 608. It also analyses the impact of carbon emission reduction and waste resource utilisation of enterprises on new energy product innovation and quality based on a circular economy perspective, as well as the mediating role of new energy innovation. The model results of this paper show that the use of waste gas resources by companies is an important factor in improving the quality of their products. However, it does not positively affect the innovation of new energy products. In addition, the model results reveal that companies' carbon reduction behaviour is beneficial to their new energy product innovation but has a negative impact on their product quality that warrants our attention. The results of this paper are beneficial to the company's internal governance, such as the R&D and innovation activities of new energy products and the control of product quality. At the same time, the findings of this study will fill the research gap between companies' waste gas resource utilisation and new energy product innovation. However, this paper only focuses on Chinese companies from 2015 to 2020. Future research could consider other long-term results or markets in other countries or regions.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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