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Carbon emission and corporate cash holdings: evidence from the 2008 financial crisis of Türkiye within TOPSIS and ARIMAX approaches

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Abstract

Purpose – This study tests the relationship between carbon emissions and corporate cash holdings in terms of 2008 financial crisis in the listed firms of Borsa Istanbul (BIST).

Design/methodology/approach – This study models Türkiye's carbon emissions as a function of gross domestic product, per capita energy consumption and per capita carbon emission, utilizing annual data sourced from the official database of the World Bank. The analysis employs the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) and autoregressive integrated moving average with exogenous variables (ARIMAX) model, drawing upon a dataset comprising 1,130 firm-year observations from Türkiye.

Findings – The TOPSIS results indicate that reductions in per capita CO_2 emissions and carbon intensity require firms to minimize cash holdings for transactional purposes, as well as lower debt and trade credit level. In contrast, for firms listed on BIST, improvements in operating cash flow and overall firm performance are essential. These findings underscore the importance for regulators, policymakers and corporate executives to consider the effects of environmental regulation on corporate cash holdings and to develop related policy measures aimed at mitigating the adverse impact of carbon intensity. Furthermore, the ARIMAX results reveal no significant overall relationship between carbon emissions and corporate cash holdings, except in two areas: working capital management, where cash ratios are positively associated, and firm performance, where both return on assets and EBITM margin exhibit significant positive effects in the long run.

Practical implications – Overall, this study examines new comprehensive evidence from carbon intensity as not only working capital management policy in the firm-specific level but also financial performance factor plays an important role for listed firms' investment decision-making.

Originality/value – Prior studies have identified a relationship between carbon emission and cash holding levels, whereas this study investigates how global financial crisis, as an institutional environment factor, influences the value of cash holdings in Türkiye before and after the financial crisis. Our analysis addresses the critical issue of corporate cash holdings, with a particular focus on their implications for carbon emissions as a key sustainability indicator. The motivation for this study stems from growing global concern over climate change and the adverse effects of greenhouse gas emissions arising from economic activities on corporate financial policies, particularly cash holding behavior.

Keywords Carbon intensity, Corporate cash holdings, Ideal best solution, 2008 Financial crisis

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1. Introduction

Cash is the most liquid current asset and is vital to daily business operations. Cash constitutes a significant component of the firm's total assets and generally refers to money and demand deposits (Akgün, 1998). While the percentage of assets held in cash is very small, effective cash management is crucial to a firm's solvency. Therefore, successful cash management helps companies avoid both financial difficulties and the high opportunity cost of holding excess cash (Akgün, 2021, 2024).

However, holding cash is also an opportunity cost of capital, meaning cash generally yields lower returns than other investments (Elmaasrawy *et al.*, 2025; Chen *et al.*, 2020). Conversely, firms operating with low of cash holdings may face two adverse consequences: an inability to meet debt obligations on time and a decline in income due to insufficient liquidity (Akgün, 1996).

Corporate cash holdings represent a critical indicator of the efficiency of working capital management. As a central element of corporate finance theory, working capital management plays a key role in determining firms' liquidity and profitability by overseeing the balance of short-term assets and liabilities, thereby ensuring the fulfillment of current obligations in day-to-day operations (Akgün and Karataş, 2021).

Cash holdings decision is one of the most significant decisions taken by the financial managers for firms (Akgün, 1996). Thus, cash holdings decision is significantly influenced by the firm's internal environment and the external environment in which the firm operates (Elmaasrawy *et al.*, 2025; Islam, 2012). Firms experiencing financial constraints, especially during financial crises, often hold cash to finance profitable investment projects cheaply and avoid costly external financing (Elmaasrawy *et al.*, 2025; Tawfik *et al.*, 2024a; Chen *et al.*, 2020).

During periods of financial crisis, firms tend to place a stronger emphasis on maintaining higher level of cash holdings to strengthen their financial conditions (Salehi *et al.*, 2019). In times of heightened uncertainty, precautionary motivation drives firms to increase cash reserves to buffer against potential future crisis, even at the expense of postponing or forgoing investment opportunities (Tan and Aksoy-Hazir, 2022). The financial and economic consequences of the 2008 global financial crisis, in particular, have undercovered the importance of these decisions, drawing the attention of executives, scholars, investors, shareholders and regulators worldwide.

Firms with strong cash flows typically maintain larger cash reserves to enhance liquidity, thereby allocating more fun to operational needs and unforeseen investment opportunities (Opler *et al.*, 1999), particularly during the financial crisis. Additionally, according to Keynes's theory of liquidity preference, firms are inclined to hold more liquid assets during financial crisis to manage risk effectively and meet short-term obligations (Tarighi *et al.*, 2024). Nevertheless, inappropriate managerial decisions in adopting working capital management policy during such periods may lead to liquidity losses and jeopardize the firm's operating sustainability (Zimon and Tarighi, 2021). In this context, the key consideration is that, during financial crisis, one of the most effective strategies to mitigate economic challenges is to make well-informed decisions regarding the level of corporate cash holdings and design of working capital management policies (Salehi *et al.*, 2019).

The 2008 financial crisis opened policymaker discussions on the compatibility between economic growth and environmental and corporate sustainability. Thus, the decline in business production due to the financial crisis led to downward changes in consumption and investment patterns, resulting in reductions in energy consumption and, consequently, carbon dioxide ($CO_{2)}$ emissions (Jalles, 2020).

Over the years, the integration of environmental, social and governance (ESG) criteria into corporate strategy has become a central axis of institutional reform and shareholder alignment. This trend is particularly evident in firms' financial decisions and is expected to play a significant role in maintaining optimal cash flow and driving sustainable development (Srairi and Katep, 2025). In this context, financially constrained companies – particularly during the

2008 financial crisis – listed on Borsa Istanbul (BIST) in Türkiye can hold cash to finance environmental prevention activities regarding carbon emissions. To do this, we think that cash holdings can significantly support to finance carbon intensity control investment since they have low financial cost and high liquidity, which is consistent with Zhang *et al.* (2020).

Overall, while carbon intensity exerts a detrimental impact on firm profitability, corporate assets are often allocated efficiently in relation to cash holding level (CHL) (Wang, 2023). For instance, if a firm could accurately predict its future cash flow, it would be able to optimize its working capital requirements and credit alternatives, thereby aligning debt maturities with expected cash inflows. However, under conditions of cash flows uncertainty, firms may increase liquid assets holdings or resort to more long-term borrowing (Akgün, 1998). In this context, the analysis of both environmental and financial information becomes essential for reducing uncertainty, thereby assisting investors, shareholders and creditors in their decision-making (Akgün, 2020b), particularly during periods of financial crisis.

Moreover, examining the impact of 2007–2008 global financial crisis on carbon emissions and corporate cash holdings is critical, as financial crisis may generate new risks that compel firms to consider both their environmental performs and firm profitability (Arco-Castro *et al.*, 2024). This raises a key research question: to what extent do firm performance, working capital management, leverage and firm size mitigate or exacerbate the relationship between corporate cash holdings on CO_2 emissions among listed firms in Türkiye during the 2008 financial crisis?

A more important question is whether the carbon intensity of BIST-listed firms would have increased their cash holdings during the 2008 financial crisis. However, if BIST firms raise cash by using debt financing due to high carbon emissions, this could lead to excessive financial risk and thus negatively impact corporate cash holdings and profitability. Therefore, if firms with lower financial access can accumulate cash to avoid the challenges of carbon intensity, especially during financial crises, they should face a higher cash holding, as companies with lower financial access tend to have higher cash holdings (Chen *et al.*, 2020a).

Several of recent studies have examined the determinants of cash holdings from the perspective of carbon emissions (Amin *et al.*, 2024; Alam *et al.*, 2022) and financial performance (Lewandovski, 2017). These studies largely emphasize the precautionary motivation, whereby firms maintain higher cash balances to safeguard against uncertainty in future cash flow or profitability (Yuan and Gao, 2022), particularly during financial crisis or in volatile operating environmental.

Corporate cash holdings are also closely linked to firm's hedging policies, which represent critical financial decision, especially under crisis conditions. Global financial crises often create heightened economic policy uncertainty, restrict firms' access to financial markets and reinforce precautionary behavior. Consequently, firms are expected to hold higher level of cash during such periods (Lozano and Yaman, 2020). For example, Lozano and Yaman (2020) find that financial crisis positively influenced cash-holdings policy of European firms prior to the crisis but exerted a negative effect in the post-financial crisis period.

Following the 2008 financial crisis, the efficiency of working capital management and the level of corporate cash holdings became particularly important for listed firms (Akgün and Karataş, 2021). Although short-term financial management has increasingly attracted scholarly attention worldwide, limited research has addressed the relationship between cash holdings, carbon emission, working capital and firm performance during the financial crisis in the context of Türkiye. While the growing empirical evidence points to a connection between corporate cash holdings and carbon intensity, firm-level associations between the level of cash-holdings behavior of Turkey listed companies and their carbon intensity remain underexplored during the 2008 crisis. This study aims to fill this gap by providing comprehensive evidence on carbon intensity as both firm-specific determinants of working capital management and a significant financial performance factor influencing investment decisions in listed firms.

Against this financial backdrop, the study examines whether the 2008 crisis prompted listed firms in Türkiye to increase cash holdings in response to carbon emission and whether such behavior can be attributed to heightened precautionary motive (Lozano and Yaman, 2020). While prior research has acknowledged this relationship in other contexts, the issue has not been directly investigated within Türkiye.

Research in the literature examining the relationship between renewable energy consumption and CO_2 emissions in developing countries is comprehensive, and policies to increase local renewable energy infrastructure to encourage renewable energy consumption are generally recommended (Wang *et al.*, 2022a, b). Although there are extensive studies on the factors affecting carbon emissions and renewable energy consumption, there is no study on how Türkiye's 2008 financial crisis will change this relationship with carbon intensity.

This study employs the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) approach and ARIMAX model to examine the relationship between carbon emission, financial performance and working capital management, with a particular focus on cash holdings metrics in BIST-listed firms over a ten-year period. In doing so, it contributes to the growing body of literature on sustainable accounting and finance by providing a comprehensive evaluation that incorporates firm-specific variations in cash holdings levels. The study has two main contributions to the existing literature. First, it provides evidence on the impact of carbon emission on corporate cash holdings within the context of the 2008 financial crisis of Türkiye. Second, it contributes to the understanding of carbon intensity policies in BIST-listed firms by identifying the underlying factors that drive significant effects in the pre- and post-crisis periods.

The remainder of the study is organized as follows: The next section reviews the related literature and develops the hypotheses. Section 3 outlines the research design, methodology and data. Section 4 presents the empirical results, while Section 5 provides discussion and concluding remarks.

2. Literature and hypotheses development

2.1 Literature review and hypotheses development

Cash is essential to a firm's financial health, serving as the lifeblood of the business and enabling smooth operational continuity. This importance arises from several motivations. First, the transactional motive supports daily operations and routine transactions (Yang *et al.*, 2025; Akgün, 2021; Hou and Liu, 2020). Second, the speculative (agency) motive allows firms to hold cash for potential profit-generating investment opportunities (Akgün, 2021). Third, the precautionary motive ensures that firms maintain cash serves as a measure to mitigate unforeseen risks and uncertainties, thereby safeguarding business continuity (Akgün, 2021; Opler *et al.*, 1999). Of these motivations, the existing literature identifies precautionary motive as one of the most important, and the existing literature continues to focus on this reason (Lozano and Yaman, 2020).

Cash holdings are strongly associated with hedging policies, a crucial financial decision for firms, especially in a crisis periods (Lozano and Yaman, 2020). Prior studies, examining the impact of the financial crisis on cash holdings, document that investors tended to increase the value of corporate cash holdings during the financial crisis, with many firms amending their investment and cash holding policies due to this crisis (Shiau *et al.*, 2018).

Before the 2008 financial crisis, many countries made significant strides in corporate sustainability by improving energy efficiency and reducing CO_2 emission intensity and CO_2 emissions. However, during the financial crisis, the decline in economic activity led to a decrease in CO_2 emissions, and as consumer spending shifted, firms reduced production. For example, Sadorsky (2020) documents that the carbon intensity effect decreased in the post-financial crisis period for Australia, China, Germany, France, the UK, Italy, Russia, Turkey and the United States.

During the 2008 crisis, capital expenditures and borrowings for bank-dependent firms also fell sharply, leading to a shock in the supply of bank credit. In this context, the crisis periods in 2008 can severely impact BIST firms' precautionary motive. In other words, the underlying effects of the 2008 financial crisis, such as firms' future cash flow expectations, cash flow volatility levels (Kahle and Stulz, 2013) and uncertain expectations regarding future carbon emission investment opportunities, may increase firms' cash holding levels. For example, Lozano and Yaman (2020) find that cash holding policies in both the short-term and long-term crisis periods may be linked to shifting uncertainty levels and thus to firms' precautionary motives in European firms.

Moreover, cash holding represents a critical strategic decision for firms. Both macro-level factors, such as economic policy uncertainty and global financial crisis, and firm-specific factors, including financing constraints, create risks that influence cash holdings behavior. Generally, higher uncertainty induces firms to maintain larger cash reserves (Chen *et al.*, 2023). For example, Javadi *et al.* (2023) find that firms increase cash holdings to hedge against the adverse effects of carbon emissions within a precautionary framework. Chen *et al.* (2023) demonstrate a direct link between economic policy uncertainty and the cash holdings of China-listed firms. Similarly, Ning *et al.* (2024) report that the financing restrictions imposed by green credit policy have reduced excessive cash holdings among heavily polluting Chinese firms following the financial crisis.

During financial crises, such as COVID-19 pandemic, firms often respond to sudden economic uncertainty by increasing their cash reserves to manage cash flow fluctuations and meet operational requirements (Yang *et al*., 2025). While maintaining high cash holdings for precautionary motives provides a buffer against market turbulence, excessive cash reserves may also have adverse effects on firms.

Cash holdings play a particularly critical role during the financial crises. High level of cash enables firms to mitigate under-investment problems, and consequently, firms with substantial cash reserves are better positioned to improve operating performance in the post-crisis period (Chang and Yang, 2022).

Cash holdings represent a crucial element of a firm's financial strategy because they are one of the most common tools firms use to mitigate financial risks, manage unexpected cash flow fluctuations, reduce both transaction costs and external financing costs, meet daily financial needs and finance long-term investments. Furthermore, increasing global economic and political uncertainties have made cash reserves increasingly important for firms' financial stability (Almustafa *et al.*, 2025).

According to signaling theory, carbon reduction behavior is an important indicator of companies' commitment to low-carbon environmental protection and social responsibility. According to the findings of Zheng and Jin (2023), businesses that reduce carbon emissions can have a significant impact on corporate sustainability, but improvements in sustainability can have the opposite effect. In this context, their findings show that corporate sustainability can positively support the impact of enterprises on carbon reduction and sustainable development, while there is a significant negative relationship between cash flow and corporate sustainability.

For governments, climate policy is identified as an important antecedent for mitigating the impact of economic developments on firms' cash holdings, as climate policy is strongly linked to economic developments and firms' financial decisions (Almustafa *et al.*, 2025). This perspective is particularly important for firms operating on the BIST in Türkiye, where efforts to build a sustainable economy reflect the interaction between international sustainability goals, economic diversification and institutional indicators.

CO_2 emissions and performance have gained international importance worldwide, driven by increased emphasis on environmental accountability, climate change and reducing carbon footprints. Furthermore, achieving better carbon performance often requires companies to invest heavily in new technologies and green innovations (Al Rabab'a *et al.*, 2024). According to prior studies, low-performing firms attempt to justify their performance

through CO_2 emission costs. However, shareholder theory predicts a positive link between firms' financial growth and social disclosures. For example, the results of Akbaş and Canikli's (2019) show that firm profitability has positive effects on the transparency of publicly traded firms in Türkiye. Similarly, Lewandowski's (2017) findings indicate a significantly positive for the association between carbon emission and Tobin's *Q*, while revealing a significantly negative linear relationship between carbon performance and profitability with return on assets (ROA).

The literature on corporate cash holding can be broadly categorized into three strands. The first strand examines the determinants of corporate cash holdings (Opler *et al.*, 1999; Bates *et al.*, 2009; Çam and Gümrükçü, 2025; Dittmar *et al.*, 2003) across advanced and emerging economies. The second strand focuses on cash holding in the context of financial crisis (Arslan *et al.*, 2006; Chan and Yang, 2022; Chen *et al.*, 2023; Jebran *et al.*, 2019; Lian *et al.*, 2011; Lozana and Yaman, 2020; Nguyen Thi *et al.*, 2023; Tekin and Burgazoğlu, 2022; Tan and Aksoy-Hazir, 2022; Tran, 2023). The third strand investigates the relationship between carbon emission and cash holdings (Alam *et al.*, 2022; Amin *et al.*, 2024; Gao and Gao, 2023; Javadi *et al.*, 2023; Liu *et al.*, 2022; Sakariyahu *et al.*, 2023; Yuan and Gao, 2022; Zhang *et al.*, 2022). This study contributes to the third strand by examining the relationship between carbon emission and cash holding in the context of Türkiye's listed firms during the 2008 financial crisis. This study addresses this gap by analyzing how carbon emission influences cash-holding decisions using the TOPSIS approach and the ARIMAX model across BIST-listed firms. In doing so, it seeks to determine whether firms with higher cash holdings were able to enhance their operating performance before and after the 2008 financial crisis.

Carbon emission represents a critical challenge, not only for current populations but also for nature and future generations worldwide, including in Türkiye. Accordingly, modeling the impact of carbon emissions on corporate cash holdings during the 2008 financial crisis in Türkiye constitutes a first step toward mitigating these emissions. For instance, Yamacli and Tuncsiper (2024) demonstrate that, based on the coefficient of determination and other performance criteria, deep learning model outperforms ARIMAX model in forecasting annual carbon emission, particularly during crisis periods such as COVID-19.

Firms, investors and shareholders tend to adopt risk-averse strategies, often delaying or reducing investments in green technologies when policy and economic outcomes are uncertain. Consequently, economic policies uncertainty and global financial crisis can significantly influence firms' environmental behavior, which is critical for the transition to low-carbon economy (Oprea *et al.*, 2024). For example, Sudarmaji *et al.* (2024) find, using ARIMAX modeling, that while economic growth remains an important predictor of carbon emissions, decoupling is possible through policy measures, energy-efficient practices and transitions to lower carbon activities. Furthermore, Sakariyahu *et al.* (2023) report that participation in emissions trading schemes has significant positive effects on firm cash holdings, particularly for firms facing high insolvency risk.

Akgün (1996) emphasizes that in manufacturing enterprises, firms should adopt appropriate trade receivables and inventory policy and consider inflation and financial crisis when evaluating cash surplus. Similarly, Chang and Yang (2022) find that firms with higher cash holdings experience more rapid improvements in operating performance post-financial crisis, underscoring the importance of maintaining adequate cash reserve to buffer against unexpected shocks. Tran (2023) demonstrates that economic policy uncertainty negatively affects cash holdings in the pre-crisis period but positively influences cash levels in the post-crisis period. Benkraiem *et al.* (2020) indicate that during crisis, firms' propensity to retain cash, coupled with global diversification, is positively association with cash holdings, reflecting heightened information asymmetry challenges faced by international firms relative to domestic firms. In contrast, Tekin and Burgazoglu (2022) find that corporate sustainability negatively impacts cash holdings during the COVID-19 crisis: firms with higher ESG scores in Malaysia and Türkiye maintain lower cash reserves, whereas those in Saudi Arabia exhibit higher cash balances.

During the 2008 financial crisis in Türkiye, corporate cash holdings may have decreased due to external financial constraint or increased as result of precautionary motive (Nguyen Thi *et al.*, 2023; Lian *et al.*, 2011; Arslan *et al.*, 2006). For instance, Lian *et al.* (2011) and Arslan *et al.* (2006) provide evidence supporting the precaution motive, showing a positive impact of the financial crisis on corporate cash holdings in China and Türkiye, respectively. In contrast, Nguyen Thi *et al.* (2023) report that financial crisis can reduce corporate cash holdings. Similarly, Tan and Aksoy-Hazir (2022) find a positive relationship between the financial crisis and cash holdings levels among Turkish firms.

Enhancing corporate environmental responsibility and ensuring good corporate governance can help firms mitigate the adverse effect of carbon risk in securing trade credit. Ben-Nasr *et al.* (2025) document that carbon risk negatively affects trade credit in US firms, indicating that suppliers evaluate a firm's reliability based on its carbon intensity when providing informal financing.

Trade credit, along with gross and net working capital (NWC), negatively influences corporate cash holdings because it can serve as a substitute for cash (Nguyen Thi *et al.*, 2023). In this context, it is important to examine how the 2008 financial crisis of Türkiye contributed to weak, moderate and strong effects of carbon emission on corporate cash holdings (see Figure 2). Tarighi *et al.* (2024) report that the COVID-19 crisis led to increases in working capital management ratios, such as the current ratio and cash ratio, while firms in Iranian manufacturing sectors reduced reliance on working capital financing policies and trade credit with account receivables. Conversely, Akgün and Karataş (2021) find a significantly negative relationship between firm performance and gross working capital in code-law countries among European nations. Similarly, Salehi *et al.* (2019) demonstrate a significantly negative relationship between changes in cash holdings and stock excess returns, while observing no meaningful relationship between changes in working capital and stock surplus returns. In contrast, Zimon and Tarighi (2021) find that the COVID-19 crisis did not significantly impact working capital management policies in Polish small and medium-sized enterprises.

When firms have both adequate cash holdings and positive working capitals, the latter can significantly influence operating profit (Akgün and Karataş, 2021). For instance, Salehi *et al.* (2018) report that despite holding substantial total assets, listed firms on Tehran Stock Exchange in Iran may face challenges in meeting short-term liabilities during the post-crisis period. Overall, corporate cash holding decisions, firm performance and working capital management policy are influenced by carbon intensity, particularly during the 2008 financial crisis (Gao and Gao, 2023) in Türkiye. For example, Lian *et al.* (2011) find that the firms with lower leverage, lower capital expenditures and reduced NWC are more likely to increase cash holdings in Chinese firms. Similarly, Hu *et al.* (2024) demonstrate that firm size, NWC and cash flow from operating (CAFOR) are all significantly and positively associated to cash holdings level.

During periods of crisis, firms may prioritize financial profitability to ensure corporate survival rather than satisfy the diverse expectations of investors, employers and shareholders (Arco-Castro *et al.*, 2024; Salem *et al.*, 2018). In this context, maximize profits and improve the working capital management efficiency are critical for mitigating costs associated with carbon intensity risk (Wang *et al.*, 2022a, b). For instance, Akgün (2019) find that the working capital management efficiency of BIST 100-listed firms was significantly negatively affected in the post-financial crisis period.

According to Opler *et al.* (1999), larger firms typically have access to more financing resources, which can lead to lower cash holdings. However, evidence is mixed. Jebran *et al.* (2019) report that firm size is positively associated with cash holdings pre-crisis but negatively associated post-crisis. Çam and Gümrükçü (2025) find that the firm size coefficient is not statistically significant, although it exhibits a negative sign. Consistent with transaction motive observed by Dittmar *et al.* (2003), firm size is generally negatively correlated with cash holdings among BIST-listed firms. In contrast, Mollick and Haidar (2023) suggest that larger US oil and gas firms, benefiting from greater profitability and financing resources, are better able to evaluate alternative investment opportunities, improving performance relative to smaller firms.

Leverage (LEVERAG) also plays a significant role. Jebran *et al.* (2019) find that LEVERAG positively impacts cash holdings post-crisis, indicating that firms increase leverage ratios to bolster cash reserves after financial distress. Similarly, Nguyen Thi *et al.* (2023) report that financial LEVERAG is positively associated, while firm size is negatively associated with cash holdings, suggesting that smaller firms with high financial leverage face higher debt costs and therefore hold more cash. Conversely, Opler *et al.* (1999) and Hu *et al.* (2024) find that LEVERAG negatively affects cash holdings, while firm size has a positive association. Çam and Gümrükçü (2025) further reveal that in Türkiye, increases in working capital, capital expenditures and leverage are generally associated with lower cash holding during financial crisis. Based on literature, we test the following hypothesis.

H1. The relationship between carbon emissions and corporate cash holdings of Turkey listed firms are significantly and negative effect during times of the financial crises.

H2. The relationship between carbon emissions and financial performance of Turkey listed firms are significantly negative effect in times of financial crises.

2.2 Conceptual model

After these main themes, a conceptual model illustrating the relationship between variables is available in Figure 1.

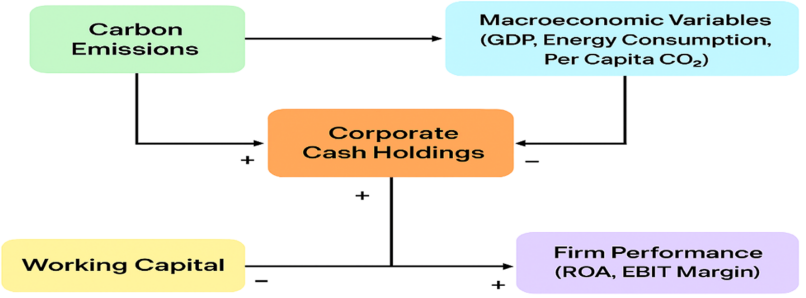

Figure 1. Conceptual model. **Source(s):** Composed by authors

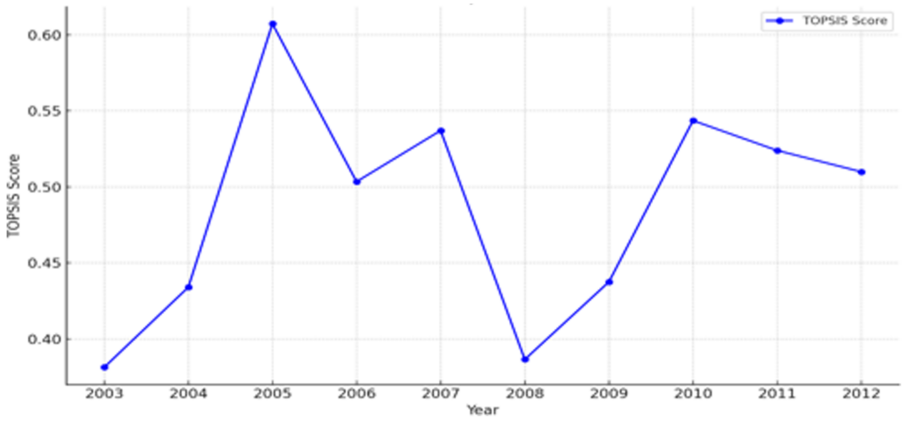

Figure 2. Topsis scores by year (2003–2012)

This diagram illustrates the causal relationships between the key variables in the study within a directed network structure. "*Corporate Cash Holdings*", located at the center of the diagram, is positioned as the main conceptual node that both influences and ultimately reshapes all other variables. Companies with high carbon emissions tend to hold more cash because they perceive future environmental policies and regulatory risks more strongly. Macro-economic indicators (GDP, energy consumption, CO_2 per capita) drive both emission levels and cash holding behavior, and the direction of this influence can vary depending on the economic climate. Working capital is generally positively correlated with cash holdings because it represents short-term liquidity, but this relationship may weaken during cyclical imbalances. As firm performance (especially ROA and earning before interest tax (EBIT) margin) increases, cash holdings also increase due to the resources obtained being held as investment or risk buffers. Thus, Figure 1 presents a holistic decision chain, starting with carbon and macro conditions and extending through cash holdings to working capital and performance. The diagram shows that a company's cash holding behavior is simultaneously fueled by both the external environment and its internal financial structure. Firms with high carbon emissions accumulate more cash reserves in case environmental regulations become stricter in the future. Macroeconomic conditions (gross domestic product (GDP), energy, CO_2 per capita) can drive both emissions and cash holdings up or down. Internally, working capital generally tends to increase with cash flow, but the strongest positive impact comes from firm performance (ROA, EBIT). In short, environmental risk + macro conditions trigger the decision to hold cash; this cash level, in turn, creates a financial equilibrium that directly connects with working capital and performance.

3. Study design

3.1 Sample

Data for this study were collected from the AMADEUS database, a comprehensive source of financial information on Turkish-listed firms provided by Bureau Van Dijk Electronic Publishing. Carbon emission variables were obtained from the World Bank. Our dataset initially included financial data for all publicly traded firms on BIST between 2003 and 2012. Firms with missing values for any relevant financial ratios were excluded, resulting in a balanced sample of 113 listed firms across various sectors, yielding a total of 1,130 firm-year observations.

Table 1 presents descriptive statistics for listed firms, illustrating carbon emissions and cash holdings patterns across the long-term, pre-financial crisis and post-financial crisis periods in Turkey. Notably, based on Table 1, the long-term average value of Net Assets Efficiency Ratio-Net Cash Flow from Operating to Total Assets (NCAFOTA) exceeds that of cash holdings and other financial metrics. In the pre-crisis, CAFOR exhibits higher value compared to corporate cash holdings, firm performance and working capital management ratios, suggesting a distribution more peaked than the normal distribution. In the period of post-financial crisis, ROA has the highest values relative to other variables. Additionally, our results indicate that the mean value of CO2Intensity and per capita CO_2 emissions (CO2PC) were lower during the pre-crisis period than in the post-crisis period. Across all variables, positive significance is observed; however, CO2Intensity, return on equity (ROE), EBITM margin (EBITM) and NWC exhibit statistically negative minimum levels in the long term. In the pre-crisis period, ROA, ROE and EBITM have negative minimum values, whereas in the post-crisis period, ROA, ROE and NWC demonstrate negative effects.

3.2 Variables

Our dependent variable is corporate cash holdings. Following current prior studies (Akgün and Memiş Karataş, 2025; Liu *et al.*, 2022; Yuan and Gao, 2022; Akgün and Karataş, 2021; Opler *et al.*, 1999; Dittmar *et al.*, 2003), we employ five measures to proxy the firm cash holdings.

Table 1. Descriptive statistics

Variables	All sample Mean	Std.	Min.	Max.	Pre-crisis Mean	Std.	Min.	Max.	Post-crisis Mean	Std.	Min.	Max.
CHL	42.454	22.935	12.940	87.436	0.087	0.048	0.004	0.128	0.112	0.020	0.085	0.137
NCAFOTA	5754.946	2027.008	2010.34	8298.396	53.30	23.33	24.94	87.44	31.61	18.58	34669	53.07
CAFOR	0.034	0.013	0.0018	0.048	6828.01	1899.99	4348.25	8298.40	4681.88	1660.15	2010.34	6164.48
CIE	0.214	0.045	0.152	0.269	0.027	0.015	0.0018	0.039	0.041	0.0057	0.034	0.048
CASH2	3.868	0.405	3.278	4.387	0.202	0.047	0.152	0.269	0.227	0.043	0.174	0.264
CO2PC	3.131	0.068	2.989	3.206	21245	0.36	46813	45995	42461	0.17	4.00	14336
CO2Inten.	2.070	2.870	−2.828	5.710	43160	0.020	42064	44256	45872	0.062	36192	41699
ROA	42.454	22.935	12.940	87.436	28491	45750	−2.83	26054	13181	45660	−0.68	22767
ROE	6.592	19.591	−27.876	52.0237	45912	22.65	−1.22	52.02	45901	16.59	−27.88	13.38
EBITM	4.235	5.561	−5.128	12.7247	16893	32325	−5.13	26634	45661	26330	45778	21367
Tobin's *Q*	0.100	0.210	0.000	0.5253	0.00071	0.0002	0.0006	0.0010	0.199	0.272	0.00006	0.525
ARTA	136.07	24.314	87.707	166.060	153.92	17472	140.22	166.06	118.23	45828	87.71	136.28
APTA	0.191	0.0232	0.161	0.2232	0.211	0.0086	0.202	0.223	0.171	0.012	0.161	0.187
GWCR	0.476	0.0735	0.293	0.5585	0.434	0.083	0.293	0.498	0.519	0.028	0.487	0.558
NWCR	0.090	0.115	−0.201	0.1877	0.140	0.047	0.090	0.188	0.041	0.146	−0.201	0.163
LiquidR	2.200	0.669	1.143	3.2125	34700	0.74	41640	34001	16469	0.55	31048	44256
CurrentR	4.024	2.765	0.0316	9.6880	31444	26665	0.032	19450	43586	46813	0.578	25447
CASHR	2.912	0.572	2.1291	3.7997	31444	0.59	41306	17593	35096	0.62	47150	29281
TA	13.719	0.574	12.206	14.1466	13.44	0.72	44531	13.97	14.00	0.14	13.78	14.15
LEVERAG	0.566	0.126	0.434	0.8456	0.500	0.070	0.434	0.582	0.631	0.142	0.458	0.846
Obs.	1,130	1,130	1,130	1,130	565	565	565	565	565	565	565	565

Note(s): We used to follow two financial crisis period: before crisis (2003–2007) and after crisis (2008–2012)
GWCR: gross working capital ratio; NWCR: net working capital ratio

Source(s): Composed by authors

First, CHL is calculated as the ratio of cash and cash equivalents to total assets. Second, CAFOR to Operating Revenue (CAFOR) is computed as CAFOR divided by operating revenue. Third, NCAFOTA follows prior studies (Opler *et al*., 1999; Bates *et al*., 2009; Akgün, 2020; Akgün and Karataş, 2021). Fourth, cash interactive effect (CIE) is calculated as the CHL multiplied by total liabilities and divided by total assets (Akgün and Karataş, 2021). Finally, CASH2 is defined as cash and cash equivalents divided by the total assets minus cash and cash equivalents (Bates *et al*., 2009).

Our primary independent variable is carbon emissions. Carbon intensity is typically measured by scaling carbon emissions (in tons) with firm's specific financial metrics such as assets, equity and sales (Altunbas *et al*., 2023; Amin *et al*., 2024). Additionally, CO_2 emissions per unit of GDP serve as a commonly used indicator to assess carbon reduction at the national level (Zhang *et al*., 2022). Accordingly, we employ two independent variables: carbon emission per capita and carbon intensity.

Corporate cash holdings may influence on firm profitability. To capture this effect, we include firm performance proxies: ROA, ROE and EBIT margin (EBITM). Furthermore, Tobin's *Q* calculated as market capitalization divided by total asset -is used as a market performance proxy (Akgün, 2020).

Corporate cash holdings also impact working capital management policies. The independent variables for this domain include seven key proxies: accounts receivable to total assets (ARTA) and accounts payable to total assets (APTA), representing trade credit and firm characteristics; gross working capital ratio (GWC), NWC ratio (NWC) and working capital ratios (Akgün, 2021). For example, Akgün (2019) finds that working capital ratios associated with economic value added (EVA) and efficiency declined in terms of ARTA during the post-crisis period compared to the pre-crisis period, while APTA improved.

Finally, we include the following control variables to account for potential firm level influences on the corporate cash holdings. These include firm size (FSIZE) measured as the natural logarithm of total assets, and leverage (LEVERAG) defined as total debt divided by total assets (Akgün, 2020). All indicators used in this study are summarized in Table 2.

3.3 Methodology

This study aims to examine the predictive capacity of various uncertainty indices related to linkage between carbon emissions, cash holdings, financial performance, firm-specific factors and working capital management policy for forecasting pre- and post-financial crisis outcomes. To investigate these relationships comprehensively, we employ two analytical models: the TOPSIS and the autoregressive integrated moving average (ARIMA) with exogenous variables (ARIMAX). The primary objective is to determine which model better predict corporate cash holdings before and during the 2008 financial crisis.

Using a multi-criteria decision-making (MCDM) approach such as TOPSIS, we first prioritize the performance values for each of the identified (Negi and Kharde, 2021) cash holdings factors based on financial data analysis in the pre- and post-financial crisis. Specially, we apply the TOPSIS method to estimate the effect of carbon emission on corporate cash holding, following Weng *et al.* (2024) and Saraji and Streimikiene (2024). Developed by Hwang and Yoon in 1981, the TOPSIS method identifies an ideal solution that maximizes benefits while minimizing costs (Lee and Wong, 2019; Weng *et al*., 2024). This approach is particularly valuable for decision-makers, as it facilitates the evaluation and ranking of alternatives according to multiple criteria, thereby simplifying complex financial decision-making and ensuring that all relevant factors are considered before reaching a final decision (Saraji and Streimikiene, 2024).

The TOPSIS method defines as positive relative proximity index and assesses the distance from the negative ideal solution, subsequently selecting the alternative with the highest similarity to the positive ideal solution (Lee and Wong, 2019; Tzeng and Huang, 2011). In practice, TOPSIS compares a set of alternatives by assigning weight to each criterion,

Table 2. Definition of variables

Variables	Description	Source
1. Corporate cash holdings		
Cash holding level (CHL)	Cash and cash equivalent divided by total assets	Akgün (2020)
Cash2	The ratio of cash and equivalents to total assets minus cash and equivalents	Yuan and Gao (2022)
Cash interactive effect (CIE)	Cash holding level and multiple by total liabilities divided by total assets	Akgün and Karataş (2021)
Cash flow from operating-to-operating revenue (CAFOR)	Cash flow from operating divided by operating revenue	Akgün (2020)
Net cash flow from operating to total assets (NCFOTA)	Net cash flow from operating divided by total assets	Akgün (2020)
2. Carbon emission ratios		
CO_2 intensity	Ratio of carbon emission (kg) to equivalent energy use	wits.worldbank.org
CO_2 emissions per capita	Ratio of carbon emission (tons) to per capita	wits.worldbank.org
3. Firm performance ratios		
Return on assets (ROA)	Earnings after tax divided by total assets and multiplied by 100	Akgün (2020)
Return on equity (ROE)	Earnings after tax divided by firm's shareholders' equity and multiplied by 100	Akgün (2020)
EBIT margin (EBITM)	This indicator is calculated by adding interest and tax back to earnings after tax. Obtained value was divided by firm's sales and multiplied by 100	Akgün (2020)
Tobin's *Q*	Market Capitalization divided by total assets	Knezevic and Dobromirov (2016)
4. Working capital ratios		
Gross working capital (GWC)	Current assets divided by total assets	Akgün (2021)
Net working capital (NWC)	Current assets minus current liabilities divided by total assets	Akgün (2021)
Account receivables to total assets (ARTA)	Account receivables divided by total assets	Martinez-Sola *et al.* (2014)
Accounts payable to total assets (APTA)	Accounts payable divided by total assets	Akgün (2020)
Liquidity ratio (LiquidR)	Current assets minus Inventory divided by total current liabilities	Akgün (2020)
Current ratio (CurrentR)	Current assets over current liabilities	Akgün (2020)
Cash ratio (CASHR)	Cash and cash equivalents over current liabilities	Akgün (2020)
5. Control variables		
Firm size (TA)	Natural logarithm of total assets in $US	Akgün (2020)
Firm leverage (LEVERAG)	Total debt divided by total assets	Akgün (2020)

Source(s): Composed by authors

normalizing the scores and calculating the geometric distance between each alternative and the ideal solution (Lee and Wong, 2019). Instead of relying on complex utility functions, the method systematically prioritizes actions by comparing each criterion, producing numerical results that reflect the harmony or incompatibility between alternatives and facilitating the selection or ranking the options (Akgün and Günay, 2021).

Applying the TOPSIS method to the cash holdings variables and carbon emissions data, the estimated results are illustrated in Figure 2. As shown in Figure 2, the TOPSIS score in 2005 is a higher on average than that observed during the 2008 financial crisis. These findings indicate that corporate cash holdings were significantly influenced by the 2008 financial crisis in Türkiye.

In addition, we employed a multivariate analysis using the ARIMAX model to estimate the effect of carbon emission on corporate cash holding in the Türkiye-listed firms, following the approaches of Sing *et al.* (2026) and Tissaoui *et al.* (2022). The ARIMAX model extends the conventional ARIMA framework by incorporating exogenous or explanatory variables, enabling the modeling of a dependent variable through both its autoregressive terms and external influences (Yamacli and Tuncsiper, 2024).

The ARIMA methodology provides a succinct representation of stationary time series data using two polynomials: one for autoregression (AR) and other for MA. In the context of big data analytics, forecasting can be particularly challenging, as historical data may provide limited predictive value, necessitating greater emphasis on the recent observations (Ramarao *et al.*, 2017). For example, Zou and Yang (2004) proposed an algorithm for weights and combining ARIMA models to enhance forecasting accuracy. Nevertheless, selecting the optimal modeling amidst multiple factors remains a critical challenge. The ARIMAX model addresses this by integrating ARIMA with exogenous variables – such as carbon emission impacts on cash assets pre- and post-crisis – through linear regression, thereby improving forecast performance relative standard decomposition methods.

The ARIMAX model was selected due to its efficacy in capturing both historical dynamics and the influence of exogenous variables, offering robustness, interpretability and suitability for our study objectives (Yamacli and Tuncsiper, 2024). This approach allows for univariate time series analysis while accounting for the effects of external factors on cash holdings (Andreas *et al.*, 2022) during the pre- and post-financial crisis periods. Examining corporate cash holdings with ARIMAX can also identify potential anomalies such as autocorrelation, thereby mitigating bias in estimating cash holdings and in assessing financial crises–related volatility. The model explicitly considers different autoregressive (AR), MA and exogenous (X) orders to enhance accuracy (Sing *et al.*, 2026).

Furthermore, the ARIMAX model is well suited for testing causal relationships among variables, with multicollinearity and linearity diagnostics ensuring validity (Anggraeni *et al.*, 2017). In this study, ARIMAX is applied to forecast economic variables – specially, cash holdings – that exhibit high fluctuation and uncertainty. Our application integrates an autoregressive component to account for the influence of past exogenous variable values on current observations (Wang *et al.*, 2021; Sudarmaji *et al.*, 2024), providing a robust framework to estimate the effect of climate-linked variables, such as CO_2 intensity on corporate cash holdings.

ARIMAX modeling will also construct a framework for forecasting CO_2 emissions' impact on cash holdings and identify the key predictors. This model, signified as (p, d, q), is commonly used in statistics.

$$\varphi p(B)(1-B)d\,Zt = \theta q(B)et \tag{1}$$

The ARIMAX model is commonly used for long-term forecasting due to its ability to include two variables, namely the dependent variable and the primary indicator, to predict its future cash flow value. The ARIMAX model (p, d, q) may be stated in the following manner (Sudarmaji *et al.*, 2024):

$$(1-B)d\,\varphi p\,(B)Zt = \Delta + \theta q\,(B)et + a1X1,t + a2\,X\,2,t + .\, + ak\,Xk,t \tag{2}$$

where μ, a, a., ak are constants. The ARIMAX model subsequently subjected to diagnostic tests, including the normality test. This model strikes a balance between efficiency and simplicity, making it well suited for capturing key dynamics such as trends and financial crisis in the data.

In this study, as stated above, two complementary methods were used together: TOPSIS and ARIMAX. These two methods were chosen because the study aimed to analyze both multi-criteria performance evaluation and changes over time, as well as the effects of external

factors, within the same framework. Thus, the study offers a more robust and consistent methodological structure that integrates measurement and evaluation with time-series analysis. Additionally, TOPSIS was chosen for evaluation because it is considered an effective and easily applicable criterion for ranking and monitoring the firms' environmental performance. Besides this, advantage of TOPSIS is the environmental performance measurements of all alternatives on features that can be evaluated, at least for both the best and worst dimensions.

In this study, the TOPSIS method was used to convert financial (ROA, cash ratio, asset turnover) and environmental (CO_2 intensity, per capita emissions) indicators, despite their different scales and orientations, into a single performance score. This method normalized and weighted the criteria, making them comparable and allowing firms/periods to be ranked according to their "closeness to ideal" level. The resulting TOPSIS scores facilitated our understanding of the financial–environmental balance, particularly during crisis periods, and guided subsequent ARIMAX analysis to determine which variables were more decisive. This model was chosen to measure the impact of external factors (e.g. carbon intensity, energy efficiency or economic size) on financial performance, particularly in the pre- and post-crisis periods. Consequently, the TOPSIS method undertakes the decision-making and comparison aspects of this study, while the ARIMAX model is used for statistical validation of the results and future predictions. In addition, for the ARIMAX analysis, we used standard diagnostic checks were performed (e.g., tests for autocorrelation, heteroscedasticity and model stability).

Figure 3 presents a correlation Heatmap for cash holdings and CO_2 emissions in BIST-listed firms. As illustrated, CAFOR exhibits a strong positive relationship (0.91) with CO2PC, indicating that CAFOR activities is closely associated with CO2PC increases in carbon emissions per capita. Similarly, CHL is positively correlated with CO2PC (0.43),

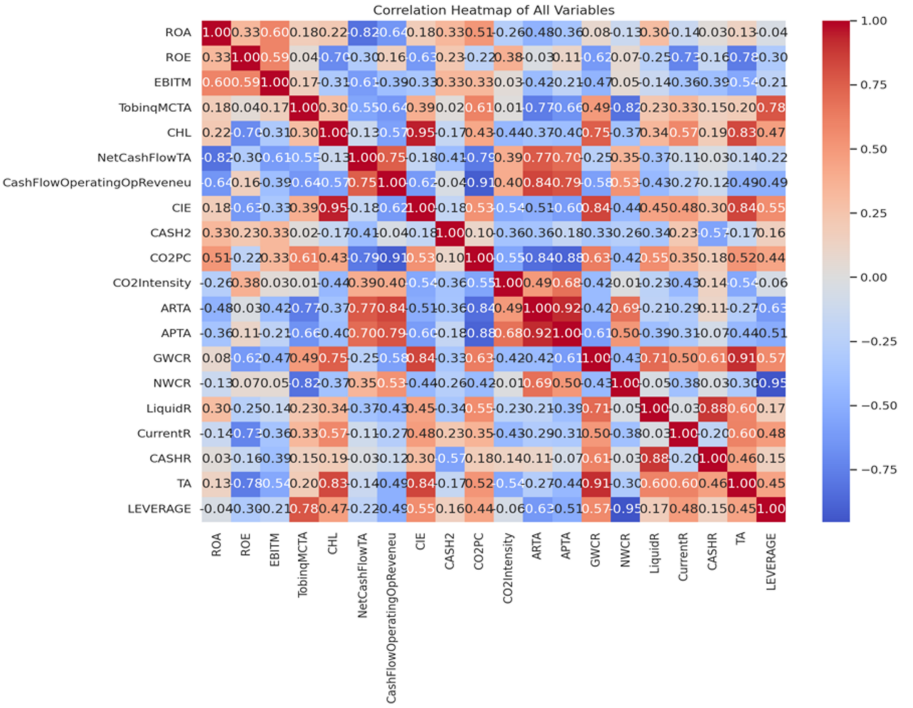

Figure 3. Correlation Heatmap of all variables with ARIMAX

suggesting that cash holdings levels are significantly linked to changes in carbon emissions. In contrast, NCAFOTA displays a strong negative correlation with CO2PC (−0.79), implying that higher net cash flow is associated with lower CO_2 emissions, consistent with Oprea *et al.* (2024), who highlight Türkiye's investments in cleaner energy and efforts to reduce air pollution.

Regarding firm performance, NCAFOTA is strongly positively correlated with ROA (0.82), indicating that cash holdings are closely related to carbon emissions, potentially due to improved energy efficiency, which is consistent with Oprea *et al.* (2024). However, NCAFOTA exhibits a weak negative relationship with ROE (−0.30) and negative correlations with both EBITM (−0.61) and Tobin's *Q* (−0.55). These results suggest that higher cash holdings in Turkey's listed firms are associated with higher ROA but lower ROE, EBITM and Tobin's *Q*. CHL has a very weak positive correlation with ROA (0.22), implying a limited relationship carbon emissions and cash holdings for this measure during the sample period. Additionally, ROE is a strongly negatively correlated with cash holding level (POPCHL) (−0.70), while other performance indicators show weak associations: EBITM (−0.31) and Tobin's *Q* (−0.30).

CAFOR shows a moderate positive correlation with both ROA and Tobin's *Q* (0.64), indicating a potential link between cash holdings policy and firm performance, while it has a weak positive relationship with ROE (0.16) and a weak negative relationship with EBITM (−0.39). CIE displays weak positive correlations with ROA (0.18), EBITM (0.33) and Tobin's *Q* (0.39), but a moderate negative correlation with ROE (−0.63). Similarly, CASH2 exhibits weak positive correlations with all firm performance indicators.

Regarding trade credit, ARTA has strong positive correlations with both CAFOR (0.84) and NCAFOTA (0.77), whereas APTA shows a moderate-to-weak negative correlation with cash holdings. GWC is strongly positively correlated with both CIE (0.84) and CHL (0.75), while NWC exhibits a moderate-to-weak negative correlation with CHL (−0.37). Among control variables, firm size strongly influences both CHL and CIE, whereas LEVERAGE demonstrates a moderate-to-weak positive correlation with cash holdings, suggesting a potential link between credit policy uncertainty, higher economic activity and carbon emissions.

In the analysis, we re-estimate equation by using five alternative cash holdings measures, namely CHL, NCAFOTA, CAFOR, CIE and CASH2. Given the nature of corporate cash holdings, we examine its relationship with carbon emissions across Türkiye context using the following models:

$$\begin{aligned} CHL_{it} = {} & \alpha_i + \beta_1 CO2PC_{it} + \beta_2 CO2Intensity_{it} + \beta_3 ROA_{it} + \beta_4 ROE_{it} + \beta_5 EBITM_{it} \\ & + \beta_6 TobinQ_{it} + \beta_7 GWC_{it} + \beta_8 NWC_{it} + \beta_9 ARTA_{it} + \beta_{10} APTA_{it} + \beta_{11} LiquidR_{it} \\ & + \beta_{12} CASHR_{it} + \beta_{13} CurrentR_{it} + \beta_{14} Controlvariables_{it} + \varepsilon \end{aligned} \tag{3}$$

$$\begin{aligned} CASH2_{it} = {} & \alpha_i + \beta_1 CO2PC_{it} + \beta_2 CO2Intensity_{it} + \beta_3 ROA_{it} + \beta_4 ROE_{it} + \beta_5 EBITM_{it} \\ & + \beta_6 TobinQ_{it} + \beta_7 GWC_{it} + \beta_8 NWC_{it} + \beta_9 ARTA_{it} + \beta_{10} APTA_{it} + \beta_{11} LiquidR_{it} \\ & + \beta_{12} CASHR_{it} + \beta_{13} CurrentR_{it} + \beta_{14} Controlvariables_{it} + \varepsilon \end{aligned} \tag{4}$$

$$CIE_{it} = \alpha_i + \beta_1 CO2PC_{it} + \beta_2 CO2Intensity_{it} + \beta_3 ROA_{it} + \beta_4 ROE_{it} + \beta_5 EBITM_{it} + \beta_6 TobinQ_{it} + \beta_7 GWC_{it} + \beta_8 NWC_{it} + \beta_9 ARTA_{it} + \beta_{10} APTA_{it} + \beta_{11} LiquidR_{it} + \beta_{12} CASHR_{it} + \beta_{13} CurrentR_{it} + \beta_{14} Controlvariables_{it} + \varepsilon \quad (5)$$

$$CAFOR_{it} = \alpha_i + \beta_1 CO2PC_{it} + \beta_2 CO2Intensity_{it} + \beta_3 ROA_{it} + \beta_4 ROE_{it} + \beta_5 EBITM_{it} + \beta_6 TobinQ_{it} + \beta_7 GWC_{it} + \beta_8 NWC_{it} + \beta_9 ARTA_{it} + \beta_{10} APTA_{it} + \beta_{11} LiquidR_{it} + \beta_{12} CASHR_{it} + \beta_{13} CurrentR_{it} + \beta_{14} Controlvariables_{it} + \varepsilon \quad (6)$$

$$NCAFOTA_{it} = \alpha_i + \beta_1 CO2PC_{it} + \beta_2 CO2Intensity_{it} + \beta_3 ROA_{it} + \beta_4 ROE_{it} + \beta_5 EBITM_{it} + \beta_6 TobinQ_{it} + \beta_7 GWC_{it} + \beta_8 NWC_{it} + \beta_9 ARTA_{it} + \beta_{10} APTA_{it} + \beta_{11} LiquidR_{it} + \beta_{12} CASHR_{it} + \beta_{13} CurrentR_{it} + \beta_{14} Controlvariables_{it} + \varepsilon \quad (7)$$

where $Co2Intensity_{it}$ and $Co2PC_{it}$ take one of the carbon emission ratios' proxies defined earlier, for listed firms i in year t, ε is an error term and α_i is a firm-specific effect.

4. Results

Table 3 presents the results of TOPSIS analysis for the sample. According to Table 3, the year 2005 represents the optimal scenario, indicating that firm profitability was higher compared to other years, while cash holdings and carbon intensity were relatively low. The year 2010 is ranked second in the long-term evaluation. Overall, the TOPSIS rankings for listed firms over the 2003–2012 period indicate that 2005 achieved the highest performance score, followed by 2010 s place, 2007 in third and 2003 ranked lowest. In the pre-financial crisis period, 2003 was ranked third, whereas 2004 achieved first place. Notably, despite cash holdings ranking fourth in 2008 among BIST-listed firms due to the heightened financial crisis in 2007–2008, 2010 secured the top rank, reflecting the recovery and stabilization of firm's post-crisis. This indicates a consistent trend aligning with broader economic outcomes.

Ain this analysis, all variables were assigned equal weight in the TOPSIS methods. Examination of Table 3 shows that the worst-performing year was 2003, followed by 2004 and 2008, which ranked eighth and ninth, respectively. Overall, the year 2005 emerged as the most effective period, considering all criteria, including corporate cash holdings, carbon emission, working capital ratios and firm performance. This suggests that BIST-listed firms were able to utilize their cash levels of efficiently in the pre-2008 global crisis period.

Table 4 shows the evaluation criteria and purpose for TOPSIS results.

According to Table 4, the analysis indicates that the effectiveness of cash holdings and prioritization of carbon emission and firm performance in the BIST-listed firms exhibit a positive association with ROA, ROE, EBITM, Tobin's *Q*, NCAFOTA, CAFOR, CIE, CASH2, NWC, LiqudR, CurrentR and capital management, where cash ratios (CASHR) and firm size represent maximum target, whereas CHL, CO2PC, CO2Intensity, ARTA, APTA, GWC and LEVERAG demonstrate positive alignment at minimum target level. These TOPSIS findings suggest that the effectiveness of cash holdings and carbon emission management serve as strong positive indicators for the evaluated alternatives in the listed.

In this study, TOPSIS method was applied to rank alternatives based on predefined criteria. Initially, a decision matrix and a normalized decision matrix were constructed, followed by the

Table 3. TOPSIS results in the long-term, pre- and post-crisis periods

Year	ROA	ROE	EBITM	Tobin's *Q*	CHL	NCAFOTA	CAFOR	CIE	CASH2	CO2PC	CO2Intensity	ARTA
	Panel A: Long-term period											
2003	−0.156	−0.011	−0.202	0.235	0.204	0.403	0.403	0.224	0.152	0.277	0.321	0.426
2004	0.098	0.031	−0.099	0.219	0.228	0.267	0.417	0.224	0.230	0.281	0.319	0.428
2005	0.104	0.810	0.501	0.379	0.008	0.184	0.416	0.012	0.269	0.284	0.321	0.378
2006	0.131	−0.019	0.401	0.271	0.263	0.259	0.261	0.258	0.183	0.312	0.316	0.361
2007	0.315	0.130	0.276	0.248	0.191	0.115	0.218	0.183	0.172	0.343	0.318	0.389
2008	−0.038	−0.434	0.041	0.225	0.220	0.230	0.309	0.224	0.262	0.336	0.306	0.350
2009	0.025	0.055	0.061	0.458	0.175	0.244	0.298	0.248	0.185	0.335	0.311	0.351
2010	0.310	0.208	0.210	0.454	0.253	0.087	0.243	0.296	0.248	0.345	0.299	0.306
2011	0.045	0.109	0.180	0.046	0.216	0.107	0.222	0.260	0.173	0.360	0.314	0.289
2012	0.308	0.146	0.298	0.202	0.282	0.060	0.100	0.316	0.264	0.369	0.313	0.226
	Panel B: Pre-financial crisis											
2003	0	0.009	0	0.141	0.769	1	0.927	0.865	1	1	0.256	0.975
2004	0.539	0.061	0.147	0.093	0.865	0.528	1	0.865	0.333	0.957	0.471	1
2005	0.553	1	1	1	0	0.241	0.994	0	0	0.831	0	0.257
2006	0.609	0	0.858	0.012	1	0.499	0.217	1	0.730	0.437	1	0
2007	1	0.180	0.680	0	0.723	0	0	0.696	0.826	0	0.702	0.418
	Panel C: Post-financial crisis											
2008	0	0	0	0.002	0.421	0.924	1	0	0.014	0.896	0.588	0.995
2009	0.180	0.761	0.074	0.002	0	1	0.947	0.263	0.867	1	0.222	1
2010	1	1	0.654	0	0.727	0.146	0.684	0.778	0.167	0.819	1	0.642
2011	0.238	0.846	0.539	1	0.395	0.256	0.584	0.389	1	0.244	0	0.505
2012	0.993	0.904	1	0.891	1	0	0	1	0	0	0.095	0

(*continued*)

Table 3. Continued

Year	APTA	GWCR	NWCR	LiquidR	CurrentR	CASHR	TA	LEVERAGE	Distance+	Distance-	TOPSIS Score	Rank
	Panel A: Long-term period											
2003	0.212	0.293	−0.090	0.032	0.145	0.152	0.290	0.312	0.078	0.350	0.3814	10
2004	0.223	0.293	−0.090	0.247	0.172	0.230	0.297	0.322	0.092	0.112	0.4341	8
2005	0.211	0.189	0.154	0.114	0.106	0.269	0.331	0.241	0.087	0.105	0.6072	1
2006	0.203	0.274	0.177	0.185	0.124	0.183	0.319	0.257	0.064	0.132	0.5034	6
2007	0.201	0.320	0.188	0.293	0.174	0.172	0.319	0.229	0.042	0.156	0.537	3
2008	0.187	0.314	0.106	0.185	0.115	0.262	0.354	0.316	0.128	0.082	0,3866	9
2009	0.179	0.334	0.125	0.321	0.191	0.185	0.329	0.322	0.118	0.089	0,4375	7
2010	0.163	0.321	0.163	0.223	0.131	0.248	0.332	0.243	0.103	0.097	0.544	2
2011	0.162	0.360	−0.201	0.279	0.170	0.173	0.372	0.356	0.152	0.064	0.524	4
2012	0.160	0.341	−0.201	0.216	0.137	0.264	0.395	0.448	0.138	0.071	0.506	5
	Panel B: Pre-financial crisis											
2003	0.505	0.896	2.85e	0.129	0.875	0.488	0.845	0.124	2.726	3.007	0.524	3
2004	1	0.895	0	0.744	1	0.968	0.966	0	2.389	3.252	0.576	1
2005	0.455	0	0.651	0	0	0	0	0.990	3.283	2.592	0.441	5
2006	0.053	0.645	0.893	0.395	0.637	0.262	0.679	0.647	2.589	2.803	0.520	4
2007	0	1	1	1	0.627	1	1	1	2.557	3.202	0.556	2
	Panel C: Post-financial crisis											
2008	1	0	0.842	0	1	0	1	0.640	3.106	2.878	0.481	4
2009	0.702	0.446	0.894	1	0	1	0.447	0.678	2.562	3.088	0.546	2
2010	0.113	0.162	1	0.279	0.397	0.210	0.652	1	2.458	2.984	0,5483	1
2011	0.062	1	0.580	0.694	0.584	0.732	0	0.446	2.607	2.644	0.504	3
2012	0	0.593	0	0.229	0.551	0.282	0.883	0	3.214	2.678	0.455	5

Note(s): We followed two financial crisis periods: before crisis (2003–2007) and after crisis (2008–2012)
Source(s): Composed by authors. Proceed data, 2025

Table 4. Evaluation criteria and purpose for TOPSIS results

Variables	Purpose
ROA	Maximum
ROE	Maximum
EBITM	Maximum
Tobin's *Q*	Maximum
CHL	Minimum
NCAFOTA	Maximum
CAFOR	Maximum
CIE	Maximum
CASH2	Maximum
CO2PC	Minimum
CO2Intensity	Minimum
ARTA	Minimum
APTA	Minimum
GWC	Minimum
NWC	Maximum
LiquidR	Maximum
CurrentR	Maximum
CASHR	Maximum
TA	Maximum
LEVERAG	Minimum

Source(s): Composed by authors. Proceed data, 2025

assignment of weights to each criterion. Subsequently, the distances to the ideal and negative-ideal solutions were computed. These weighted calculations provide BIST-listed firms with a systematic framework for evaluating operational units and facilitating comparative assessments across different activities. Finally, the relative scores for each alternative were calculated, enabling a performance ranking from highest to the lowest (Akgün and Günay, 2021).

The alternative with the highest model "*Ci**" value is considered the top-ranked option, and the performance ranks of the alternatives are determined by arranging the "*Ci**" values in descending magnitude. According to Table 5, the TOPSIS performance percentages indicate that the highest-ranked years are 2005, 2010, 2007, 2011, 2012, 2006, 2009, 2004, 2008 and 2003, respectively. From this analysis, it is evident that 2005, 2010 and 2007 occupy the top three positions. Specifically, 2005, representing the pre-crisis, is ranked first under the TOPSIS method and is regarded as the most suitable classifier for predicting the impact of carbon

Table 5. Results of TOPSIS

Year	*Ci**	Rank
2003	0.381	10
2004	0.434	8
2005	0.607	1
2006	0.503	6
2007	0.530	3
2008	0.387	9
2009	0.438	7
2010	0.544	2
2011	0.524	4
2012	0.510	5

Note(s): *Ci**: The relative closeness of each decision point to the ideal solution

intensity on corporate cash holdings in the dataset. Conversely, 2010, ranked first for the post-crisis period, is considered the best classifier for estimating estimate carbon intensity's effect on corporate cash holdings for that year.

In addition, the ARIMAX model was employed to determine the appropriate corporate cash holdings levels using the outputs of the prediction models. Table 6 presents the ARIMAX results for the sample. The results indicate that, overall, carbon emission does not exhibit a significant influence on cash holdings across all models for BIST-listed firms. In contrast, firm performance measured by ROA demonstrates a strong and positive significant effect on cash holdings proxied by CAFOR and net cash flow from operating to total assets (NCAFOR), and a moderate positive influence on CHL, CIE and CASH2. Firm performance measured by EBITM shows a moderate positive significant effect on CHL and CAFOR, and a weak positive effect on CIE and CASH2, whereas NCAFOTA does not appear to contribute. No significant relationship is observed between cash holdings and firm performance measured by ROE or Tobin's *Q* in any model.

Table 6. Estimation of ARIMAX model

	All sample				
Dependent variables	CHL	CASH2	CIE	CAFOR	NCAFOTA
CO2PC	0.651	0.635	0.635	0.635	0.714
	(−0.003)	(−0.009)	(−0.088)	(−1.234)	(−0.032)
CO2Intensity	0.782	0.712	0.712	0.712	0.694
	(−0.002)	(−0.005)	(−0.054)	(−0.876)	(−0.021)
ROA	0.021*	0.032*	0.032*	0.011**	0.003***
	(0.012)	(0.046)	(0.543)	(12.345)	(2.346)
ROE	0.342	0.421	0.287	0.287	0.406
	(−0.004)	(−0.012)	(−0.321)	(−3.456)	(0.543)
EBITM	0.045*	0.082*	0.082*	0.038*	0.514
	(0.009)	(0.035)	(0.457)	(8.765)	(18.765)
Tobin's *Q*	0.214	0.287	0.421	0.421	0.511
	(−0.057)	(−0.023)	(0.188)	(−2.345)	(0.123)
ARTA	0.412	0.198	0.412	0.154	0.466
	(0.035)	(0.057)	(0.190)	(4.321)	(0.235)
APTA	0.536	0.154	0.287	0.287	0.445
	(−0.021)	(−0.068)	(−0.277)	(−3.210)	(−0.188)
GWC	0.198	0.321	0.187	0.123	0.159
	(0.068)	(0.089)	(0.321)	(−6.543)	(0.765)
NWC	0.423	0.423	0.254	0.423	0.289
	(−0.032)	(−0.046)	(−0.290)	(−2.345)	(−0.543)
LiquidR	0.038*	0.008***	0.154	0.089*	0.075*
	(0.123)	(0.257)	(0.346)	(5.432)	(0.453)
CurrentR	0.287	0.074*	0.198	0.198	0.264
	(0.046)	(0.123)	(0.234)	(3.456)	(0.321)
CASHR	0.089*	0.015**	0.047*	0.042*	0.066*
	(0.088)	(0.346)	(0.512)	(7.654)	(0.346)
LEVERAG	0.154	0.048*	0.009**	0.047*	0.307
	(−0.112)	(−0.188)	(−0.654)	(−15.678)	(−12.345)
AIC	−45.21	−12.34	−8.76	1023.45	125.67
BIC	−40.32	−7.45	−3.45	1028.34	130.56
No of obs.	1,130	1,130	1,130	1,130	1,130

Note(s): Coefficients are reported in parentheses. ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively

Source(s): Composed by authors. Proceed data, 2025

Regarding trade credit and working capital management variables, ARTA, APTA, GWC and NWC do not show a significant contribution to cash holdings in any model. However, Liquidity Ratio (LiquidR) exhibits a strong positive significant effect on CHL and CASH2, a moderate positive effect on NCAFOTA and a weak positive effect on CAFOR. CIE does not show any contribution. Similarly, current ratio (CurrentR) demonstrates a weak positive significant effect on CASH2. For the CASH ratio, cash holdings exert a strong positive effect on CASH2, a moderate positive effect on CAFOR and CIE and a weak positive association with CHL and NCAFOTA. Finally, leverage (LEVERAG) shows a significantly moderate negative effect on cash holdings in the long term.

According to ARIMAX analysis, ROA is the variable that most strongly and positively affects financial performance. In other words, increasing profitability significantly strengthens the liquidity and financial resilience of businesses. ARTA (asset turnover) also has a similar positive effect; the more efficiently assets are used, the greater the firm's cash generation capacity. On the other hand, CO_2 intensity, an environmental variable, negatively affects financial performance. As carbon intensity increases, costs increase and liquidity is suppressed. The effect of CO2PC is weaker, but generally negative. The lagged value of the liquidity ratio (Cash Ratio) in the model is positive and significant. This indicates a behavioral continuity in firms' liquidity management. Furthermore, the variable representing the crisis period is significantly negative and significant; economic crises clearly weaken financial performance. Overall, ARIMAX findings reveal that financial performance is shaped by both internal factors (profitability, asset efficiency, liquidity policy) and external factors (environmental pressures and crisis conditions) and that these effects do not progress equally and symmetrically over time.

In ARIMAX modeling, the procedure is first followed by ARIMA modeling on the residuals, which are stationary in both variance and mean, thereby forming the ARIMAX model. In contrast, Vector Autoregressive with Exogenous Variable (VARX) modeling is applied after confirming that the data meet the necessary assumptions, namely stationary in variance and mean. In this context, the selection of the VARX model order is determined by the smallest Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values (Andreas *et al.*, 2022).

The results indicate that the optimal VARX order is indeed based on the smallest AIC and BIC values. Table 7 presents the AIC and BIC values for each possible order within the VARX model. Furthermore, Table 7 summarizes the models used for projecting corporate cash holdings. Specially, five ARIMA models – CHL, NCAFOTA, CAFOR, CIE and CASH2 – are employed to forecast cash holdings for Türkiye-listed firms. The AIC is used to rank the models, with the lowest AIC value representing the best-fitting model. According to Table 7, in the pre-crisis period, the smallest AIC value for cash holdings is observed for Tobin's *Q*, while the smallest BIC value occurs for APTA. For the post-crisis period, the smallest AIC value appears for CIE, whereas the smallest BIC value is again observed for APTA.

Based on Table 7, it is observed that univariate modeling through the ARIMAX model provides higher prediction accuracy for cash holding levels using CAFOR and NCAFOR, as well as firm performance using ROE for AIC values, compared to the multivariate VARX model, both in the pre- and post-financial crisis periods. Similarly, for BIC values, the highest prediction accuracy is obtained for cash holding levels with CAFOR and NCAFOR and firm performance with EBITM in both pre- and post-financial crisis periods. In both cases, the direction of chance in the criteria values indicates a decrease followed by improvement. Consequently, cash holdings level and CO_2 per capita (CO2PC) decreased in the pre-crisis period compared to the post-crisis period, while CO2Intensity increased and worsened. Therefore, higher carbon intensity led firms to hold more corporate cash in BIST-listed firms during the pre-crisis period compared to the post-crisis period, which aligns with the findings of Wang (2023).

Table 7. Comparing AIC and BIC value for variables

Variables	AIC (pre-crisis)	AIC (post-crisis)	AIC_Dif. (2008–2012 to 2003–2007)	BIC (pre-crisis)	BIC (post-crisis)	BIC_Dif. (2008–2012 to 2003–2007)	Direction of change
CHL	−5.759	−16.534	−10.775	−7.600	−18.375	−10.775	Decreased (improvement)
NCAFOR	42.885	39.918	−2.967	41.044	38.077	−2.967	Decreased (improvement)
CAFOR	76.197	74.192	−2.005	74.355	72.351	−2.004	Decreased (improvement)
CIE	−15.068	−23.663	−8.595	−16.909	−25.504	−8.595	Decreased (improvement)
CASH2	−5.571	−13.422	−7.851	−7.412	−15.263	−7.851	Decreased (improvement)
CO2PC	1.544	−1.139	−2.683	−0.297	−2.980	−2.682	Decreased (improvement)
CO2Intensity	−12.407	−3.490	8.917	−14.248	−5.331	8.916	Increased (worsening)
ROA	25.221	27.121	1.900	23.380	25.280	1.899	Increased (worsening)
ROE	43.782	38.374	−5.408	41.940	36.533	−5.406	Decreased (improvement)
EBITM	33.866	23.958	−9.908	32.0249	22.117	−9.907	Decreased (improvement)
Tobin's *Q*	−48.882	6.664	55.546	−50.723	4.823	55.545	Increased (worsening)
ARTA	36.105	38.092	1.987	34.264	36.251	1.987	Increased (worsening)
APTA	−20.388	−21.427	−1.039	−22.229	−23.268	−1.039	Decreased (improvement)
GWCR	−0.998	−12.359	−11.361	−2.839	−14.200	−11.361	Decreased (improvement)
NWCR	−10.139	−0.932	9.207	−11.981	−2.773	9.207	Increased (worsening)
LiquidR	16.411	9.706	−6.705	14.570	7.864	−6.706	Decreased (improvement)
CurrentR	23.349	28.084	4.735	21.508	26.243	4.735	Increased (worsening)
CASHR	14.681	8.614	−6.067	12.840	6.77	−6.066	Decreased (improvement)
TA	16.370	1.895	−14.475	14.529	0.053	−14.476	Decreased (improvement)
LEVERAGE	−3.988	2.188	6.176	−5.829	0.347	6.177	Increased (worsening)

Source(s): Composed by authors. Proceed data, 2025

5. Discussion and conclusion

5.1 Practical implications

Corporate cash holdings play a crucial role in firm performance, carbon emission and working capital management policies during periods of crisis, such as 2008 global financial crisis, particularly for BIST firms. This study contributes to the existing literature by examining the impact of carbon emissions on cash holdings in context of the Türkiye's 2008 financial crisis.

As noted by Yang *et al.* (2025), during times of uncertainty, firms tend to increase their cash holdings for precautionary motives. In this regard, Türkiye-listed firms should consider financial and investment uncertainties when making decisions and adjust their strategies based

on firm-specific characteristics, consistent with Tan and Aksoy-Hazir (2022). Regulators, policymakers and executives can improve strategies to mitigate the adverse effects of financial crisis by providing supportive policies and guidance to listed firms facing uncertainty and financial constraints.

While prior studies primarily focus on the determinants of cash holding during economic crisis, this study extends the literature by demonstrating that the effect of Türkiye's 2008 financial crisis on carbon emission and cash holdings differs between the pre- and post-crisis periods. These insights can assist investors, shareholders and other financial information users in making informed investment and working capital decisions under varying economic conditions. Furthermore, this study provides practical guidance for cash managers to mitigate the harmful effects of carbon emissions on corporate cash holdings during crisis periods.

Individuals, communities, governments, policymakers, private sector actors and organizations collectively influence consumption patterns, social participation, supportive policy implementation and innovation. Such societal efforts are critical in accelerating the adoption of renewable energy sources and mitigating climate change impacts (Saraji and Streimikiene, 2024). Accordingly, advancing renewable energy usage may improve cash holding levels of BIST-listed firms, reduce carbon emissions and promote sustainable development, particularly during financial crises.

This study addresses a significant gap in the current literature by examining how a firm's carbon emissions affect its cash holdings, the ability to secure trade credit. Specifically, it investigates the impact of carbon intensity on corporate cash holdings for Türkiye-listed firms. In light of the growing emphasis on reducing carbon footprint, understanding financial consequences of carbon emissions is essential. Our findings, based on comprehensive MCDM approaches applied to sample of Türkiye firms, reveal a modest link between carbon emissions and a firm's ability to access trade credit, differing from results of Ben-Nasr *et al.* (2025). This suggests that short-term lenders and firm executives may perceive higher carbon emissions as a risk, offering new insights for the literature.

Corporate cash managers can leverage these insights by implementing carbon reduction policies and strategic action strategic plans to strengthen trade credit relationship with suppliers. Policymakers may also use these findings to revise regulations and enhance environmental sustainability oversight for BIST-listed firms. Introducing tax incentives or subsidies for low-carbon firms could further encourage green management practices. By aligning financial policies with environmental goals, policymakers can foster corporate accountability, supporting both economic stability and global sustainability. These findings carry significant implications for corporate cash managers and policymakers, corroborating the observations of Ben-Nasr *et al.* (2025).

In summary, the study demonstrates that the annual carbon emission data of BIST-listed firms can be effectively modeled using both TOPSIS and traditional ARIMAX methods. This facilitates estimation of carbon emission impact on corporate cash holding, providing a foundation for policy adjustments aligned with objectives such as Paris Agreement, consistent with Yamaçlı and Tunçsiper (2024).

Overall, this study demonstrates that for BIST-listed firms, during crisis periods such as the 2008 global financial crisis, cash managers play a significant role in mitigating the negative impact of carbon emissions on firm financial decisions and corporate cash holdings through working capital management policies. Furthermore, green management practices, particularly during financial crises, can increase the use of renewable energy, improve cash asset levels for BIST-listed firms, reduce carbon emissions and contribute to the sustainable development of Turkish firms.

5.2 Theoretical implications

This study applied the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a MCDM approach, to analyze corporate cash holdings in BIST-listed firms. Cash

holding levels were prioritized annually based on their significance, highlighting the importance of implementing carbon emission reduction policies to mitigate the negative impacts of CO_2 emissions on firms' cash holdings. The study emphasizes identifying the primary drivers of cash holdings in BIST firms and prioritizing corrective actions to manage detrimental carbon emission.

The findings indicate that the combined use of TOPSIS and ARIMAX models allows for the identification and prioritization of key contributors to corporate cash holdings, enabling firms to implement targeted strategic measures. The TOPSIS result revealed that the effectiveness of cash holdings and carbon emission prioritization in the BIST firms is maximized for firm performance indicator such as ROA, ROE, EBITM, Tobin's *Q*, NCAFOTA, as well as cash holdings measures including CAFOR, CIE and CASH2, alongside working capital management ratios (NWC, LiqudR, CurrentR and CASHR). Conversely, variables such as CHL, CO2PC, CO2Intensity, ARTA, APTA and GWC were positive at minimal level.

These results suggest that corporate cash holdings in Türkiye were influenced by the 2008 financial crisis, implying that investors and shareholders focus more on agency costs, precautionary motive and transaction motive post-crisis period, consistent with Tran (2023). Consequently, the findings highlight that carbon emission level and environmental regulations should be managed to minimum corporate cash holdings, thereby encouraging investment in low carbon initiatives. Furthermore, the control variable LEVERAG exhibits a significantly negative influence on cash holdings in the long term. Collectively, these empirical insights provide guidance for management strategy and policy, particularly during the 2008 of financial crisis, to balance the interests of employers, shareholders and investors.

In sum, corporate cash holdings play a crucial role in firm performance, carbon emission and working capital management policies after the periods of 2008 global financial crisis in the Turkish firms based on improving renewable energy usage.

ARIMAX results demonstrate that CAFOR has a strong positive relationship with cash holdings and CO2PC, while CHL exhibits a moderate positive link. In contrast, NCAFOTA shows a strong negative association with CO2PC, supporting the notion that investors and shareholders emphasize the role of cash holdings for firms' survival under high external financial constraints, consistent with Tran (2023) and Sakariyahu *et al.* (2023). VARX modeling further indicates that cash holdings and CO2PC decreased pre-crisis and improved post-crisis, whereas CO2Intensity increased, consistent with Wang (2023).

Comparing the post-crisis period with the pre-crisis period, cash holdings are higher in the post-crisis period, indicating that firms operating in the BIST allocated more funds for speculative purposes to take advantage of unexpected investment opportunities, consistent with the results of Akgün (2021) and Opler *et al.* (1999). However, surprisingly, before the crisis, CAFOR exhibits a higher value compared to corporate cash holdings, firm performance and working capital management ratios.

Overall, this study prioritizes the cash reserve levels of BIST-listed firms annually according to their importance using MCDM approaches and reveals that prioritizing the implementation of environmental policies is necessary to mitigate the negative impact of CO_2 emissions on Türkiye firms' cash holdings. In this context, it has been observed that in Turkish firms, particularly in the periods after the 2008 global financial crisis, cash holdings have increased and more cash has been held for speculative purposes, with a focus on developing renewable energy use in terms of firm performance, carbon emissions and working capital management policies.

5.3 Limitations and further research

The use of data only from BIST-listed firms in Türkiye is a key limitation of this study. Prior research indicates that corporate cash management policies differ across sectors; while this study investigates carbon emission, corporate cash holdings and firm-level characteristics

during economic uncertainty, it does not account for sectoral differences. In this context, future research should further examine and compare sectoral differences, which could purpose to increase awareness of environmental sustainability among policymakers, stakeholders and other information users as well as to improve relationships with shareholders, by examining the carbon emissions, corporate cash holdings and firm-level characteristics of BIST-listed firms during Türkiye's 2008 financial crisis, considering sectoral differences. Additionally, the analysis is limited to BIST-listed firms during Türkiye's 2008 financial crisis and spans a relatively narrow ten-year period (2003–2012).

Corporate cash holdings remain critically important for firm performance and working capital management during crisis. Therefore, future research could need to focus on the relationship between carbon intensity, working capital management, firm value and firm profitability, considering sectoral differences among both listed and unlisted Turkish firms, and provide broader insights for policy and managerial decision-making.

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