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THE IMPACT OF CARBON MANAGEMENT ON ENVIRONMENTAL PERFORMANCE: EVIDENCE FROM MANUFACTURING FIRMS IN MALAYSIA

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ABSTRACT

This study aims to investigate the impact of carbon management on environmental performance. By applying the Natural Resource-Based View (NRBV) and Legitimacy Theory, this study examines key dimensions of firm-level carbon management that influence the environmental performance of manufacturing firms in Malaysia A questionnaire survey was conducted among 220 manufacturing firms registered with the Federation of Malaysian Manufacturers to achieve the research objectives. Data were analysed using structural equation modeling revealed that carbon governance (β=0.424) had the strongest impact, followed by carbon disclosure (β=0.339), carbon operations (β=0.360), and carbon accounting (β=0.280). Policymakers and industry players can leverage these insights to refine carbon management practices, improve operational efficiency, and achieve long-term cost savings, thereby enhancing manufacturing firms' environmental performance and overall competitiveness.

***Keywords**:* Manufacturing; carbon governance; carbon operation; carbon accounting; carbon disclosure; environmental performance

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1. INTRODUCTION

In Malaysia, the manufacturing sector is a key economic driver, contributing approximately 23% to the country's GDP in 2024 (DOSM, 2024). However, this growth has also led to a 6.5% increase in CO2 emissions between 2020 and 2021, largely driven by fossil fuel-intensive industrial activities (MacroTrends, 2024). This rising trajectory underscores the urgent need for more effective carbon management practices to enhance environmental performance (EP).

Carbon management (CM) encompasses governance, operations, accounting, and disclosure practices that collectively influence environmental outcomes. Prior literature conceptualizes CM under three key themes. First, CM includes tools and systems that support the measurement, monitoring, and reduction of carbon emissions (Corbett, 2013), making such practices accessible to both SMEs and large enterprises (Kovác et al., 2025; Eleftheriadis & Anagnostopoulou, 2024). Second, CM is viewed as an integrated organizational system combining governance, processes, and technology to enhance EP (CDP, 2010). Third, CM functions as a strategic approach that enables firms to implement environmental policies and improve operational effectiveness, particularly in the management of carbon emissions (Porter & Van der Linde, 1995; Klassen & McLaughlin, 1996; Pandey et al., 2011). Thus, effective CM contributes to improved EP, including emission reductions, resource efficiency, regulatory compliance, and competitiveness (Barbosa et al., 2023; Nair et al., 2025).

The Malaysian manufacturing sector has significant potential to improve EP through robust CM systems (Suhaimi & Chandran, 2024; Mukhtar et al., 2024). Several studies highlight the importance of various CM practices including roles of carbon governance in strategic oversight (Susskind et al., 2020). Carbon operations in improving operational efficiency and reducing emissions (Khan et al., 2022), carbon accounting in measuring and monitoring GHG emissions (Deswanto & Siregar, 2018; Diantimala & Amril, 2018), carbon disclosure in promoting transparency and stakeholder trust (Usmani et al., 2021; Farooq et al., 2022; Nassani et al., 2023). Integrating these practices enables firms to comply with regulations while achieving cost savings, resource optimization, and competitive advantages (Shurrab et al., 2019; Tang & Luo, 2014; Aris & Auzair, 2024).

Despite the proposed CM model, its practical implementation in Malaysia remains unclear. Effective compliance requires strong enforcement, adaptive strategies, and continuous staff training; otherwise, governance misalignment may undermine organizational effectiveness (Crifo et al., 2019). Moreover, the transition toward net-zero emissions demands a robust regulatory framework and transformative value-chain changes (Nilsson et al., 2021). Challenges also persist in carbon accounting due to measurement uncertainties (Aris & Auzair, 2024) and in carbon disclosure due to difficulties in ensuring transparency and consistency in reporting (Nishitani et al., 2020). Building on these gaps, this study examines how CG, C0, CA, and CD impact firms' EP.

This study is grounded in the NRBV theory, which posits that efficient resource management enables firms to achieve competitive advantage through environmental responsibility (Hart & Dowell, 2011). The central premise of NRBV is that firms can sustain competitive advantage by leveraging environmental and social responsibility as strategic asset (Hart, 1995). Several studies have applied NRBV, enriching the literature and justifying its use in this study (Mura et al.,

2019; Tang & Demeritt, 2018; Benjamin et al., 2020). While NRBV emphasizes internal strategic capabilities, Legitimacy Theory (LT) explains external pressures for irms face to align with societal expectations through transparency and disclosure (Gray et al., 1995; Deegan, 2002). A firm is considered legitimate when its operations conform to societal norms and expectations (Tilling, 2004).Together, NRBV and LT provide complementary theoretical foundations, explaining both the strategic value of CM and the need for stakeholder legitimacy. Several studies have applied LT, further supporting its relevance to this research (Yu & Ramanathan 2016; Irawati et al., 2019; Appannan et al., 2020; Ekawati et al., 2019; Ong et al., 2021; Lubis et al., 2019; Hardiyansah et al., 2021; Aulia & Agustina 2015). Therefore, this study extends these theories by offering a novel perspective on how firms strategically manage carbon-related factors to enhance EP. The findings provide valuable insights for policymakers, regulators, managers, and other stakeholders, highlighting potential cost savings, competitive advantages, and reputational benefits from sustainable practices. The following sections address the central research question: What factors within a firm's CM influence the EP of manufacturing firms in Malaysia?

2. LITERATURE REVIEW AND HYPOTHESES

2.1 Carbon Governance and EP

Carbon governance (CG) involves stakeholders collaborating to reduce carbon emissions (Bulkeley & Moser, 2007). Tang and Luo (2014) identify three drivers of effective climate action: First, strong board governance links to lower emissions (Abdullah et al., 2024; Zhu et al., 2024; Bel-Oms et al., 2025). and robust climate strategies (Augustine, 2019; Elsayih et al., 2021; Pham & Ho, 2024). Second, aligning disclosure with actual performance improves accountability and credibility, thereby enhancing both transparency and environmental outcomes (Bui et al., 2020). Third, employee motivation toward sustainability ensures that environmental goals are integrated across organizational levels, amplifying management support (Junsheng et al., 2020). However, Crifo et al. (2019) warn that governance mechanisms may fail when board incentives are misaligned or when firms engage in greenwashing, prioritizing symbolic actions over substantive emission reductions (Kim & Lyon, 2015; Zervoudi et al., 2025; Kathan et al., 2025; Zhang, 2025). Thus, evidence remains mixed regarding whether CG leads to substantive environmental improvements rather than symbolic compliance. (Yang et al., 2024; Pratama et al., 2025; Torres, 2024; Velte, 2023). Accordingly, the first hypothesis is suggested:
H1: There is a positive influence between carbon gov*ernance and EP.*

2.2 Carbon Operation and EP

Carbon operation (CO) involves managing and reducing carbon emissions (Benjaafar & Daskin, 2012). Tang and Luo (2014) identify three key factors for successful reduction strategies. First, setting measurable and time-bound emission targets drives firms to reduce emissions more effectively and systematically (Dahlmann et al., 2019). Second, embedding policies such as carbon trading and emission controls in supply chains provides firms with both financial and environmental benefits (Chen & Lin, 2021). Third, optimizing value chains by reusing waste and recycling fosters long-term sustainability and competitiveness (Nascimento et al., 2019). These practices strengthen decision-making, risk management, and long-term resilience (Christ &

Burritt, 2013; Journeault, 2016). Although overly ambitious targets and greenwashing may pose challenges (Lyon & Montgomery, 2015), empirical evidence shows that well-designed carbon operations improve EP, stimulate innovation, and increase efficiency. For example, green supply chain programs with binding targets significantly enhance carbon performance (Zou et al., 2024; García Alcaraz et al., 2022), while integrating carbon trading policies promotes green innovation and improves ESG outcomes in heavy-polluting industries (De Souza Barbosa etal.,2023; Dai & He, 2025). Hence, the second hypothesis is proposed:
H2: There is a positive impact between carbon operation and environmental performance

2.3 Carbon Accounting and EP

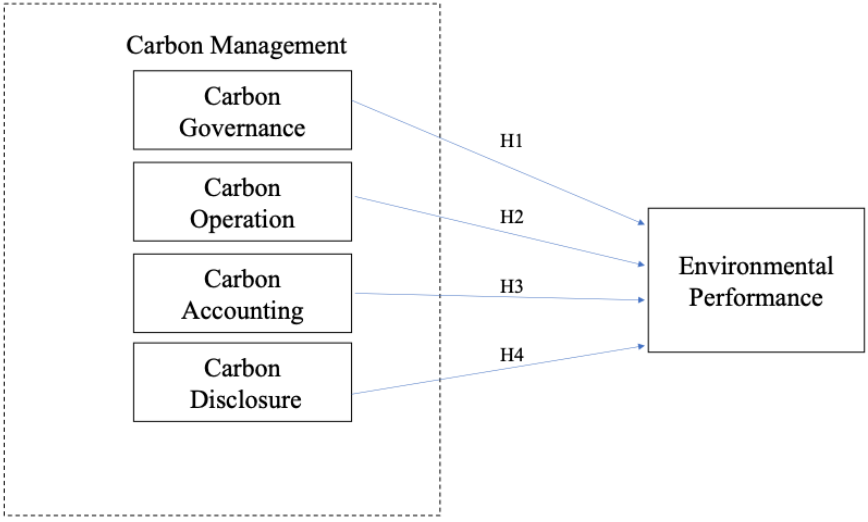
Carbon accounting (CA), or "greenhouse gas accounting," tracks carbon dioxide equivalents (CO_2e) released by a company or activity (Young, 2010). Tang and Luo (2014) identify two key factors in CA. First, carbon inventory systems enable firms to identify emission sources and benchmark efficiency, with carbon footprint tools reshaping industry performance rankings (Keivani et al., 2020). Second, carbon assurance mechanisms, such as ISO 14001-based systems, significantly improve the reliability and credibility of sustainability reporting, as shown in Indonesia's pulp and paper sector (Erwin, 2021 However, inconsistencies in methods and standards may reduce comparability (Cullen & Allwood, 2022), and financial constraints can hinder advanced CA adoption (Zhao et al., 2023). Nonetheless, by enhancing measurement accuracy and credibility, CA provides firms with a robust basis for reducing emissions and improving sustainability. Furthermore, CA systems enable data-driven decision-making and continuous improvement in CM practices**.** Recent findings further indicate that mature carbon accounting enables organizations to identify emissions hotspots, set precise reduction targets, and align with sustainability goals, thereby amplifying the impact of CM strategies (Onat et al., 2025; Di Vaio et al., 2025; Liu et al., 2025). Thus, the third hypothesis is proposed:
H3: There is a positive effect between carbon accounting and EP.

2.4 Carbon Disclosure and EP

Carbon disclosure (CD) involves firms sharing information about carbon-related activities to address stakeholder concerns (Meng et al., 2014; Li et al., 2018). Tang and Luo (2014) highlight two key aspects: First, stakeholder engagement, including board independence and digital platforms for e-engagement, strengthens connections between firms and stakeholders, fostering trust and legitimacy in disclosure practices (Alhumud et al., 2025; Pennesi & Giuliani, 2025; Journeault, 2016). Second, strategic and well-designed disclosure practices increase transparency and accountability, reinforcing firms' environmental legitimacy and improving overall performance. However, some firms still exaggerate environmental initiatives to build a favorable image (Cho et al., 2023), and inconsistent reporting standards remain a concern (Alam et al., 2022). Moreover, as highlighted by Page et al. (2025), Wu et al. (2025), and Moses et al. (2025), disparities between voluntary and mandatory disclosure regimes can widen the "credibility gap" in global carbon reporting practices. Despite these challenges, the literature consistently emphasizes that transparent and credible disclosure mechanisms strengthen stakeholder trust and firm reputation. Hence, the final hypothesis is posited:
H4: There is a positive association between carbon disclosure and EP.

Figure 1 depicts the theoretical structure of this study, emphasizing the interconnectedness among carbon governance, carbon operation, carbon accounting, and carbon disclosure factors.

Figure 1. Theoretical Framework

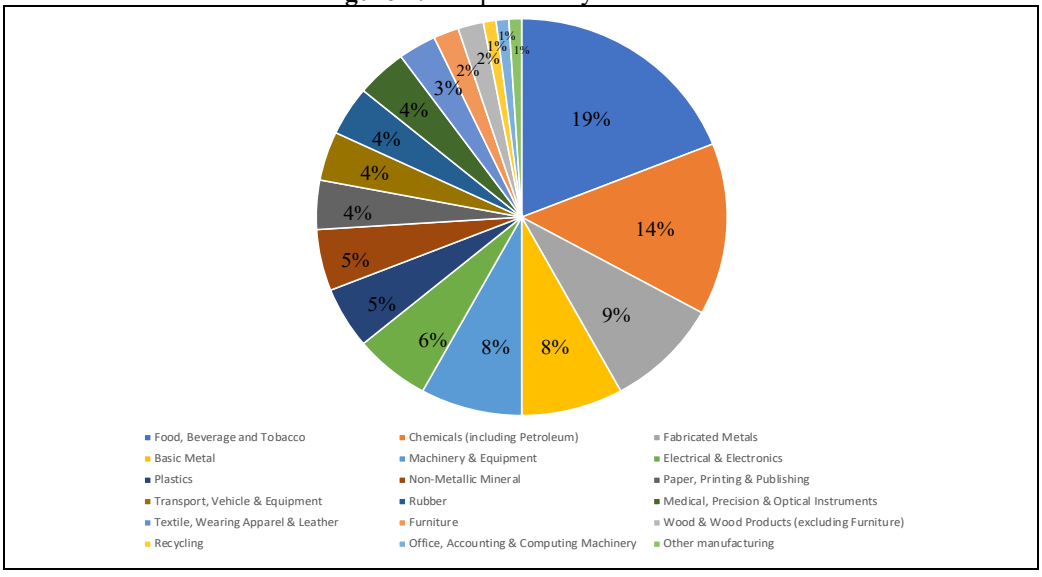


3. METHODOLOGY

3.1 Sampling and Data Collection

According to the Federation of Malaysian Manufacturers (FMM) 2021 Directory, Malaysia has approximately 3,600 manufacturing firms across 18 subsectors. A sample size of 1,000 firms was selected using proportionate stratified sampling following Krejcie and Morgan (1970) and Hair et al. (2006), with systematic sampling applied within each subsector (Cavana et al. 2001). Online questionnaires were distributed to top officials between 1st January 2023 to 30th June 2023. Of the 230 responses received, 220 usable questionnaires remained after excluding incomplete submissions, yielding a 22% response rate, which is acceptable for this sector (Delgado-Verde et al. 2014; Agostini et al. 2017). Although non-response bias is a potential concern, early and late respondents revealed no significant differences across key variables, indicating minimal bias. This issue is acknowledged in the limitations section. This issue is acknowledged and further discussed in the limitations section. Figure 2 presents the distribution of respondents by subsector, with food, beverage, and tobacco representing the largest share (19%), followed by the basic metal industry (14%).

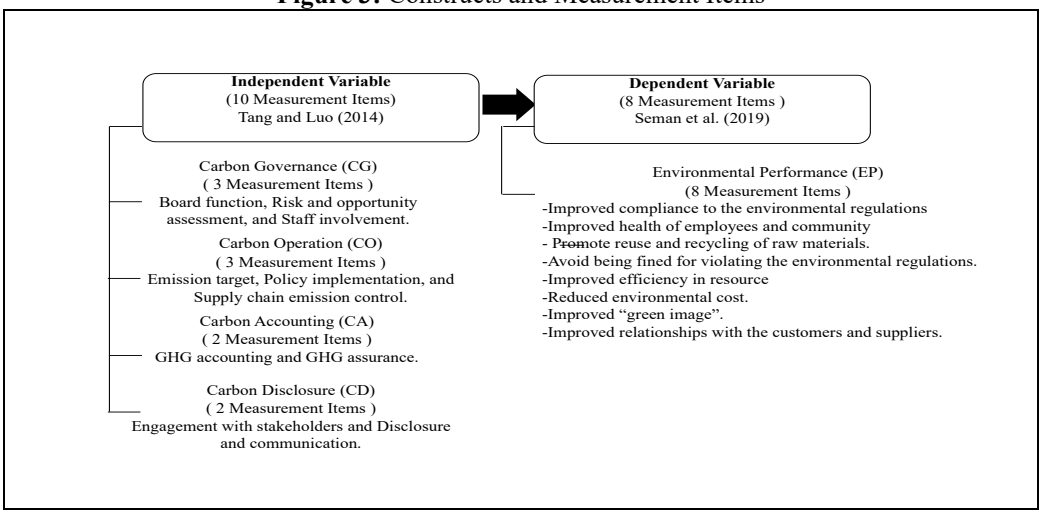
Figure 2: Sample size by sub-sectors



3.2 Measurements and variables

Figure 3 displays the five constructs: CG, CO, CA, and CD (independent variables), and EP (dependent variable). CG, CO, CA, and CD were measured with 10 items based from Tang and Luo (2014) using CDP Scoring Methodology. To ensure comparability across constructs, the data for CG, CO, CA, and CD was standardized before analysis. EP was assessed using 8 items from Seman et al. (2019), with a 5-point Likert scale (1 = lowest, 5 = highest in the industry).

Figure 3: Constructs and Measurement Items



4. RESULTS AND DISCUSSION

4.1 Demographic profile

The target population includes firms of various sizes and ages within the manufacturing sector. Figure 4 shows that 35% of these firms have fewer than 100 employees, 38% have 100-200 employees, and 27% have over 200 employees. This indicates a range of company sizes, with larger firms having more resources and public pressure to adopt environmental practices. Additionally, 50% of the firms are over 10 years old, 43% have been operating for 5-10 years, and 7% are less than 5 years old, suggesting a mix of mature and emerging businesses.

Figure 4: Profile of Firms

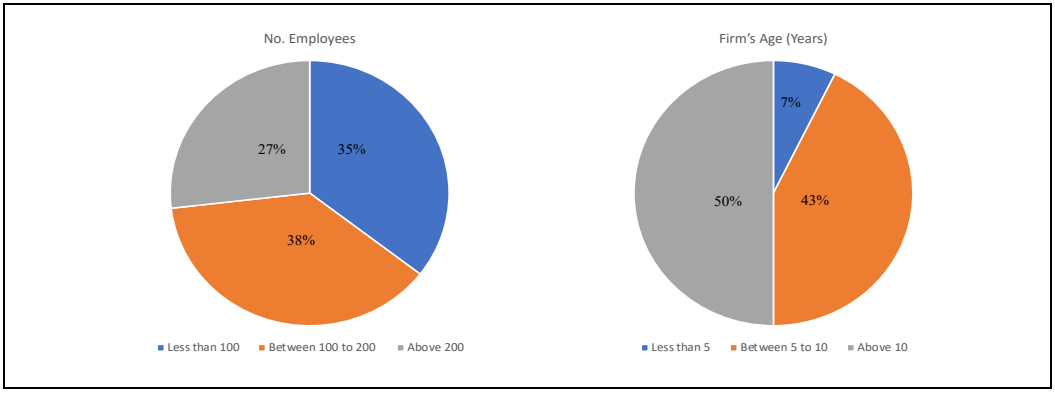


Figure 5: Profile of Respondents

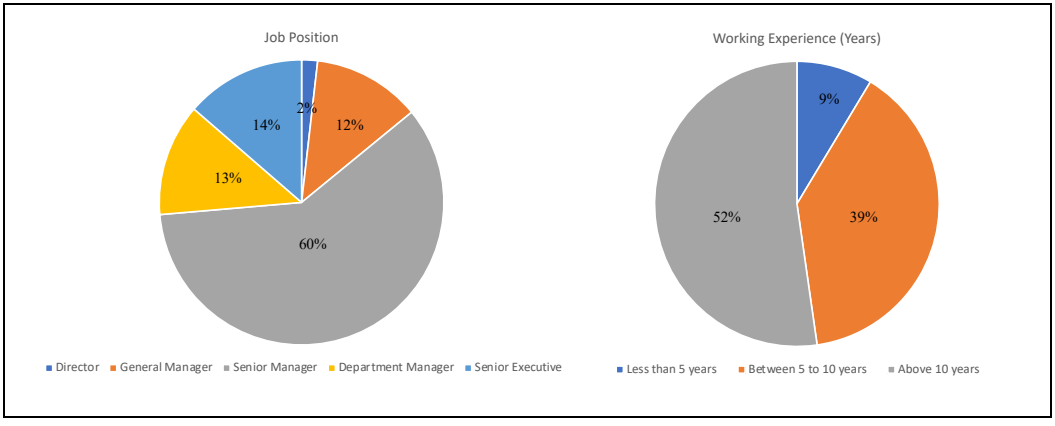


Figure 5 shows that most respondents hold executive or managerial positions, with 2% being directors, 12% general managers, 60% senior managers, 13% department managers, and 14% senior executives. Regarding work experience, 9% have at least 5 years, 39% have 1-5 years, and

52% have over 10 years, representing a diverse range of career stages that could influence decision-making within the firms.

4.2 Descriptive Statistic

Table 1 illustrates the results of the mean, median and standard deviation (SD) for each variable used in this study.

Table 1: Descriptive statistics

Variables	Mean	Median	SD
EP	3.411	3.500	0.698
CG	0.000	0.548	0.895
CO	0.000	0.270	0.609
CA	0.000	0.100	0.630
CD	0.000	0.610	0.676

EMP=environmental managerial performance; EOP=environmental operational performance; CG=carbon governance; CO=carbon operation; CA=carbon accounting; CD=carbon disclosure

The results indicate EP has a mean of 3.411, a median of 3.500, and a standard deviation (SD) of 0.698. CG has a mean of 0.000, a median of 0.548, and an SD of 0.895. CO has a mean of 0.000, a median of 0.270, and an SD of 0.609. CA has a mean of 0.000, a median of 0.100, and an SD of 0.630. CD has a mean of 0.000, a median of 0.610, and an SD of 0.676. The means for CG, CO, CA, and CD are zero due to standardization, which transformed the data to a mean of zero and a SD of one for comparability. Standardization does not change the relationships among variables or the significance of the results; rather, it ensures that variables measured on different scales contribute equally in the analysis, thereby preventing bias from scale differences.

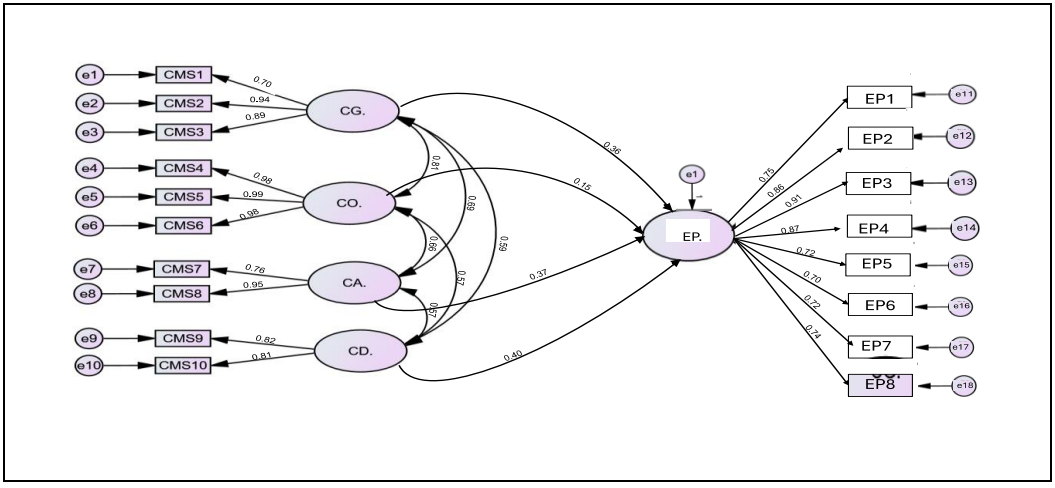
4.3 Confirmatory Factor Analysis

This study used structural equation modeling (SEM) with SPSS V28.0 and AMOS V29.0 to analyze variable relationships (Hair et al. 2010). It follows a two-stage SEM process: confirmatory factor analysis (CFA) for reliability and validity (Hair et al. 2016), and a structural model to test hypothesized relationships (Hair et al. 2006).

4.3.1 Measurement model

Figure 6 illustrates the CFA measurement model for CG, CO, CA, CD, and EP. In this model, CG and CO were each assessed using three items, CA and CD were measured with two items each, and EP was evaluated using eight items.

Figure 6: CFA Measurement Model



Based on the results in Table 2, the fit indices such as $\chi 2/df = 2.673$ (with a significant p-value of 0.003), SRMR=0.0373, RMSEA =0.067, GFI=0.943, AGFI=0.912, CFI=0.978, and TLI=0.966, all suggest that the model fits the data well without any modifications.

Table 2: Summary of Model Fit

Goodness of Fit	$\chi 2$ /df	SRMR	RMSEA	GFI	AGFI	CFI	TLI
Recommended Value	2 to 5	< 0.08	≤ 0.08	≥ 0.90	≥ 0.90	≥ 0.90	≥ 0.90
Measurement Model	2.673	0.0373	0.067	0.943	0.912	0.978	0.966

Note: N=220; *p-value=0.001*; SRMR (standardized root mean squared residual); RMSEA (root mean square error of approximation); GFI (goodness-of-fit index); AGFI (adjusted goodness-of-fit index); CFI (comparative fit index); TLI (Tucker-Lewis index)(Browne & Cudeck 1993; Hu & Bentler 1999; Kline 2005)

All the factor loadings in Table 3 for the measurement items (CMS1 to CMS10, and EP1 to EP8) exceed the 0.70 threshold, with only one item (CMS1 = 0.679) falling slightly below the ideal 0.70 threshold. This item was retained due to its theoretical relevance and the strong overall reliability of the construct (CR = 0.787), consistent with recommendations that loadings above 0.60–0.70 can be acceptable in SEM (Sarstedt et al., 2019). The composite reliability (CR) for all constructs (CG, CO, CA, CD, and EP) is above 0.70, ranging from 0.787 to 0.989 which is considered satisfactory (Preacher & Hayes 2008). The Average Variance Extracted (AVE) values for CG, CO, CA, CD, and EP range from 0.691 to 0.968, indicating that the measurement scales adequately capture the constructs' variance.

Table 3: Summary of Measurement Model

Constructs	Items	Factor Loadings	CR	AVE
Carbon Governance (CG)	CMS1	0.679	0.787	0.627
	CMS2	0.935		
	CMS3	0.888		
Carbon Operation (CO)	CMS4	0.977	0.989	0.968
	CMS5	0.986		
	CMS6	0.975		
Carbon Accounting (CA)	CMS7	0.763	0.848	0.739
	CMS8	0.947		
Carbon Disclosure (CD)	CMS9	0.815	0.801	0.668
	CMS10	0.808		
Environmental Performance (EP)	EP1	0.745	0.930	0.627
	EP2	0.860		
	EP3	0.910		
	EP4	0.866		
	EP5	0.724		
	EP6	0.699		
	EP7	0.720		
	EP8	0.737		

Additionally, discriminant validity was attained because the square roots of AVEs (the values in bold in Table 4) for CG (0.831), CO (0.984), CA (0.860), CD (0.818) and EP (0.792) are greater than the corresponding correlation between each pair of constructs. The results suggest that the measurement scales used to evaluate EP, CG, CO, CA, and CD are reliable and valid for assessing their respective constructs.

Table 4: Discriminant Validity

	CR	AVE	EP	CG	CO	CA	CD
EP	0.930	0.627	**0.792**				
CG	0.787	0.691	0.364	**0.831**			
CO	0.989	0.968	0.153	0.805	**0.984**		
CA	0.848	0.739	0.372	0.690	0.655	**0.860**	
CD	0.801	0.668	0.397	0.588	0.569	0.570	**0.818**

4.3.2 Structural model analysis

The beta (β) path coefficient as shown in Figure 7 demonstrated the direction and relationship between the exogeneous and endogenous constructs. All the fit statistic values, the CMIN>df =1.974, and GFI=0.963, AGFI=0.917, CFI=0.985, and TLI=0.973 are above the cut-off value of 0.90. Additionally, the SRMR=0.0477 and RMSEA=0.067 are superior to the advised value of 0.08 supports its suitability for testing hypotheses and make predictions about the relationships among the variables in the datasets.

Figure 7: Structural Model

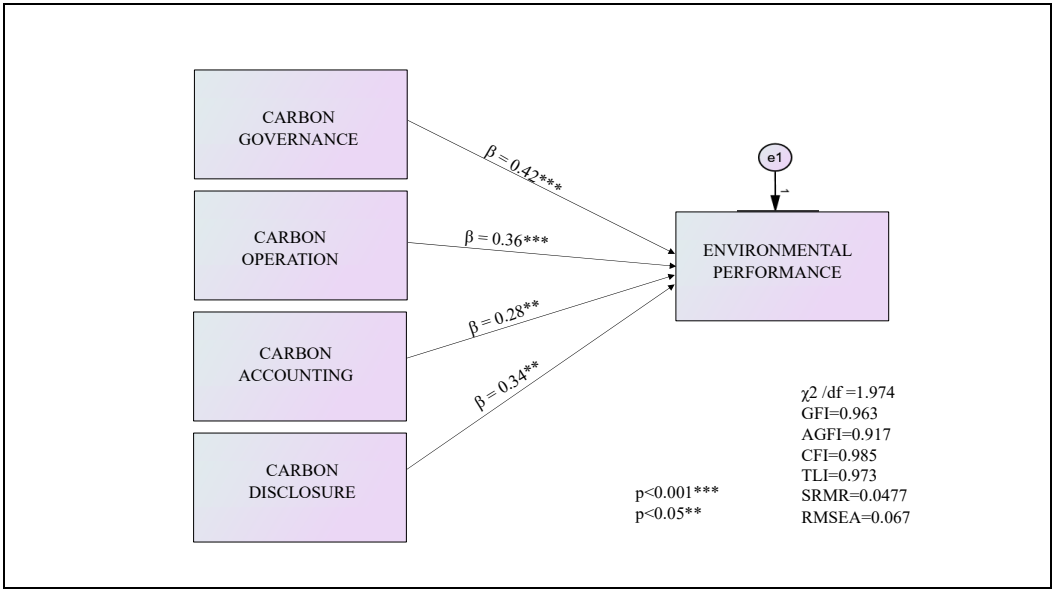


Table 5 reveals that all hypothesized path coefficients (H1, H2, H3, and H4) demonstrate significant positive relationships with the dependent variable, EP, as indicated by their β-values, t-values, and p-values. Specifically, the H1 path shows the strongest relationship with a high β-value of 0.424 and a highly significant p-value ($p < 0.001$). The 95% confidence interval (CI) of 0.283 to 0.565 further confirms this robust positive effect. For H2, the path exhibits a moderately strong positive relationship with a β-value of 0.360 and significance at $p = 0.031$. The CI (0.035 to 0.685) supports its reliability and indicates a positive effect, though with a wider potential range of outcomes.

Table 5: Results of path coefficients

Path	β - value	S.E.	t-value	p-value	LB 5%	UB 95%	Decision
H1:CG=> EP	0.424	0.072	5.889	0.000***	0.283	0.565	Supported
H2:CO=> EP	0.360	0.166	2.169	0.031**	0.035	0.685	Supported
H3:CA=> EP	0.280	0.064	4.375	0.000***	0.155	0.405	Supported
H4:CD=> EP	0.339	0.140	2.421	0.016**	0.065	0.613	Supported

Level of significance at ***p<0.001; **p<0.05

The H3 path also demonstrates a positive effect, with a β-value of 0.280, significant at $p < 0.001$, and a CI of 0.155 to 0.405. Although slightly weaker than H1 and H2, it is still clearly supported. For H4, the path shows a moderate positive effect with a β-value of 0.339 and significance at $p = 0.016$. The CI (0.065 to 0.613) indicates a positive relationship, and the effect remains statistically supported.Together, these results indicate that all examined constructs (CG, CO, CA, CD) have significant and positive effects on EP. Among these relationship, H1 exhibits the strongest effect, followed by H2 and H4, while H3 demostrates a smaller yet meaningful effect. These findings confirm that all hypotheses were supported.

Building on these results, CMS practices through CG, CO, CA, and CD in manufacturing firms are crucial determinants of EP in Malaysia.The results further indicate considerable variation in CM practices across firms. Descriptive statistics (Table 1) reveal high variability in CG (SD=0.895) and moderate variability in CO (SD=0.609), CA (SD=0.630), and CD (SD=0.676). Consistent with Jalilibal et al., (2021), higher variability suggests the influence of differing internal and external firm-specific factors, while moderate dispersion reflects variation within expected ranges for organizational practices. Based on these interpretations, several key findings can be inferred:

First, the strong positive relationship with a β-value of 0.424 in the H1 path indicates that CG is the strongest predictor of EP among Malaysian manufacturing firms. This aligns with the NRBV's emphasis on strategic resource orchestration from the top, highlighting that top-down commitment, such as board support and ESG committees, is an essential first step for effective CM. Additionally, the observed high variability SD (0.895) in CG is consistent with prior literature (Sial et al., 2022; Luo and Tang, 2016; Tang and Luo, 2014; Nwokolo et al., 2023), which emphasizes that regulatory pressures, organizational policies, and internal sustainability commitment shape governance practices. Importantly, this focus extends beyond legal compliance to proactive engagement in industry-wide green initiatives (Abdul Aziz et al., 2018; D'Angelo et al., 2023). Contrary to concerns about misaligned board goals and greenwashing (Crifo et al., 2019; Kim & Lyon, 2015), the findings indicate effective alignment between sustainability objectives and business strategy, reflecting genuine commitment to carbon governance in the Malaysian context (Tao, 2025). The influence of strong policies, regulatory frameworks, and awards such as the Prime Minister's Hibiscus Award (PMHA) further reinforces this genuine commitment.

Second, the positive relationship with a β-value of 0.360 in H2 path indicates that CO significantly influences EP, supporting the NRBV notion that operational resource management is critical for translating strategic intentions into measurable outcomes. The observed moderate variability SD (0.609) in CO reflects adherence to operational standards and environmental regulations, such as SIRIM Eco-Labelling and the Environmental Quality Act 1974. While prior studies highlight challenges like ineffective carbon targets or greenwashing (Stavroulakis et al., 2022; Lyon & Montgomery, 2015), Malaysian firms demonstrate consistent carbon operations driven by regulatory compliance and genuine carbon reduction efforts, suggesting effective internalization of sustainability practices into operations (Sharaf-Addin & Al-Dhubaibi, 2025; Abdalla et al., 2024; Aris & Auzair, 2024; Sarkar et al., 2021).

Third, the H3 path shows the weakest positive effect (β = 0.280) of CA on EP, which may indicate that carbon accounting is often perceived as a bureaucratic or compliance-oriented task rather than a strategic tool for driving EP (McDonald et al., 2024; Swalih et al., 2024). Nonetheless, the moderate variability SD (0.630) aligns with prior studies (Chang et al., 2015; Maheswari & Kavitha, 2020; Erwin, 2021; Keivani et al., 2020), which note differences in reporting methods and standards. The positive effect suggests that firms with robust sustainability strategies and third-party assurance can leverage CA for accurate carbon data tracking, consistent with NRBV's focus on leveraging environmental resources for strategic advantage. Furthermore, the supportive regulatory framework in Malaysia, including Green Practices Guidelines (RMKe-12) and SDG 12.6, helps firms transform CA from a routine reporting exercise into a credible and strategic component of EP.

Fourth, the H4 path demonstrates a positive effect of CD (β = 0.339) on EP, validating Legitimacy Theory. Transparent reporting allows firms to gain societal trust, align with stakeholder expectations, and reinforce legitimacy (Sun et al., 2025; Gezgin et al., 2024). The moderate variability SD (0.676) reflects differences in commitment to transparency and adherence to reporting standards. Initiatives such as the Simplified ESG Disclosure Guide (SEDG) for SMEs by SC and CMM provide practical guidance, enabling firms to meet stakeholder expectations effectively. Although greenwashing concerns persist (Cho et al., 2023; Alam et al., 2022), regulatory support mitigates these risks and enhances the effectiveness of carbon disclosures.

Overall, the findings show that top-down leadership is the most influential driver of carbon governance, while carbon accounting has the weakest effect due to its compliance-oriented nature. Operational practices and disclosure show roles by linking strategic intent with implementation and legitimacy. Together, NRBV and Legitimacy Theory condfirm that a holistic carbon management approach, spanning governance, operations, accounting, and disclosure, enhances environmental performance among Malaysian manufacturing firms.

5. CONCLUSION

This study extends Natural Resource-Based View (NRBV) theory by demonstarting that carbon governance (CG), carbon operations (CO), carbon accounting (CA), and carbon disclosure (CD) significantly and positively influence environmental performance (EP). The findings confirm that CM practices operationalize NRBV strategies, including pollution prevention, product stewardship, and sustainable development. Specifically, CG enhances resource efficiency and emission reduction, CO supports sustainability through recycling and green logistics, CA enables accurate emissions tracking and waste reduction, and CD strengthens stakeholder relationships via transparent reporting. In addition, the results support Legitimacy Theory, as CG and CO signal firms' commitment to environment and societal expectations, CA enhances legitimacy through transparent environmental measurement, and CD reinforces stakeholder trust by aligning organizational actions with expectations for accountability and sustainability.

The study also offers valuable practical insights for policymakers and regulators regarding the implementation of carbon pricing mechanisms in Malaysia, including voluntary carbon markets, emissions trading systems, and carbon taxes. The CM practices examined in this study may be incorporated into existing frameworks or new regulations that incentivize sustainable behaviour through financial and regulatory benefits, including reduced corporate tax rates or tax credits, priority access to grants from the Malaysian Green Technology and Climate Change Corporation (MGTC), preferential vendor selection by government-linked companies (GLCs), enhanced financing opportunities under the Green Technology Financing Scheme (GTFS), and eligibility for incentives under the Green Investment Tax Allowance (GITA) and Green Income Tax Exemption (GITE). Furthermore, regular audits and reporting requirements, supported by collaboration with industry stakeholders, could strengthen compliance and embed sustainability within corporate governance structures. Aligning Malaysia's National Sustainability Reporting Framework (NSRF) with the International Sustainability Standards Board (ISSB) would further enhance transparency and accountability, supporting stronger EP.

For industry players, the results provide a strategic framework to align carbon governance, operations, accounting, and disclosure practices to support sustainable business models. Beyond energy efficiency, firms may invest in research and development for sustainable manufacturing processes, leading to eco-friendly production methods that meet carbon reduction targets while reducing operational costs. Over time, firms can benefit from lower operating costs and carbon offsets/credits. This dual advantage strengthens firms' competitiveness in both domestic and international markets. Overall, integrating CM into operations supports eco-friendly production, reduces costs, earns carbon credits, and improves competitiveness, while advancing national and global sustainability goals, particularly SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

Despite these contributions, the findings should be interpreted in light of several limitations. First, sampling and generalizability are constrained by reliance on the Federation of Malaysian Manufacturers (FMM) directory, which contained outdated contact information and may not fully represent the Malaysian manufacturing sector. Future studies could improve generalizability by focusing on specific industries, such as chemicals, food and beverages, metals, or electrical and electronics (Lee et al., 2022). Second, the cross-sectional design limits causal inference;

therefore, longitudinal studies are recommended. Third, the use of self-reported data may introduce response and social desirability biases, which future research could address through objective measures or data triangulation. Fourth, the response rate of 22% raises the possibility of non-response bias, although early–late respondent analysis indicated no significant differences. Finally, reliance on a single respondent per firm may result in common method bias, which future studies could mitigate by using multiple respondents or integrating survey and archival data. Notwithstanding these limitations, this study provides a solid foundation for advancing carbon management research in Malaysia and extending the application of NRBV and Legitimacy Theory across industries.

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