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Received 7 March 2023
Revised 8 May 2023
30 November 2023
12 April 2024
Accepted 15 April 2024

The mediating effect of eco-innovation on low-carbon supply chain practices toward manufacturing firm performance in Malaysia

Atikah Shamsul Bahrin
Department of Postgraduate and Professional Studies, Universiti Teknologi MARA, Shah Alam, Malaysia, and
Ahmad Rais Mohamad Mokhtar, Ariff Azly Muhamed and Veera Pandiyan Kaliani Sundram
Faculty of Business and Management, Universiti Teknologi MARA, Shah Alam, Malaysia

Abstract

Purpose – This study aims to provide a novel approach to examining the connection between several aspects of low-carbon supply chain practices (LCSCPs), eco-innovation (EI) and the performance of manufacturing firms in Malaysia.

Design/methodology/approach – The current study employed a quantitative research strategy, utilizing survey data collected from a sample of 120 manufacturing firms located in Malaysia. The main aim of this study was to analyze the research framework and test the proposed hypotheses.

Findings – The results of the study indicate that EI has a mediating role in the link between LCSCP and manufacturing firm performance (MFP). EI serves as a mediating factor in the association between MFP and four components of LCSCPs, specifically low-carbon product design, low-carbon process improvement, low-carbon purchasing and low-carbon logistics.

Practical implications – The results of this study hold significant potential for supply chain professionals in their endeavors to decrease carbon emissions. Practitioners can help eliminate carbon footprints (CFs) by selecting the right LCSCP techniques that support EI and MFP. When creating low-carbon management methods in supply chain management (SCM), practitioners must take into account the potential mediating role of EI.

Originality/value – To date, this work is one of the first efforts to investigate the role of EI as a mediator between LCSCP and MFP. Moreover, this research adds to the existing knowledge and improves understanding of how low-carbon development is being implemented in Malaysia, with the ultimate objective of achieving carbon neutrality by 2050.

Keywords Low-carbon supply chain practices, Eco-innovation, Manufacturing firm performance, Supply chain management

Paper type Research paper

This study was funded by the Ministry of Higher Education, Malaysia under the Fundamental Research Grant Scheme with the project titled “Modelling Integrated Closed-loop Supply Chain towards a Circular Economy: An Isomorphism’s Perspective” (No: FRGS/1/2021/SS01/UITM/02/15).

Journal of International Logistics and Trade
Vol. 22 No. 3, 2024
pp. 110-133
Emerald Publishing Limited
e-ISSN: 2508-7592
p-ISSN: 1738-2122
DOI 10.1108/JILT-03-2023-0013

1. Introduction

The manufacturing industry plays a pivotal role in global economic development, yet its operations often come at a significant environmental cost, primarily due to carbon emissions. With increasing awareness of climate change and its detrimental effects, there's a growing urgency for industries to adopt sustainable practices, particularly in their supply chains. The concept of low-carbon in supply chain management (SCM) is gaining acknowledgment from both academia and industry. Both academia and the corporate sector are increasingly interested in using low-carbon practices (LCPs) in SCM. For example, studies by Yang *et al.* (2022), Bonsu (2020) and Cooke (2020) emphasize that Tesla's Gigafactories, powered by renewable energy, produce electric vehicles with significantly lower carbon emissions compared to traditional automotive manufacturing plants. Moreover, the adoption of LCPs throughout the supply chain is commonly referred to as low-carbon supply chain practices (LCSCP). The issue of global warming has escalated in the past decade, with carbon emissions being the main underlying factor that needs to be tackled. Moreover, manufacturers are the main contributors to carbon emissions, so many countries have begun to implement ways to reduce carbon emissions (Tang *et al.*, 2022). Although there has been an effort from industrial organizations to adopt price reduction, carbon reduction and greenhouse gas (GHG) emission reduction initiatives (Saxena *et al.*, 2018; Jensen, 2012), there is still a significant number of organizations that have not completely grasped the strategies required to successfully embrace LCPs into their SCM. Under some conditions, enterprises are obliged to give priority to the surveillance of carbon data, especially when it is conducted by public sector organizations. The implementation of selection criteria in materials for product design, along with enhanced efforts in operational and production processes, procurement solutions and structure and reverse logistics strategies, may lead to rapid changes that surpass the capabilities of most manufacturing firms over a span of several years (Thornley-Walker, 2010; Bakar *et al.*, 2016).

However, the current prevailing scenario suggests that cheaper alternatives are more likely to be selected than low-carbon alternatives, failing to achieve low-carbon objectives in the supply chain (Ibbotson and Farrell, 2019). The observed phenomena is likely due to the specialists in the sector having little understanding and the supplier chain prioritizing tangible cost savings over intangible low-carbon solutions. To tackle these difficulties, organizations need to develop and implement innovative solutions that enable the reduction of negative environmental impacts resulting from carbon emissions in the supply chain. In contemporary times characterized by technical advancements, a much more sustainable solution primarily arises from the implementation of eco-innovative approaches (Azevedo *et al.*, 2012). The observed phenomena can be linked to the experts' insufficient expertise in the sector and the supply chain's focus on quantifiable cost savings rather than intangible low-carbon solutions. To tackle these difficulties, organizations need to develop and implement innovative solutions that enable the reduction of negative environmental impacts resulting from carbon emissions in the supply chain. The objective of this initiative is to support the growth of domestic manufacturing sectors by implementing environmentally conscious practices, as highlighted in the studies conducted by Lee *et al.* (2022), Mustaffa *et al.* (2022) and Jaafar *et al.* (2014).

Although there are only a few contemporary literary works that provide a full understanding of the relationship between LCSCP and company performance, there is a significant lack of available knowledge about the mediating role of eco-innovation (EI) in influencing LCPs and firm performance.

Previous research has primarily focused on investigating the relationship between LCPs and firm performance (Das and Jharkharia, 2019; Lee and Ahn, 2019; Jabbour and de Sousa Jabbour, 2014), EI and firm performance (Das, 2021; Bossle *et al.*, 2016) and LCPs and EI (Xin *et al.*, 2019; Neto *et al.*, 2014; Azevedo *et al.*, 2012), respectively. This study aims to fill the research vacuum by examining the interrelationships between the LCSCP, EI and MFP in Malaysia. Research is scarce on LCSCP in the specific context of its application in underdeveloped countries, particularly Malaysia. Furthermore, there is a lack of academic research and analysis undertaken to provide a theoretical framework, backed by empirical evidence (Yang *et al.*, 2021), on the influence of LCSCP on company performance, specifically within the industrial sectors.

2. Literature review

The study's conceptual framework proposes that the implementation of LCSCP by the manufacturing sector will directly and indirectly impact firm performance, with the involvement of EI acting as a mediating factor. Upon completing a thorough investigation of multiple literary works on theoretical views, it becomes clear that most of them utilize the essential framework of the resource-based view (RBV) theory as their main theoretical basis. The current study additionally employed additional theoretical foundations to develop the proposed framework (see Figure 1), which incorporates the institutional theory.

The institutional theory examines the impact of external social, technological and political variables on organizational behavior, specifically about the adoption of low-carbon emissions practices (Dubey *et al.*, 2015; Zhu *et al.*, 2007; Zhu and Sarkis, 2007). Furthermore, according to Liu *et al.* (2022), the institutional theory, it is said that the primary driver for changes in an organization's structure and conduct is the need for legitimacy, rather than efficiency or competition. Furthermore, in light of the presence of diversity, this study posits that top management plays a pivotal role as the primary human agent in translating external pressures into suitable managerial responses (Luo *et al.*, 2017). These answers involve

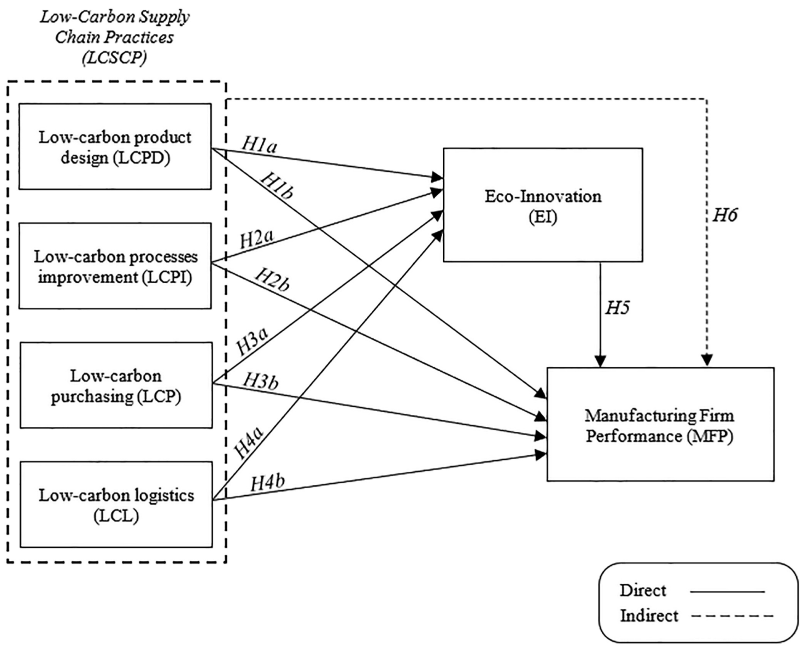

Figure 1.
Research model

Source(s): Authors' work

modifying organizational structures and creating policies that are in line with institutional attitudes. In the next section, a more detailed explanation is given on the connections between specific LCSCPs, EI and manufacturing firm performance (MFP) as proposed in the previous hypothesis.

2.1 An overview of low-carbon supply chain practices (LCSCPs)

LCPs are referred to as the tools and techniques used by organizations to reduce CFs, just not only at their firm level but also across their value chains (Isaksson *et al.*, 2010; Morali and Searcy, 2013). Uses of LCPs transit the traditional supply chain into a low-carbon supply chain (LCSC) which attempts to reduce total CFs across the supply chain including manufacturing, transportation, storage, consumption and recycling through direct or indirect activities (Ambekar *et al.*, 2019). Thus, considering the existence of LCSCP in the literature can help in the development and improvement of manufacturing industries. Hence, LCSCP are regarded as a perfect recipe for the success of several firms from various manufacturing industries (Bai *et al.*, 2017). For example, Böttcher and Muller (2015) defined low-carbon operations; Nishitani *et al.* (2016) investigated the role of the environmental management system (EMS) on a firm's willingness to adopt low-carbon supply chain; and Khan and Qianly (2017) analyzed the impact of environmental factors, such as GHGs, fossils fuels and renewable energy on green logistics. Also, Jabbour and de Sousa Jabbour (2014) developed three dimensions of low-carbon operation and management practices, namely, low-carbon products, low-carbon production and low-carbon logistics. Whereas, Lee and Ahn (2019) employed five dimensions such as low-carbon product development, low-carbon process improvement, employee engagement, initiative participation and supply chain cooperation to measure LCSCPs. Furthermore, Das and Jharkharia (2019) included several other important variables to conceptualize LCSCPs, namely, low-carbon purchasing, low-carbon product and design and low-carbon manufacturing and logistics on firm performance. As a result after a thorough evaluation of various LCPs in SCM-related literature, a set of LCSCP dimensions is recorded for this study in Table 1.

Firstly, Low-carbon Product Design (LCPD), is related to product and process stewardship such as less environmental impact through the designing of products, less usage of hazardous substances and usage of more reusable and recyclable materials (Böttcher and Müller, 2015; Klassen and Whybark, 1999; Snir, 2001). Also, Song and Lee defined LCPD as the capability of replacing components that produce fewer GHG emissions. The reduction of The reduction of emissions in the production process requires end-of-pipe control technology and energy-efficient equipment (Shaharudin *et al.*, 2019; Klassen and Whybark, 1999; Das and Jharkharia, 2019). Secondly, according to Böttcher and Muller (2015), "low-carbon" application should also extend to the production and manufacturing process, known as the Low-carbon Processes Improvement (LCPI), which is crucial for obtaining the finished goods.

Many LCPs can support the search for an LCPI; for example, the adoption of information systems with data on carbon dioxide (CO^2) emissions during the production process, energy management systems and energy efficiency, renewable and non-fossil fuel energy and consumption, substitution of carbon-intensive raw materials, search for more eco-efficient equipment and adoption of recycling and remanufacturing approaches in the production process (Jabbour and de Sousa Jabbour, 2014). Thirdly, LCP can be classified as an environmentally focused purchasing which includes evaluation and development of suppliers, substitution of material through environmentally friendly sourcing and reuse and recycling of materials (Rao and Holt, 2005; Selvaraju *et al.*, 2017). LCP includes the selection of suppliers based on their carbon performances such as carbon reduction goals and strategies, top management support, CF measurement and risk assessment, training

Year	Author(s)	LCSCP LCPD	LCPI	LCP	LCL	EI	MFP
2022	Ullah, Abbas, Tariq, Mahmood and Kaechele			✓		✓	
2022	Viale, Vacher and Bessouat			✓		✓	
2021	Das	✓				✓	✓
2021	Geng, Lai and Zhu					✓	✓
2021	Wanke, Jabbour, Antunes, . . . and Gonzalez	✓	✓		✓		
2020	Kowalska and Szyja			✓		✓	
2019	Ambekar, Prakash and Patyal	✓	✓	✓			
2019	Das and Jharkharia	✓		✓	✓		✓
2019	Lee and Ahn	✓	✓				✓
2017	Bai, Sarkis and Dou		✓				✓
2017	Costantini, Crespi, Marin and Paglialunga					✓	✓
2017	Das and Jharkharia	✓				✓	
2017	Stawiarska				✓	✓	
2016	Bossle, de Barcellos, Vieira and Sauvée					✓	✓
2016	Nishitani, Kokubu and Kajiwara			✓			✓
2015	Böttcher and Müller	✓	✓		✓		
2015	Choudhary, Sarkar, Settur and Tiwari				✓		✓
2015	Mele and Russo-Spena		✓			✓	
2014	Cheng, Yang and Sheu					✓	✓
2014	Doran and Ryan					✓	✓
2014	Jabbour and de Sousa Jabbour	✓	✓		✓		
2014	Mitra and Datta			✓			✓
2014	Neto, Jabbour and de Sousa Jabbour	✓				✓	

Source(s): Authors' compilation

Table 1.
Evaluation of dimension from past literature

and development of suppliers for emissions reduction and technology transfer for emissions reduction (Hsu *et al.*, 2014; Kuo *et al.*, 2015; Long and Young, 2016; Nishitani *et al.*, 2016). A firm can also put pressure on its suppliers to implement an environmental certification program such as International Organization for Standardization (ISO) 14001 (Jiang and Bansal, 2003; Mitra and Datta, 2014; Zulfakar *et al.*, 2019). Last but not least, logistics and SCM activities in manufacturing contribute significantly to climate change and are accountable for a significant amount of carbon dioxide emissions. For example, CO^2 from transportation can be emitted during the acquisition of raw materials and the distribution of the final products (Rasi *et al.*, 2021; Sundram *et al.*, 2011). Thus, organizations have to make an effort to reduce the emissions from transportation and manufacturing-related activities (Das and Jharkharia, 2019). A study done by Hoen *et al.* (2014) found a significant reduction in total transportation emissions by switching transportation modes. Similarly, the study by Liljestrand *et al.* (2015) states that transport emissions can also be reduced through investment in infrastructure, new vehicle technologies and alternative fuels.

2.2 The general idea of eco-innovation (EI)

EI is defined as developing a product in a way that reduces environmental externalities, such as solid waste, pollution, water consumption and environmental risk (Pujari, 2006; Das and Jharkharia, 2017). In the literature, EIs are classified as product and process and radical and incremental EI (Pujari, 2006). Product and process EI means the capability of improving a product and process by adopting eco-design technology, eco-efficient equipment, lifecycle assessment, cleaner technology and end-of-pipe control (Rennings, 2000). On the other hand, radical and incremental EI means a remarkable change in product and process and continuous or gradual change in product and process, respectively (Hellström, 2007). The goal of EI is to reduce environmental externalities and improve products for less environmental impact (Cheng *et al.*, 2014). Some literature suggests EI is used as a liable factor for improving a firm's environmental and economic performance (Neto *et al.*, 2014; Bossle *et al.*, 2016; Das, 2021).

2.3 The concept of manufacturing firm performance (MFP) in Malaysia

Manufacturing firms are gradually realizing significant economic and environmental benefits from sustainable practices (EPA report, 2020). Furthermore, the manufacturing performance purpose is developed to meet the sustainable development goals (Bag *et al.*, 2020a, b) reviewed from literature and cluster of papers that study green supply chain, low-carbon economy, environmental management and performance, innovation and social concern (Atasu *et al.*, 2020; Bag and Pretorius, 2020). In the last decade, the green initiative has taken a turn to be an important cause in creating an innovative cause for the manufacturing sector (Sundram *et al.*, 2018a). Hence, the Malaysian manufacturing sector has remained an important contributor to the Malaysian economy (Rusli *et al.*, 2012; Bahrin and Sundram, 2014). Moreover, in the context of national green policies, manufacturing companies must deal with the challenges in the market and opportunities of SCM through the adoption of LCPs that will help enhance performance (Vatumalae *et al.*, 2022; Mkumbo *et al.*, 2019). Manufacturing organizations may vary in their adoption of carbon management methods due to variances in how managers evaluate the outcomes of their actions in response to supply chain performance problems.

3. Theoretical framework and hypothesis developments

3.1 Relationships between LCPD, EI and MFP

In the context of product design, the term "LCPD" refers to the strategic incorporation of environmental ideas and considerations into the initial stages of the design process. The concept of the CF has been defined in studies by Wiedmann and Minx (2008) and Green *et al.* (2012) as "a quantification of the combined quantity of CO^2 emissions that are directly and indirectly generated by a particular activity or accumulated throughout the various stages of a product's life cycle". To enhance operational efficiency, manufacturing enterprises must enhance their attention towards the domain of product and package design within the supply chain by employing approaches related to environmental intelligence through EI (Zhu *et al.*, 2008; Mitra and Datta, 2014). Studies by Hart (1995), Kuo (2013) and Du *et al.* (2015), state that the process of improving manufacturing performance involves the development of a product with reduced environmental consequences, conducting a comprehensive evaluation of its lifetime and substituting materials with a lower environmental footprint (Sundram *et al.*, 2018a). Taking this into consideration, the hypotheses that have been presented are as follows:

H1a. The LCPD relates positively to EI.

H1b. The LCPD relates positively to MFP.

3.2 Relationships between LCPI, EI and MFP

Due to several factors, those responsible for making decisions at every stage of the supply chain are facing significant pressure to achieve reductions in carbon emissions. These include the volatile prices of energy and materials, heightened regulatory scrutiny and the expectations of stakeholders such as competitors and customers who prioritize environmentally sustainable practices and products (Choudhary *et al.*, 2015; Sarkis *et al.*, 2010; Seuring and Müller, 2008). Concerning this matter, the case of automotive suppliers in Böttcher and Müller (2015) considered LCPI as one of the strategies employed to mitigate GHG and carbon emissions throughout the production and manufacturing processes. According to Lee and Ahn (2019) and Bai *et al.* (2017), the implementation of low-carbon processes enables enterprises to use novel process technologies that effectively mitigate GHG emissions within the SCM framework. Moreover, Das and Jharkharia (2019) asserted that in LCSCs, implementing process optimization techniques allows organizations to optimize their energy resource utilization by shifting to cleaner and more environmentally friendly alternative replacements. Consequently, this greatly improves the general efficiency of the organization. Based on this information, the following hypotheses have been put forward:

H2a. The LCPI relates positively to EI.

H2b. The LCPI relates positively to MFP.

3.3 Relationships between LCP, EI and MFP

Mitra and Datta (2014) state that the LCP function is employed as an independent concept in the literature on green supply chain. The procurement process plays a crucial role in the sustainable SCM of the manufacturing industry, as it enables executive management to exert influence on performance outcomes (Mkumbo *et al.*, 2019; Sundram *et al.*, 2017; Krause *et al.*, 2009). Similarly, top management develops EI solutions and strategic structures by successfully building cooperation with suppliers and customers in creating emission reduction knowledge through the purchasing approach (Rajagopal *et al.*, 2016; Syakirah *et al.*, 2020). In the context of emission reduction by Plambeck (2012), LCP is effective in enhancing environmental supplier selection, creating low-carbon production capabilities and reducing GHG emissions in manufacturing performance. Moreover, based on Tseng *et al.* (2021) and Brogi and Menichini (2019), LCP can include ISO 14000 and the EMS through a proficient and streamlined implementation inside the EI strategy of the supply chain. Similarly, the LCP exerted influence on the organization to adopt an environmentally friendly approach through the implementation of ISO 14000, as stated by Das and Jharkharia (2019). This could be seen as a promising asset for improving manufacturing efficiency. Based on this information, the following hypotheses have been suggested:

H3a. The LCP relates positively to EI.

H3b. The LCP relates positively to MFP.

3.4 Relationships between LCL, EI and MFP

Low-carbon Logistics (LCL) refers to the systematic effort to reduce GHG emissions generated by manufacturing logistical activities such as transportation, warehousing and distribution (Das and Jharkharia, 2019; Alkhayyal and Gupta, 2018). There are studies by Qian *et al.* (2019) and Wang *et al.* (2019), that show evidence that a proper EI along the transportation and production activity within and across the manufacturing company could be a source for LCL mode. Furthermore, it is proven by Tian *et al.* (2023), Moshood *et al.* (2021) and Das and Jharkharia (2018), that the development of LCL can effectively reduce energy consumption and prevent global issues that are majorly contributed by manufacturing vehicles. Additionally, LCL's innovative exchange system among shipping partners in the supply chain enables them to reduce logistics costs and control the release of CO^2 emissions to the environment (Fransoo and Mora-Quiñones, 2021; Alves *et al.*, 2017). Organizations must consider LCL as a factor that might impact their strategic approach to environmental sustainability, particularly in ensuring a carbon-efficient transportation plan (He *et al.*, 2017). Additionally, the concept of LCL plays a crucial role in identifying the most efficient manufacturing performance solution and enhancing the decision-making process about environmental innovation (Tian *et al.*, 2023; Das and Jharkharia, 2018). Based on this information, the following hypotheses have been suggested:

H4a. The LCL relates positively to EI.

H4b. The LCL relates positively to MFP.

3.5 Relationships between EI and MFP

The major purpose of this research project is to investigate whether or not there is a link between EI and the efficiency with which manufacturing organizations carry out their daily responsibilities (Nishitani *et al.*, 2016). This objective will be achieved by examining the correlation between EI and the performance of manufacturing companies.

A firm performance can be based on the triple bottom line of environmental, economic and social performance (Bossle *et al.*, 2016; Sundram *et al.*, 2018b). EI may be described as a subtle or significant alteration of a product's or a procedure's design to enhance a firm's environmental performance (Das and Jharkharia, 2017). To enhance efficiency, manufacturing businesses must enhance their emphasis on EI. There is a limited number of studies proposing that EI in the green technology implementation to the production process can improve the efficiency and capability of firm performance (Neto *et al.*, 2014; Bossle *et al.*, 2016; Das, 2021). This can be characterized by implementing EI in the supply chain of a manufacturing company to manage wastewater treatment, mitigate the risk of pollution release and minimize the presence of dangerous compounds in the environment. This implies that EI can increase firm performance in the manufacturing industry. In light of this, the following hypothesis has been proposed:

H5. The EI relates positively to MFP.

3.6 Mediating effect of EI on LCSCP and MFP

The significant expansion in the manufacturing sector in developing nations not only boosts overall economic activity but also contributes more to global carbon emissions (Rusli *et al.*, 2012; Bahrin and Sundram, 2014). In addition, decision-makers and officials worldwide are increasingly focusing on reducing global warming. Manufacturing organizations are now being compelled to recognize the significance of incorporating low-carbon purchasing into their SCM to the growing environmental concerns. The LCSCP concept emerged from the integration of LCPs within the SCM framework. This approach has been adopted by several organizations as a means to mitigate carbon emissions both within their operations and throughout their entire SCM (Isaksson *et al.*, 2010; Morali and Searcy, 2013). Firstly, to effectively execute LCSCP strategies, organizations must possess LCPD capabilities to identify suitable sources for the development of new environmentally friendly goods and packaging designs (Das and Jharkharia, 2019; Böttcher and Müller, 2015). Secondly, it is required to include the concept of LCPI in conjunction with robust green knowledge-based systems and technology to research process improvement (Lee and Ahn, 2019; Sundram *et al.*, 2016a). Thirdly, it is important to incorporate the concept of LCP in the decision-making process, which is derived from the collection of input from both suppliers and consumers (Kuo *et al.*, 2015; Long and Young, 2016). Finally, it is central to incorporate the concept of LCL to actively mitigate carbon emissions in high-performance logistics operations (Sundram *et al.*, 2020; Ali *et al.*, 2020).

Recently, EI has been given more importance in determining the low-carbon impact on the SCM (Neto *et al.*, 2014; Bossle *et al.*, 2016; Das, 2021). On another note, Lin *et al.* (2013) find that boosting a firm's competitiveness and the economic performance of its goods are essential prerequisites for EI. In addition to this, EI also contributes to the success of a company's production performance (Przychodzen and Przychodzen, 2015). With the appropriate understanding of EI, companies may enhance their performance in the supply chain by increasing their productivity, reducing the amount of waste they produce and mitigating the environmental harm that their operations cause (Sundram *et al.*, 2016b; Azevedo *et al.*, 2012). For example, Chen (2014) analyzed EI as a mediator between green operations and environmental performance; Costantini *et al.* (2017) investigated the direct and indirect effects of EI for reducing the environmental impact of different sectors; Geng *et al.* (2021) analyzed the effect of EI on firm's environmental and economic outcome, as also the moderating impact of the environmental system between them. This study examines the impact of EI on the adoption of LCPs throughout the supply chain and the resulting improvements in a firm's economic, operational and environmental performance. Given this context, the following hypotheses have been proposed for careful examination:

H6a. The EI mediates the relationship between LCPD and MFP.

H6b. The EI mediates the relationship between LCPI and MFP.

H6c. The EI mediates the relationship between LCP and MFP.

H6d. The EI mediates the relationship between LCL and MFP.

4. Methodology

The study employed a structured quantitative research strategy to investigate the interplay among LCSCPs, EI and MFP in Malaysia. Rooted in a deductive approach and underpinned by positivist epistemology, the research formulated hypotheses derived from existing theories to be empirically tested (Bryman and Bell, 2015; Saunders *et al.*, 2019). Utilizing quantitative methods, numerical data about LCSCP, EI and MFP were systematically measured and analyzed. Adopting a cross-sectional design, data were collected from manufacturing firms in Malaysia at a single point in time, offering insights into the prevailing relationships among LCSCP, EI and MFP within the Malaysian manufacturing landscape.

4.1 Sampling design and data collection

The study focused on individual manufacturing enterprises as the unit of investigation. This is because manufacturing enterprises are more susceptible to generating carbon emissions and are also expected to proactively address this issue. The data on LCPs is gathered by measuring four dimensions: LCPD, LCPI, LCP and LCL. The data is gathered by online distribution using e-mail questionnaires that were modified from several prior research projects that focused on LCPs, EI and company performance. The online questionnaires were conducted in two iterations over a duration of four weeks. The circulation is given to 250 manufacturing firms that were randomly selected using email addresses obtained from the Federation of Malaysian Manufacturers (FMM) Directory of Malaysian Industries. Hence, the cumulative distribution would consist of a total of 500 emails dispatched over a span of 4 weeks. The online questionnaire submission yielded a final count of 122, resulting in a final response rate of 24.4%. After eliminating the incomplete survey, 120 questionnaires were kept with a 24% valid return rate as suggested by Sundram *et al.* (2016a, b). The selected 500 potential respondents were by their job function (equivalent to a senior manager or above) from several main manufacturing sectors as per in Table 5.

To assess the presence of non-response bias, the study followed Armstrong and Overton's (1977) recommendation by comparing the responses from early and late waves of returned surveys. Student's *t*-tests were conducted, revealing no statistically significant differences ($p = 0.39$) between the early-waves group ($n = 84$) and the late-waves group ($n = 36$), indicating that non-response bias was not evident.

4.2 Measurements

Based on the available literature, measurement items for all variables (LCSCP, EI, MFP) are created as per in Table 2–4.

5. Data analysis and result

In this study, hierarchical regression analysis is utilized, enabling the examination of multiple predictors, including LCSCPs and EI and their respective impacts on the outcome variable, MFP. By entering predictors in a hierarchical order, the analysis facilitates the assessment of each predictor's unique contribution to the variance in the outcome variable. Understanding the mediating role of EI in the relationship between LCSCPs and manufacturing firm's performance is crucial.

5.1 Respondents profile

According to the data presented in Table 5, most of the survey participants are male, with 93 respondents accounting for 77.5%. The remaining 27 respondents, or 22.5%, are female. The majority of responders fall between the age range of 40–49 years old, comprising 70% of the total. A significant proportion of them possess a master's degree (35.8%) and a substantial number of them are employed in the cement, iron and steel sectors (26.7%). Primarily, 81.7% of the participants occupy the role of senior management, while 32.5% are employed by enterprises that have been in operation for a period of five to 10 years. Additionally, out of the organizations participating, 39 enterprises, accounting for 32.5%, had an annual sales figure exceeding RM200,000 but falling short of RM500,000. This could also be attributed to the fact that 32.5% of the enterprises have a substantial workforce, with more than 200 but less than 500 employees.

5.2 Reliability and validity

Factor analysis was used to evaluate the presence of several dimensions in the LCSCP. The research findings revealed that the primary element of LCSCP is a multifaceted variable

Dimension	Measurement item	Source
Manufacturing firm performance	MFP1: "Reduction in energy consumption" MFP2: "Reduction in natural resource consumption" MFP3: "Reduction in greenhouse gas emissions" MFP4: "Reduction of solid waste" MFP5: "Decrease of cost for reducing energy consumption" MFP6: "Increase in market share" MFP7: "Penetration of new market" MFP8: "Acquisition of new customers" MFP9: "Increase in organizational growth"	Das (2021) Lee and Choi (2021) Lee and Klassen (2016)

Source(s): Authors' compilation

Table 2. Measurement items for MFP

Dimension	Measurement item	Source
Low-carbon product design	LCPD1: "Designing of products for less environmental impact" LCPD2: "Conduct a Life Cycle Analysis (LCA) of carbon emission during product design" LCPD3: "Use of cleaner technology such as energy-efficient equipment" LCPD4: "Use of alternative low-carbon propensity materials" LCPD5: "Collaboration with customers and suppliers for low-carbon product design"	Das (2021) Das and Jharkharia (2019) Lee and Ahn (2019) Bai *et al.* (2017) Böttcher and Müller (2015)
Low-carbon processes improvement	LCPI1: "The company conducts projects to reduce greenhouse gas (GHG) emissions in its production processes" LCPI2: "The company introduced innovative process technologies to dramatically reduce GHG emissions in your production" LCPI3: "The company substituted existing energy sources with cleaner fuels"	Lee and Ahn (2019) Alves *et al.* (2017) Bai *et al.* (2017) Jabbour and de Sousa Jabbour (2014)
Low-carbon purchasing	LCP1: "Technology transfer for emission reduction" LCP2: "Supplier training for emission reduction" LCP3: "Assessment of suppliers based on their emission reduction goals, strategy and responsible department" LCP4: "Put pressure to implement ISO 14000 and environmental management system (EMS)" LCP5: "A supplier risk assessment for failure to achieve targeted emission level"	Das and Jharkharia (2019) Jabbour and de Sousa Jabbour (2014) Mitra and Datta (2014)
Low-carbon logistics	LCL1: "Consolidation of demand for emission reduction" LCL2: "Use of low carbon transport mode for transportation" LCL3: "Use of carbon-efficient technologies for transportation" LCL4: "Use of non-conventional energy sources for some activities" LCL5: "Reduction of material consumption during production"	Das and Jharkharia (2019) Hoen *et al.* (2014) Jabbour and deSousa Jabour (2014)

Source(s): Authors' compilation

Table 3. Measurement items for LCSCP

Dimension	Measurement item	Source
Eco-innovation	EI1: "Pollution control technologies including wastewater treatment" EI2: "Cleaning technologies that treat pollution released into the environment" EI3: "Cleaner process technologies: new manufacturing processes that are less polluting and/or more resource-efficient than relevant alternatives" EI4: "Product design capability that reduces the impact of hazardous substances, wastes and pollution throughout its lifecycle" EI5: "Environmental research and development capability to curb the environmental impact"	Das (2021) Bossle *et al.* (2016) Neto *et al.* (2014)

Source(s): Authors' compilation

Table 4. Measurement items for EI

Categories	Items	Frequency	Percentage (%)
Gender	Male	93	77.5
	Female	27	22.5
Age	18–29 years old	4	3.3
	30–39 years old	22	18.3
	40–49 years old	84	70.0
	More than 50 years old	10	8.4
Level of education	PhD	22	18.3
	Master's Degree	43	35.9
	Bachelor Degree	31	25.8
	Diploma	17	14.2
	Other Professional Certificate	7	5.8
Industry sector	Automobile	6	5.0
	Electronics	16	13.3
	Engineering	8	6.7
	Consumer goods	28	23.3
	Food and beverages	6	5.0
	Textiles	11	9.2
	Pharmaceuticals	9	7.5
	Cement/iron and steel	33	26.7
	Other	4	3.3
Designation	General Manager (GM)	0	0
	Deputy GM	22	18.3
	Senior Manager	98	81.7
Year in Operation	Less than five years	23	19.2
	5–10 years	39	32.5
	11–20 years	33	27.5
	More than 20 years	25	20.8
Annual sales (thousand RM)	≤50	22	18.3
	>50; ≤200	37	30.8
	>200; ≤500	39	32.5
	>500; ≤1,000	14	11.7
	>1,000	8	6.7
Number of employees	≤200	20	16.7
	>200; ≤500	39	32.5
	>500; ≤1,000	32	26.7
	>1,000; ≤2,000	18	15.0
	>2,000; ≤3,000	7	5.8
	>3,000	4	3.3

Source(s): Authors' work

Table 5. Respondent profile (n = 120)

consisting of four dimensions, encompassing a total of 18 elements. After examining the multicollinearity among the generated components, a measure of sampling adequacy known as the Kaiser–Meyer–Olkin (KMO) value of 0.754 was found. Mitra and Datta (2014) state that a score above 0.5 signifies successful implementation of the factor analysis test and appropriate sample exploitation. Based on the previously described facts, it may be concluded that the matrix did not show any indications of multicollinearity. In addition, the Bartlett test of Sphericity yielded a very significant result [sig = 0.000]. This citation suggests that the factor analysis methodologies used were precise and suitable for evaluating the existence of several dimensions (Hair, 2010). Table 6 presents the results of the factor analysis. Upon thorough examination, this study eliminated items that had scores lower than 0.7.

Table 6.
Factor analysis of LCSCP constructs

Construct and items	Factor loading
Low-carbon supply chain practices	
Low-carbon product design	
LCPD1	0.818
LCPD2	0.804
LCPD3	0.860
LCPD4	0.730
LCPD5	0.851
Low-carbon processes improvement	
LCPI1	0.748
LCPI2	0.813
LCPI3	0.784
Low-carbon purchasing	
LCP2	0.742
LCP3	0.705
LCP4	0.920
LCP5	0.810
Low-carbon logistics	
LCL2	0.855
LCL3	0.796
LCL4	0.877
LCL5	0.840
Eco-innovation	
EI1	0.762
EI2	0.862
EI3	0.844
EI4	0.755
EI5	0.739
Manufacturing firm performance	
MFP1	0.882
MFP2	0.927
MFP3	0.926
MFP4	0.859
MFP5	0.957
MFP6	0.869
MFP7	0.880
MFP8	0.762
MFP9	0.772

Source(s): Authors' work

The measurement reliability was evaluated by utilizing Cronbach's alpha, a commonly used metric for assessing the consistency of measurements. Reliability is evidenced by a significant correlation and a high alpha level among items that test a single concept. Based on the data provided in Table 7, all of the alpha values surpass the criterion of 0.7, which is deemed suitable for conducting research in the social science field (Nunnally, 1978).

5.3 Correlation analysis

The correlation analysis presented in Table 8 demonstrates the association between the variables and also indicates the magnitude of the relationship between the four dimensions of

LCSCP on EI and MFP. In addition, Table 8 demonstrates a substantial positive relationship between all four dimensions of LCSCP and EI as the mediating variable, as well as MFP as the dependent variable.

5.4 Result of multiple and hierarchical regression analysis

According to the criteria established by Baron and Kenny (1986), one may evaluate the mediating effect of the individual dimensions of the LCSCP to examine whether LCPD, LCPI, LCP and LCL are completely mediated by EI in exerting its impact on MFP. When the EI is controlled, the coefficients of LCPD (0.1251, $p = 0.0773$), LCPI (0.1856, $p = 0.0878$) and LCP (0.1345, $p = 0.0798$) exhibit a substantial decrease in magnitude and are shown to be statistically insignificant. Existing empirical evidence indicates that there is a partial mediation of the connection between LCL, with a coefficient of 0.0772 and a p-value of 0.0094, by EI. Even though the inclusion of EI as a mediating variable decreases the size of the coefficient values, they remain statistically significant at the 5% level. In summary, three of the LCSCP were determined to be entirely influenced by EI, whilst just one was found to be moderately influenced by EI. The results of the direct and overall impact of the LCSCP, as depicted in Figure 2, are documented in Table 9, while the outcomes of the hypotheses are reported in Table 10.

6. Discussion, conclusion and implication of study

The objective of this study is to investigate the problem of carbon emissions produced by industrial firms in Malaysia. Incorporating LCPs across the SCM of manufacturing organizations is essential for resolving this problem. Nevertheless, LCPs in isolation cannot comprehensively comprehend this issue. Therefore, EI was employed as the intermediate variable to establish the link between the LCSCP and MFP. Hence, the findings offer valuable perspectives and validate the paradigm employed in this study. The findings of this study

Variables	Dimensions	Number of items	Cronbach's alpha [α]
LCSCP	LCPD	5	0.819
	LCPI	3	0.891
	LCP	5	0.788
	LCL	5	0.712
EI		5	0.862
MFP		9	0.927

Source(s): Authors' work

Table 7. Reliability analysis

	LCPD	LCPI	LCP	LCL	EI	MFP
LCPD	0.310**					
LCPI	0.402**	0.472**				
LCP	0.473**	0.418**	0.505**			
LCL	0.585**	0.356**	0.338**	0.325**		
EI	0.694**	0.636**	0.701**	0.296**	0.613**	
MFP	0.722**	0.457**	0.661**	0.384**	0.599**	0.834**

Note(s): ** Correlation is significant at the 0.01 levels, respectively (2-tailed)
Source(s): Authors' work

Table 8. Correlation analysis

validate prior research that suggests enterprises that effectively adopt LCSCPs are more inclined to exhibit elevated levels of EI (Das, 2021; Wang *et al.*, 2020) and improved manufacturing firm's performance (Liu *et al.*, 2020; Das and Jharkharia, 2019). Das (2021) conducted a study on Indian manufacturing enterprises and gathered data that offered insights into the correlations among LCPs, EI, competitiveness and economic performance. The findings suggest that there are both direct and indirect correlations between LCSCP and EI, which positively impact the competitiveness and economic performance of MFP. The case study conducted by Wang *et al.* (2019) illustrates the many forms of relationships between supply chain partners, particularly with the delegation of carbon reduction initiatives. This

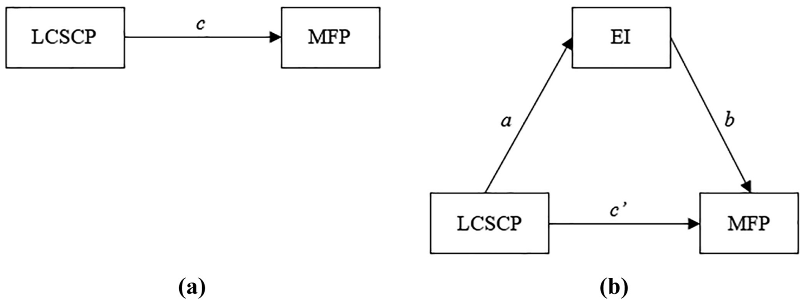

Figure 2. The total and indirect effects of LCSCP and MFP

Note(s): (a) Panel A: direct effects of LCSCP on MFP; (b) Panel B: indirect effects of LCSCP on MFP through EI
Source(s): Adapted from Sundram *et al.* (2016b)

Table 9. Direct and total effect

	Path	Coefficient	*t*-value	*p*-value
Low-carbon product design				
LCPD → MFP	*c*	0.7134	10.450	0.0000
LCPD → EI	*a*	0.4112	11.130	0.0000
EI → MFP	*b*	0.9008	15.018	0.0000
LCPD → MFP. EI	*c'*	0.1251	1.5511	0.0773
Low-carbon process improvement				
LCPI → MFP	*c*	0.6775	6.5999	0.0000
LCPI → EI	*a*	0.5478	5.4121	0.0000
EI → MFP	*b*	0.8776	19.583	0.0000
LCPI → MFP. EI	*c'*	0.1856	1.4445	0.0878
Low-carbon purchasing				
LCP → MFP	*c*	0.7453	8.6627	0.0000
LCP → EI	*a*	0.6564	8.6813	0.0000
EI → MFP	*b*	0.9276	17.058	0.0000
LCP → MFP. EI	*c'*	0.1345	1.9742	0.0798
Low-carbon logistics				
LCL → MFP	*c*	0.4012	9.6446	0.0000
LCL → EI	*a*	0.3471	8.6855	0.0000
EI → MFP	*b*	0.8717	18.476	0.0000
LCL → MFP. EI	*c'*	0.0772	3.0687	0.0094

Source(s): Authors' work

Hypotheses	Relationship	Result
H1a	LCPD → EI	Supported
H1b	LCPD → MFP	Supported
H2a	LCPI → EI	Supported
H2b	LCPI → MFP	Supported
H3a	LCP → EI	Supported
H3b	LCP → MFP	Supported
H4a	LCL → EI	Supported
H4b	LCL → MFP	Supported
H5	EI → MFP	Supported
H6a	LCPD → EI → MFP	Supported (Full mediation)
H6b	LCPI → EI → MFP	Supported (Full mediation)
H6c	LCP → EI → MFP	Supported (Full mediation)
H6d	LCL → EI → MFP	Supported (Partial mediation)

Source(s): Authors' work

Table 10. Hypotheses results

study emphasizes the significant impact that these relationships have on the supply chain, the efficiency of reducing carbon emissions and the overall sustainability of operational performance. Moreover, companies that give high importance to implementing LCPs as a component of the Malaysia Initiative for Green Economy can establish strong links across the supply chain in the manufacturing industry, thereby improving environmental, economic and operational results.

Theoretical implications derived from this study are multifaceted. Firstly, by pinpointing specific components of LCSCP – including LCPD, LCPI, LCP and LCL – and demonstrating how EI serves as a mediator, our analysis enriches existing theories. This granular examination contributes to a more nuanced theoretical framework, revealing how different aspects of LCSCP interact with EI to influence MFP. Secondly, our study makes a noteworthy contribution by revealing the mediation role of EI in each dimension of LCSCP, whether fully or partially, in shaping MFP. By establishing EI as a pivotal mediator in the intricate relationship between LCSCP and MFP, our research offers a novel theoretical perspective. This insight advances our understanding of the nuanced mechanisms through which LCSCP practices affect MFP, emphasizing the indispensable role of EI in this dynamic. Furthermore, the discovery of partial mediation between LCL and MFP presents a significant advancement in sustainable SCM. This finding challenges traditional linear mediation approaches, indicating that while EI plays a crucial role in enhancing MFP through LCL practice, there are other unexplored factors at play. Future research should delve into these factors to develop more comprehensive theoretical frameworks, enhancing our understanding of the relationship between LCL and MFP. Furthermore, in the context of Malaysia's aggressive efforts to promote sustainable development and green initiatives, adopting EI is not only essential for the long-term sustainability of the manufacturing sector, but also for accomplishing wider economic, environmental and social goals. Multinational Corporations (MNCs) and Small and Medium-sized Enterprises (SMEs) that prioritize EI have the potential to achieve greater competitiveness, cost efficiency, market entry opportunities and an improved reputation. This positions them for long-term growth and success in a quickly changing global environment.

The managerial implications drawn from this study offer actionable guidance for supply chain practitioners in Malaysia seeking to navigate the intersection of LCSCP, EI and MFP. Firstly, our findings indicate that managers can harness their existing LCSCP to catalyze EI, thereby influencing MFP. This suggests that by strategically promoting eco-friendly product design, optimizing low-carbon processes and integrating sustainable purchasing and logistics strategies, managers can significantly bolster EI, subsequently enhancing MFP. Furthermore, managers now possess the insight to discern which specific components of LCSCP are most conducive to fostering EI. However, it's important to note that practices related to LCL may only moderately influence MFP in the presence of EI. Recognizing these partially mediated practices is crucial, as they still wield influence over EI. Managers should prioritize pollution control, cleaning, cleaner process, product design and environmental research technologies to improve EI in the current industry landscape, which has low mean scores. Secondly, for managers deliberating investments in sustainable supply chain initiatives, allocating resources to enhance both LCSCP and EI is paramount to maximizing benefits for MFP. It's imperative for investment decisions to not operate in isolation but rather consider the synergistic relationship between LCSCP, EI and MFP. Managers must emphasize this synergy to top management when seeking budget allocations for SCM activities. Additionally, this study has facilitated the development of an empirical model linking LCSCP, EI and MFP, enabling supply chain managers in manufacturing firms to identify key success factors. These crucial variables can be utilized as important areas of achievement to create key performance indicators, which can then be used to measure the efficacy and efficiency of organizational resources and the entire supply chain. Furthermore, managers in the electronics industry in Malaysia have a wide range of alternatives when it comes to selecting the most suitable practices for enhancing their LCSCPs. These possibilities include practices that cover various stages of the supply chain, from upstream to downstream, as well as practices that are implemented internally inside the organization or across the entire supply chain.

The policy implications stemming from this study bear crucial significance for shaping environmental and economic policies in the Malaysian manufacturing sector, specifically Malaysia's New Industrial Master Plan (NIMP, 2030). The current NIMP 2030 places a strong focus on promoting sustainable and innovative action plans within the industrial sector. Specifically, the identification of EI as a pivotal mediator between LCSCP and MFP resonates with the Master Plan's vision of positioning Malaysia as a hub for innovation-driven industries. The study's managerial implications, calling for a culture of innovation and targeted investments in EI, provide actionable points for policymakers to refine existing policies within the NIMP 2030, directing incentives toward manufacturing firms embracing both LCPs and innovative solutions. The component-specific findings, focusing on LCPD, LCPI, LCP and LCL, offer nuanced insights for integration into the NIMP 2030, guiding policymakers to develop sector-specific guidelines or incentives. This tailored approach ensures that the manufacturing sector, vital for economic growth, becomes a key driver of environmental responsibility. Policymakers are encouraged to tailor interventions, especially in the specific components identified by the study, to enhance the effectiveness of sustainability efforts. With Malaysia's commitment to carbon neutrality by 2050, policymakers can strategically integrate LCSCP and EI considerations into national sustainability frameworks, aligning policy objectives with global environmental targets. In conclusion, the combined implications underscore the need for a proactive, targeted and integrated policy approach that leverages EI to catalyze sustainable practices, ensuring Malaysia's manufacturing sector aligns with national goals and global sustainability commitments. This holistic approach aims to position Malaysia as a frontrunner in the global carbon market landscape while steadfastly advancing towards its carbon reduction targets.

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Corresponding author
Veera Pandiyan Kaliani Sundram can be contacted at: veera692@uitm.edu.my