Circular economy practices, green innovation and financial performance: The moderating role of big data analytics

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Abstract: *Environmental pollution and resource degradation have prompted researchers and policymakers to seek solutions. Circular economy practices (CEP) can help enterprises reduce emissions into the environment and move towards sustainable development. CEP has been studied widely in developed countries but less studied in developing countries due to the limited application of CEP in enterprises and the limitation of data. This paper aims to analyse the effect of CEP on financial performance, including revenue, profit and ROA. We also analyse the mediating role of green innovation and the moderating role of big data analytics in the relationship between CEP and financial performance. The natural resource based view (NRBV) theory is used to explain the relationship between variables and establish research hypotheses. We collected data from 413 Vietnamese manufacturing enterprises and used the regression method to test the research hypotheses. The results show that CEP positively impacts financial performance through the mediating role of green innovation. Besides, big data analytics also positively impacts the relationship between CEP and green innovation. In addition to the main results above, digital transformation positively impacts financial performance, but quality management practices do not affect financial performance. The research results are empirical evidence for enterprises considering implementing CEP to move towards sustainable development.*

Keywords: *Circular economy practices, green innovation, big data analytics, digital transformation, quality management practices, financial performance, ROA.*

JEL Classification: *O14, L15, L25, D22.*

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Introduction

The world economy is growing, and the environment is being polluted and degraded. Plastic has emerged as one of the most widely utilised materials because of its cost-effectiveness, especially in packaging. Therefore, it has become a crucial element of municipal garbage management. Annually, an estimated 19–23 million metric tonnes of improperly handled plastic garbage are dumped from terrestrial sources into aquatic bodies worldwide (Bergmann et al., 2022). In addition, air pollution caused by CO_2 emissions from industrial plants is also at an alarming level through annual statistical indicators. According to the Energy Information Administration, China, the world's largest energy consumer, emitted 9,899 megatonnes of CO_2 from fossil fuels in 2020. This figure represents 30.7% of the global CO_2 emissions for that year (Cai et al., 2023). Consequently, mitigating CO_2 emissions is crucial for advancing global objectives of low-carbon development (Shen & Zhang, 2024; Zhou et al., 2024). In short, the consequences of environmental pollution are enormous; it inhibits the development of countries. Therefore, it requires efforts to research methods to help reduce environmental pollution from researchers worldwide.

Circular economy practices (CEP) are enterprise activities aimed at recycling products at the end of their life cycle (Le et al., 2023). In addition, CEP also includes activities to reduce input resources and reuse defective materials or products (Khan & Haleem, 2021). CEP can help reduce the environmental impact of production activities and help enterprises develop sustainably (Singh & Singh, 2019). Mazzucchelli et al. (2022) investigated the impact of CEP, including waste treatment, reduction and recycling, on financial performance. The findings showed that CEP enhanced financial performance through the mediating role of brand reputation. Yu et al. (2022) found that CEP positively impacted financial performance through the mediating role of environmental and innovation performance. Besides, CEP also enhances economic and sustainable performance (Chowdhury et al., 2022).

Vietnam has established itself as the most rapidly expanding economy among emerging nations, with an average growth rate of 7% in recent years (Chowdhury et al., 2022). More and more domestic and foreign companies are investing in manufacturing goods and providing services in Vietnam to optimise their supply chains because Vietnam has cheaper labour than neighbouring China (Deshmukh, 2021). The production of goods negatively impacts the environment due to industrial waste such as plastic, liquid, and carbon emissions (Shen & Zhang, 2024). In that context, scholars and policymakers have recognised the CEP metric as a means to address the constraints of the conventional linear economic model (Chowdhury et al., 2022). During COP26, prime minister Pham Minh Chinh of Vietnam committed to achieving net zero emissions by 2050. Vietnam joined over 140 nations that have vowed net zero emissions by the middle of the century (Bui & Wang, 2024). Therefore, CEP is essential for policymakers and companies in Vietnam to help Vietnam achieve its net zero commitment by 2050. Environmental degradation is a global problem. Promoting the application of CEP in economic activities will help Vietnam reduce environmental pollution, thereby reducing pollution worldwide.

Various studies analyse the impact of CEP on financial performance to provide empirical evidence for researchers and policymakers. The results of these studies are still inconsistent. Some studies find that CEP has a positive impact on financial performance (Chen & Dagestani, 2023; Mazzucchelli et al., 2022; Yu et al., 2022), while others suggest that CEP has no impact or a nonlinear impact on financial performance (D'Angelo et al., 2023). Previous studies on the impact of CEP on financial performance have been mainly conducted in developed countries (Halog & Anieke, 2021; Sarfraz et al., 2023). There are very few studies on the impact of CEP on financial performance in developing countries because developing countries face technical barriers to applying CEP (Gedam et al., 2021). This study is one of the first attempts to analyse the impact of CEP on financial performance in a developing country. More studies in different contexts and countries help researchers and policymakers better understand the impact of CEP on financial performance.

This study has three main objectives to answer three research questions (*RQ*). The first question is (*RQ1*): *What is the impact of CEP on financial performance through the mediating role of green innovation?* The second question is (*RQ2*): *What is the moderating effect of big data analytics variables on the relationship*

between CEP and green innovation? The third question is (*RQ3*): *How do digital transformation (DT) and quality management practices (QMP) impact financial performance?* The data are collected from Vietnamese enterprises in the manufacturing sector. We use the natural resource based view (NRBV) theory founded by Hart (1995) to propose hypotheses and explain the relationship between variables. Based on the NRBV theory, this study proposes that CEP is an organisational resource that can create a competitive advantage through green innovation. From this perspective, enterprises can enhance CEP, creating green innovation and advantages that competitors cannot imitate. From these advantages, enterprises can improve their financial performance.

From a theoretical aspect, the study contributes to explaining the impact of CEP on financial performance through the NRBV theory. This contribution once again affirms the role of CEP in creating enterprise competitive advantages, improving business operations and changing towards sustainable development. From a practical aspect, the study contributes to providing empirical evidence of the impact of CEP on financial performance in the context of a developing country. The research results will encourage Vietnamese enterprises to apply CEP in their operations and help Vietnam achieve net zero by 2050. Achieving net zero by countries will promote sustainable development worldwide. This study is structured into five parts. After introduction, part one presents main concepts such as the natural resource-based view theory, circular economy practices, green innovation, and research hypotheses. Part two presents the research methodology. Part three presents the research results, and discussion and the last part is conclusion.

1 Theoretical background

1.1 Natural resource based view theory

Hart (1995) developed the natural resource based view (NRBV) theory based on resource-based theory (RBT) by considering the environmental impacts of manufacturing enterprises and directing enterprises towards sustainable development. NRBV theory suggests that a company may implement three strategies to establish a competitive advantage by emphasising its natural resources, including pollution prevention, product stewardship, and sustainable development (Hart, 1995). Specifically, pollution prevention can be achieved through control, which involves trapping, storing, and treating emissions and effluents, and prevention. In the early stages of pollution prevention, simple changes can lead to significant emission reductions. However, as a firm improves its environmental performance, further reductions become more challenging, often requiring significant process changes or new production technology (Hart, 1995). In this stage, enterprises can apply product stewardship strategies, including stakeholder integration, to minimise product life-cycle costs and preempt competitors. Overcoming obstacles in the product stewardship stage, enterprises will move towards sustainable development.

NRBV theory is applied in many different fields, such as quality management (Nguyen et al., 2024), human resource management (Yahya et al., 2021), marketing management (Rahman et al., 2021) and circular economy practices (Coppola et al., 2023). In this study, we use NRBV theory to explain the impact of circular economy practices on green innovation. Green innovation will help businesses save costs and meet customer requirements, thereby helping businesses have better financial performance.

1.2 Definition of key concepts

Circular economy practices (CEP) are activities in which environmental concerns are integrated into enterprise operations (Khan & Haleem, 2021). CEP is a method to promote the development of economy and sustainable performance (Chau et al., 2023; Singh & Singh, 2019). In a circular economy, products and materials are reduced and reused as much as possible. Besides, waste and chemicals that pollute the environment are minimised, and products are recycled at the end of their life cycle (Kristoffersen et al., 2021). The aforementioned actions mitigate the negative environmental effects of manufacturing operations (Khan & Haleem, 2021). The integration and synchronisation of the organisational activities of marketing, sales, manufacturing, logistics, IT, finance, and customer service inside and between enterprises contribute to the improvement of corporate performance. This result is achieved by terminating material and energy loops, minimising input resources and waste, and emission leakage out of the system (Del Giudice et al., 2021). For the given

situation, CEP allows business actions that are good for the economy, society, and the environment in many ways (Farrukh & Sajjad, 2024; Le et al., 2023; Noja et al., 2024).

Green innovation includes all kinds of new ideas that help make important goods, services, or processes that hurt the environment less and use natural resources more efficiently (Leal-Millán et al., 2017; Takalo & Tooranloo, 2021). Today, this form of innovation plays a critical role by focusing on effectively utilising natural resources to enhance the enterprise's operation. Furthermore, green innovation may facilitate sustainable development (Leal-Millán et al., 2017; Takalo & Tooranloo, 2021).

Green innovation combines innovations that reduce the environmental impact of operations by utilising enhanced technologies, systems, and management practices (Singh et al., 2020). Green innovation is distinguished from conventional technological innovation by its emphasis on facilitating the reduction of environmental effects (Singh et al., 2020). Green innovation also focuses on creating environmentally friendly products and processes by adopting eco-design principles, using fewer materials, and reducing emissions and water, electricity, and other raw material consumption (Leal-Millán et al., 2017; Singh et al., 2020). In this study, green innovation is employed by constructing green technology, processes, and products.

According to Dang and Hieu (2024), performance is measured by three indicators. The first is financial performance measured by profit, return on assets (ROS), or return on investment (ROI). The second indicator is market performance, measured by market share and revenue. The third indicator is shareholder returns, measured by shareholder returns or the enterprise's added value. Various factors influence an enterprise's financial performance. Dang and Hieu (2024) analysed the factors that influence financial performance. The results showed that government support, innovation, quality management practices, and enterprise characteristics impact financial performance. Yu et al. (2022) found that CEP positively impacted financial performance through the mediating role of environmental and innovation performance. Zhai et al. (2022) investigated the effect of digital transformation on firm performance using data from Chinese enterprises. They found that digital transformation positively impacts enterprise performance. When enterprises implement digital transformation, they have lower costs, better efficiency in operation, and better innovation. These results lead to better performance. In addition, quality management is also a factor that affects financial performance. Parvadavardini et al. (2016) collected data from 152 Indian manufacturing enterprises to investigate the impact of QMP and quality performance on financial performance. The result shows that QMP and quality performance positively impact financial performance.

1.3 Research model and hypotheses

According to NRBV, companies can implement CEPs as a strategy to gain a competitive advantage, either by preventing pollution through the use of recycled materials or by establishing policies and practices for the timely disposal of machinery and equipment. However, in the long run, this will lead to significant changes in processes or new production technology (Hart, 1995). Moreover, firms can engage in product stewardship by discontinuing environmentally harmful operations, revamping current product systems to minimise liability, and creating new products with reduced life-cycle costs (Hart, 1995). Consequently, NRBV supposes that when companies implement CEPs, they will generate new products with reduced life-cycle costs by considering the potential for product reuse after they have fulfilled their initial purpose during the design phase. This approach fosters green innovation. The relationship between CEP and green innovation is emphasised in the previous studies (Le et al., 2023; Schultz & Reinhardt, 2022). As a result, the authors propose that the implementation of CEPs has an impact on green innovation, including green process, technology, and product innovation.

H1: Circular economy practices positively impact on green innovation.

BDA is crucial in promoting circular economy strategies and improving CEP through green practices (Gupta & George, 2016; Jeble et al., 2018; Kumar & Chakraborty, 2022). The study by Kamble et al. (2021) emphasised that BDA practices improve CEP and green practices. Implementing BDA within the organisation will enable managers to promptly and accurately determine the implementation

of CEPs, thereby enhancing GI within the organisation. Khan et al. (2024) concluded that BDA moderates the effect of green practices on green innovation. Thus, the research proposes the hypothesis that BDA moderates the relationship between CEP and GI in manufacturing enterprises.

H2: Big data analytics moderately impact the relationship between CEP and GI.

According to NRBV theory, product stewardship strategy suggests focusing on Environment-friendly materials and designing more optimal production cycles. These activities can reduce production costs and increase firm performance (Pan et al., 2024). Green innovation is the process of creating environmentally friendly products and processes by implementing organisational practices, such as using fewer materials when designing products, using eco-design principles and reducing emissions. This approach also aims to reduce the consumption of water, electricity, and other raw materials, increasing financial performance, including revenue, profit, and ROA. Numerous previous researches have indicated that organisations prioritise green innovation exhibit superior overall performance compared to their competitors. This result is because they utilise their green resources and capabilities to promptly and effectively address consumer requirements (Albort-Morant et al., 2016; Leal-Millán et al., 2017). Green innovation enhances corporate image, identifying new market opportunities and boosting success. Key outcomes include environmental performance, financial performance, competitive advantages, green image, and customer loyalty. Practical green innovations increase efficiency, core competencies, and superior performance (Afum et al., 2021; Asadi et al., 2020; Leal-Millán et al., 2017; Rezende et al., 2019). Therefore, the authors suggested that green innovation drives financial performance in manufacturing enterprises.

H3: Green innovation positively impact on financial performance.

The sustainable development strategy in NRBV theory focuses on the combination of stakeholders, especially technological cooperation, to simultaneously meet economic development and environmental protection requirements (Hart, 1995). According to Chen et al. (2015), digital transformation may boost the company's potential internal resources, acquire new external resources, and coordinate and integrate all internal and external resources to promote dynamic capabilities. With the expansion of digital transformation, enterprises can respond to the rising needs of consumers and the market, gaining competitive advantages and achieving excellent economic performance (Li, 2022). Digital transformation helps enterprises to increase process efficiency and better manage resources. Hence, digital transformation can improve economic performance (Masoud & Basahel, 2023). Recently, Li (2022) also demonstrated that digital transformation enhances economic performance by analysing survey data from 223 Chinese businesses. However, the majority of investigations were conducted in industrialised nations. Consequently, investigating the link between DT and financial performance in emerging economies is still being explored. In this study, the author proposes that digital transformation positively affects financial performance.

H4: Digital transformation positively impact on financial performance.

Quality management practices (QMP) are a widely used management approach in numerous countries that assists enterprises in achieving effective performance (Nguyen et al., 2024; Sila, 2020). Companies applying QMP must standardise their processes and continuously improve quality. Quality improvement can incorporate pollution prevention, product stewardship, and sustainable development strategies from NRBV theory to reduce product defects, reduce costs, and increase performance (Nguyen et al., 2024). Some studies indicated that QMP positively affected performance (Nguyen et al., 2021; Sila, 2020). In addition, some papers, including (Ochieng et al., 2015) and Liu et al. (2021), have reported conflicting results. These papers suggest that QM has a positive impact on ROA, but it does not have an impact on profit and revenue. In contrast, a few researchers concluded that non-certified companies showed higher financial performance (Nair & Prajogo, 2009). Some authors discovered no correlation between financial performance and QMP (Kafel & Sikora, 2014). Conversely, few researchers concluded that non-certified companies exhibited superior financial performance (Nair & Prajogo, 2009). In this study, the author continues exploring the correlation between QMPs and financial

performance in the context of companies undergoing digital transformation and CEPs.

H5: Quality management practices positively impact on financial performance.

Enterprise characteristics are also one of the factors that affect financial performance. Previous studies confirmed that enterprise characteristics impact performance (Lin et al., 2019; Xia & Walker, 2015). Xia and Walker (2015) concluded that firm types positively impacted enterprise performance. Lin et al. (2019) confirmed that firm size significantly impacted financial performance. In this study, we propose firm type and firm size as control variables that affect financial performance. We propose the research model from the above hypotheses and arguments, as shown in Fig. 1.

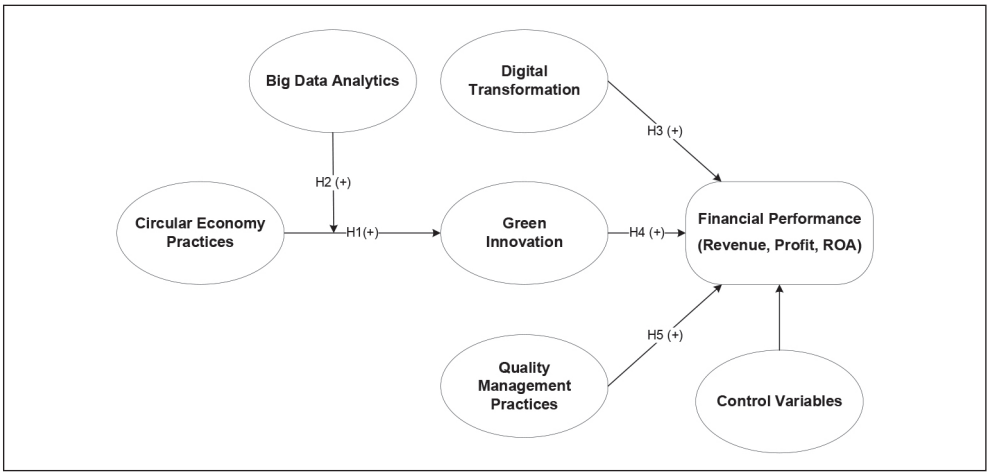

Fig. 1: Research model

Source: own

2 Research methodology and scales

This study uses quantitative methods to analyse data, such as descriptive statistics, correlation analysis and regression analysis. We use the ordinary least square (OLS) method to test the research hypotheses. According to Tabachnick and Fidell (2013), OLS regression provides the best estimates when seven OLS assumptions are met. These assumptions are linearity in its error term and coefficients, the mean of the error term is zero, no correlations between the error term and the independent variables, no serial correlation, constant error term's variance, no multicollinearity and normal distribution of residual. First, we test hypotheses *H1* and *H2* through Equation (1). In Equation (1), green innovation (GI) is the dependent variable, circular economy practice (CEP) is the independent variable, and big data analytics (BDA) is the moderate variable. The results of the hypothesis testing will be evaluated through the significance level of the coefficients β_1 and β_2. The coefficient of *CEP* * *BDA* evaluates the moderate effect of *BDA* on the relationship between *CEP* and innovation. The letter *i* represents observations with values from 1 to *n*, and α is a constant in the regression equation. Finally, ε represents the error term of the regression result.

$$INNO_i = \alpha + \beta_1 * CEP_i + \beta_2 * CEP * * BDA_i + \varepsilon_i \quad (1)$$

Next, we test hypotheses *H3*, *H4*, and *H5* through regression Equations (2–3). In Equations (2–3), Y_i is the dependent variable measured through three parameters: revenue, profit, and ROA. The independent variables

include digital transformation (*DT*), green innovation (*GI*), and quality management practice (*QMP*). *CONTROL* represents the control variables, including firm size and firm type. The coefficients λ, θ, γ, and δ are the regression coefficients. The letters μ and ν represent the residuals of the regression equation. Equations (2–3) are presented in detail as follows.

$$Y_i = \lambda + \theta_1 * DT_i + \theta_2 * INNO_i + \\ + \theta_3 * QMP_i + \mu_i \quad (2)$$

$$Y_i = \gamma + \delta_1 * DT_i + \delta_2 * INNO_i + \\ + \delta_3 * QMP_i + \delta_4 * CONTROL_i + \nu_i \quad (3)$$

In Equations (2–3), CEP and DT are measured by the Likert scale. The CEP construct is inherited from the study of Chowdhury et al. (2022) and includes four indicators as follows: "i) we work with clients/suppliers for ecological design of products/services; ii) during the design stage, we consider the possibility to reuse products after they have served their initial purpose; iii) we are using recycled materials as inputs in our processes; and iv) we have policies and practices in place to dispose of machinery and equipment on time." The DT construct is inherited from the study of Kuo et al. (2022) includes three indicators as following: "i) our company invests in digital infrastructure and facilities for digital operation; ii) our company adopts digital technology applications for digital operations; and iii) our company empowers talented personnel and organisations to achieve digital operation." Details on the definitions of variables and their measurement are presented in Tab. 1.

Tab. 1: Definition of variables in the research model

Variables	Labels	Definition
Revenue	*REV*	Revenue at the end of 2023 (billion VNDs)
Profit	*PRF*	After-tax earning in 2023 (billion VNDs)
Return on asset	*ROA*	EBIT/total asset in 2023 (%)
Digital transformation	*DT*	Likert scale from Kuo et al. (2022)
Green innovation	*GI*	Dummy variable, equals 1 if the enterprise had one of the following activities in 2023 (using cleaner technology to prevent pollution, using eco-labelling, using new technology to minimise energy consumption, reducing, reusing and recycling material); otherwise it equals 0
Quality management practice	*QMP*	Dummy variable, equals 1 if the enterprise used advanced quality management systems or obtained quality management system certificates (ISO 9001, 14001, HACCP); otherwise it equals 0
Circular economy practice	*CEP*	Likert scale from Chowdhury (2022)
Big data analytic	*BDA*	Dummy variable, equals 1 if the enterprise applies big data analytics in operations; otherwise it equals 0
Firm size	*SIZE*	Number of staff at the end of 2023
Firm Type 1	*TYPE1*	Equals 1 if the enterprise is in the food and beverage industry; otherwise it equals 0.
Firm Type 2	*TYPE2*	Equals 1 if the enterprise is in the rubber and plastic industry; otherwise it equals 0
Firm Type 3	*TYPE3*	Equals 1 if the enterprise is in the mechanical engineering and automation industry; otherwise it equals 0
Firm Type 4	*TYPE4*	Equals 1 if the enterprise is in the information technology, electronics, and telecommunications industry; otherwise it equals 0

Source: own

After proposing the research hypotheses, we designed a preliminary questionnaire based on previous studies on circular economy practice and on factors affecting financial performance of enterprises. The preliminary questionnaire will be revised by group discussions with experts, including circular economy practice researchers (three members) and company leaders (three members, including managers and supervisor) involved in quality management, innovation and digital transformation activities. After receiving comments from the experts, we revised the questionnaire and proposed the final questionnaire for the survey.

We collected data by interviewing the leaders of enterprises in the manufacturing sector based on the final questionnaire. We used the snowball sampling technique. First, we contacted our friends and alumni working in manufacturing enterprises to schedule an interview. After completing the survey by interviewing, we ask the respondents to introduce us to other companies in the manufacturing sector that they know so that we can continue to conduct the survey. After we have more information about other enterprises, we will contact them and schedule the subsequent interviews. After five months of data collection, we collected data from 413 enterprises, including 55 enterprises in the food and beverage industry, 102 enterprises in the rubber and plastic industry, 154 enterprises in the mechanical engineering and automation industry, 18 enterprises in the information technology, electronics, and telecommunications industry, and 84 enterprises in other manufacturing sectors.

3 Results and discussion

3.1 Descriptive statistics

First, we analysed descriptive statistics to see the distribution of the variables. Tab. 2 presents details of the results. Among the 413 surveyed enterprises, the average revenue is VND 804 billion (equivalent to USD 32.3 million), the maximum revenue is VND 91.536 billion, and the minimum revenue is VND 0.1 billion. Enterprises have an average profit of VND 73.7 billion (equivalent to USD 2.96 million) and an average ROA of 6.2%. Current enterprises have low ROA because enterprises are still affected by the post-COVID-19 and the negative impact of wars in Europe and the Middle East.

For the independent variables, digital transformation (DT) and circular economic practice (CEP) were measured by a Likert scale with mean values of 3.572 and 3.630, respectively. This result shows that manufacturing enterprises have invested in digital transformation

Tab. 2: Descriptive statistics

Variables	Mean	Maximum	Minimum	Std. dev.	Observations
REV	804.899	91,536.000	0.100	7,112.004	413
PRF	73.672	10,426.790	−6.811	715.006	413
ROA	0.062	11.332	−1.036	0.562	413
DT	3.572	5.000	1.000	0.955	413
GI	0.240	1.000	0.000	0.427	413
QMP	0.453	1.000	0.000	0.498	413
CEP	3.630	5.000	1.250	0.908	413
BDA	0.206	1.000	0.000	0.405	413
SIZE	66.533	880.000	3.000	73.839	413
TYPE1	0.133	1.000	0.000	0.340	413
TYPE2	0.247	1.000	0.000	0.432	413
TYPE3	0.373	1.000	0.000	0.484	413
TYPE4	0.044	1.000	0.000	0.204	413

Source: own

and circular economic practice. Cronbach's alpha analysis was used to assess the reliability of these two variables. The analysis results in Tab. 3 show that Cronbach's alpha of CEP and DT are 0.839 and 0.825, respectively. These values are all greater than 0.7, so the scale meets the reliability requirement (Hair et al., 2019).

With green innovation activities, 24% of enterprises invested in these activities in 2023, such as using cleaner technology to prevent pollution, using eco-labelling, using new technology to minimise energy consumption, and reducing, reusing and recycling material. This rate is low because green innovation activities always require a significant financial investment. Currently, enterprises in the manufacturing sector in Vietnam still face difficulties due to a lack of orders, so there is not much financial investment in innovation activities.

Tab. 3: Reliability analysis of CEP and DT variables

Variables	Indicator	Mean	*N*	Item (total correlation)	Cronbach's alpha (if item deleted)	Cronbach's alpha
Circular economy practice	*CEP1*	3.683	413	0.687	0.790	0.839
	CEP2	3.588	413	0.639	0.811	
	CEP3	3.661	413	0.689	0.789	
	CEP4	3.588	413	0.675	0.795	
Digital transformation	*DT1*	3.598	413	0.667	0.774	0.825
	DT2	3.569	413	0.663	0.777	
	DT3	3.550	413	0.715	0.725	

Source: own

For the quality management practice (QMP) variable, 45.3% of enterprises applied advanced quality management systems or obtained quality management system certificates (ISO 9001, 14001, HACCP). This rate is relatively high because manufacturing enterprises are always concerned about quality management, which contributes to the enterprises' competitiveness. The certificates will help the enterprises meet the customers' requirements. 20.6% of enterprises apply big data analytics in their operations. This rate is still relatively low because big data analytics is a new technology. In Vietnam, manufacturing enterprises lack expertise in big data analytics. Besides, enterprises have not seen the benefits of big data analytics, so they have not applied it to their operations.

For the firm size, each firm had an average of 67 employees. The largest firm had 880 employees, and the smallest had three employees. Finally, for firm types, enterprises in the food and beverage industry accounted for 13.3%, in the rubber and plastic industry accounted for 24.7%, in the mechanical engineering and automation industry accounted for 37.3%, in the information technology, electronics, and telecommunications industry accounted for 4.4%, and in other manufacturing sectors accounted for 20.3%.

3.2 Correlation and regression results

Before regression analysis, we analysed the correlation between variables in the research model to see the relationship between variables (Tab. 4). Correlation analysis helps avoid the phenomenon of multicollinearity when highly correlated variables are entered into the model at the same time (Nguyen & Nguyen, 2020). In regression Equation (1), the correlation coefficient of CEP and BDA is 0.3066. In Equations (2–3), the correlation coefficient between the three independent variables DT, GI, and QMP has values from 0.2071 to 0.3671. The correlation coefficients between independent variables are all less than 50%, so there is a weak correlation between independent variables. In other words, the possibility of a multicollinearity phenomenon in the regression equation is not high.

Tab. 4: Correlation analysis

Variables	*REV*	*PRF*	*ROA*	*DT*	*GI*	*QMP*	*CEP*	*BDA*
REV	1.0000							
PRF	0.8826	1.0000						
ROA	0.0325	0.0239	1.0000					
DT	0.1391	0.1389	0.0866	1.0000				
GI	0.1793	0.1775	0.1200	0.2459	1.0000			
QMP	0.0755	0.0354	0.0702	0.3671	0.2071	1.0000		
CEP	0.0921	0.0783	0.0755	0.6611	0.3743	0.4875	1.0000	
BDA	0.1953	0.1951	0.1240	0.1970	0.9066	0.2107	0.3066	1.0000

Source: own

We test the first and second hypotheses using regression Equation (1) with the dependent variable green Innovation (GI). The results in Tab. 5 show that the variable circular economy practice (CEP) positively impacts GI at a significance level of 5%. The regression coefficient corresponding to the variable BDA * CEP shows the moderate effect of the variable big data analysis (BDA) on the relationship between CEP and GI. The results show that BDA positively impacts the relationship between CEP and GI at a significance level of 1%. In addition, the VIF coefficients of a regression Equation (1) are all less than 2, and the White (1980) test for heteroscedasticity has a significance level greater than 5%. This result proves that regression Equation (1) does not have multicollinearity and heteroscedasticity.

Next, we conduct regression analysis using Equations (2–3), with the dependent variable being financial performance represented by three variables: revenue, profit and ROA. Equation (2) analyses the impact of independent variables on the dependent variable, while Equation (3) adds control variables (firm size, firm type). The results in Tab. 6 show that GI positively impacts financial performance in all regression equations, with a significance level of 1% to 5%. The variable digital transformation (DT) only positively impacts revenue and profit but does not affect ROA. The variable QMP does not affect the dependent variable in all regression equations. For the control variables, firm size impacts revenue and profit but does not affect ROA. The variable TYPE4 has an impact on revenue and costs, while the variables TYPE1, TYPE2 and TYPE3 have an impact on ROA.

To ensure the reliability of the regression equations, we estimated the variance inflation factor (VIF). The results showed that all VIF coefficients in Equations (2–3) were less than 2.

Tab. 5: Regression analysis with green innovation as dependent variable

Variable	Coefficient	Std. error	*T*-stat.	Prob.	VIF
Constant	−0.0309	0.0409	–0.7547	0.4509	
CEP	0.0234	0.0114	2.0533	0.0407	1.1614
BDA * CEP	0.2159	0.0060	35.9441	0.0000	1.1614
***R*-squared**	0.7929				
***F*-statistic**	784.6578				
Prob. (*F*)	0.0000				

Source: own

This result proves that the regression equations do not have multicollinearity. In addition, we also performed the White (1980) test for the regression equations. The analysis results showed that the significance level of the heteroskedasticity tests was all greater than 5%. This result proves that the regression Equations (2–3) do not have heteroskedasticity.

Tab. 6: Regression analysis with revenue, profit and ROA as dependent variable

Independent variables	Revenue		Profit		ROA	
	Equation (2)	Equation (3)	Equation (2)	Equation (3)	Equation (2)	Equation (3)
Constant	−2,479.8090	−3,452.5540	−270.3950	−334.1150	−0.0920	0.0121
DT	734.6030*	677.8280*	85.7970**	78.3770**	0.0297	0.0376
GI	2,553.7300***	2,290.9900***	263.3300***	236.6820***	0.1330**	0.1406**
QMP	107.2160	−140.5900	−56.3740	−85.5730	0.0346	0.0533
SIZE		15.3680***		0.9990**		−0.0003
TYPE1		517.4290		160.1300		−0.2148**
TYPE2		−149.0000		16.3800		−0.1627*
TYPE3		−47.6400		−1.1810		−0.1311*
TYPE4		7,202.2100***		422.4870**		−0.1649
Observations	413	413	413	413	413	413
R^2	0.0420	0.1200	0.0430	0.0750	0.0280	0.0440
***F*-statistics**	5.9490	6.8940	6.0450	4.0650	2.7930	2.8150
Prob. (*F*-stat)	0.0000	0.0000	0.0000	0.0000	0.0450	0.0410

Note: *** 1% significance; ** 5% significance; * 10% significance.

Source: own

3.3 Discussions

The regression results in Tab. 5 show that the circular economy practices (CEP) positively impact green innovation (GI). This evidence supports hypothesis *H1*. This result is consistent with the NRBV theory of Hart (1995). Adopting CEP drives GI by directing the enterprise resources, management systems, and the involvement of stakeholders toward CEP. This finding corroborates the earlier authors' contention that CEP supplies an essential environmentally friendly basis for fostering green innovations by converting the conventional linear paradigm into a sustainable development paradigm (Le et al., 2023). Furthermore, this finding supports the assertion by Schultz and Reinhardt (2022) that resources, management systems, and knowledge play a crucial role in promoting GI. Next, the regression results show that BDA positively impacts the relationship between CEP and GI. The current outcomes indicate that for enterprises applying BDA, the impact of CEP on GI will be greater than when enterprises do not apply BDA. This result supports the hypothesis *H2*. Prior studies have also identified a positive effect of BDA on green innovation (Khan et al., 2024; Le et al., 2023; Schultz & Reinhardt, 2022).

The results in Tab. 6 show that GI positively impacts financial performance, including revenue, profit and ROA, with a significance of 1% to 5%. This result supports hypothesis *H3*. The impact of green innovation on financial performance has been confirmed by previous researches (Afum et al., 2021; Asadi et al., 2020; Leal-Millán et al., 2017). Therefore, enterprises with green innovation can improve their financial performance by managing operational costs and satisfying customers and suppliers (Rezende et al., 2019). People saw the benefits

of green innovation in the form of better financial performance. This result included lower costs for materials and energy use, lower costs for getting rid of trash, and lower fines for environmental problems.

The variable digital transformation (DT) positively impacts financial performance, including revenue and profit. This finding is consistent with previous studies examining the effect of digital transformation on financial performance (Masoud & Basahel, 2023). In contrast to the above results, DT does not affect ROA. This result can be explained by the fact that enterprises spend much money to invest in assets when implementing digital transformation. Therefore, the ROA results of enterprises implementing digital transformation are not high. Besides, Li (2022) argued that the digital transformation process should be comprehensive, as organisations must assess their level of digital maturity and consider various influencing elements, including organisational culture, management team and employee preparedness, business quality processes, and IT department preparedness. In this context, it is important to note that digital transformation does not provide immediate growth in a company's profits. Specifically, during the early phase of digital transformation, enhancing a company's economic performance is expected to be limited.

Quality management practices (QMP) do not affect financial performance. This result is in contrast to the research results of Sila (2020) and Nguyen et al. (2021) but similar to the research results of Ochieng et al. (2015). Liu et al. (2021) suggested that QMP only affects financial performance in the short term. In the long term, the positive impact of QMP on financial performance will disappear one to two years after achieving quality awards or quality certification. For the control variables, firm size impacts revenue and profit but does not affect ROA. This result is explained by the fact that the larger the company and the more employees, the more revenue and profit the enterprise has. In addition, firm type has a positive effect on ROA. Enterprises in the information technology, electronics, and telecommunications industry (Type 4) have higher revenue and profit results than other enterprises. Enterprises in the food and beverage industry (Type 1), rubber and plastic industry (Type 2), mechanical engineering and automation industry (Type 3) have higher ROA results than other enterprises. This result is similar to the research results of Xia and Walker (2014) and Lin et al. (2019). Different types of enterprises have different competitive advantages and produce different products, so different types of enterprises will have different financial performance.

Conclusions

This study aims to examine the influence of circular economy practices (CEP) on financial performance, specifically on attaining sustainable development goals. Specifically, it focuses on the responsible use of resources and mitigating environmental and societal consequences of enterprise manufacturing. These efforts align with the Vietnamese government's objectives to achieve net zero carbon emissions by 2050. Using surveyed data from 413 enterprises in the manufacturing sector, we empirically tested the impact of CEP on financial performance, including revenue, profit, and ROA and obtained the following findings. First, CEP positively impacts green Innovation (GI). Second, big data analytics (BDA) moderately impacts the relationship between CEP and GI. Third, GI positively enhances financial performance including revenue, profit and ROA. Fourth, digital transformation (DT) positively enhances financial performance, including revenue and profit. In summary, this study uncovers how CEP, BDA, and DT improve financial performance in the manufacturing sector.

Based on the study results, enterprises should have business strategies in adopting circular economy practices to achieve the Vietnamese government's sustainability goals, especially in promoting digital transformation activities. Enterprises should invest in BDA to promote green innovation. Besides, policymakers should enforce waste management laws and strengthen existing policies, with stricter enforcement of recycling and waste segregation. The state should impose high taxes on materials that are difficult to recycle or cannot be recycled. In addition, the state should also provide low-interest loans or grants for startups and companies investing in circular technologies. In addition, the state can also invest in education and conduct public education campaigns to increase awareness about the benefits of recycling and sustainable consumption.

Nevertheless, this study is subject to its limitations. Firstly, this study uses the snowball

sampling method, which may have potential biases, such as the presentation of certain firm types or industries. Future research can try another sampling method to minimise the biases in the data collection. Secondly, the suggested model was first assessed using cross-sectional data, and future examinations may include longitudinal data. Primary data sources such as company annual reports, the General Statistics Office database, the Vietnam Stock Market database, and other relevant sources may be utilised to analyse the causal connection between corporate environmental success and financial success. Thirdly, this study only examined the role of CEP in the Vietnamese manufacturing industry, thereby lacking a certain degree of generality. Further enquiries can be conducted in comparable economies such as Germany, China, Japan, the United States, and others. Finally, contextual factors may alter the impact of CEP on financial performance. Prospective future research should concentrate on analysing the impact of moderating variables, such as corporate strategy, institutional environment, market risk, and atypical occurrences, on the adoption of circular economy practices.

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