

Analysing the Adoption Barriers of Low-Carbon Operations: A Step Forward for Achieving Net-Zero Emissions

Abstract

In November 2021, the 26th United Nations Climate Change Conference (COP26) was held in Glasgow, UK, the global leaders from nearly 200 countries stressed taking immediate action on the climate issue and how to ensure global net-zero emissions by 2030. It is possible to accelerate the transition to low-carbon energy systems, the present study seeks to identify and analyse key barriers to Low Carbon Operations (LCO) in emerging economies. A critical literature review was undertaken to recognise the barriers linked to the adoption of LCO. To validate these barriers, an empirical study with a dataset of 127 respondents from the Indian automobile industry was conducted. The validated barriers were analysed using Best Worst Method (BWM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) techniques. BWM is used to determine the priority ranking of barriers, while the DEMATEL method is employed to elucidate the cause-effect inter-relationships among the listed barriers. The results suggest that ‘*Economic*’ is the most influential category of barriers followed by ‘*Infrastructure*’ and ‘*Operational*’. The results also show that the barriers ‘*Economic*’, ‘*Environmental*’, ‘*Infrastructure*’ and ‘*Organizational Governance*’ belong to the cause group. Some significant managerial implications are recommended to overcome these barriers and to assist firms in the successful adoption of LCO and achieving net-zero emissions. The work was carried out in the automotive industry in India but provides findings that may have wider applicability in other developing countries and beyond.

Keywords: Low Carbon Operations; Climate Issue; Resource policy; Net-Zero Emissions; Environmental Sustainability.

1. Introduction

Currently, all people and every society are facing the issues of global warming and climate change (UNEP, 2018; Yamashita and Fujii, 2022; Sonnett, 2022). Increased industrialisation throughout the world is consuming huge amounts of fossil resources, resulting in higher carbon emissions (Wong et al., 2012; Liu and Song 2017; Wang and Zhang 2020). As an alternative, Böttcher and Müller (2015) introduced the term ‘low-carbon operations’ (LCO) defined as ‘*integrating carbon efficiency into the planning, execution and control of business processes to obtain competitive advantage*’. However, the adoption of LCO in an organization depends

on many activities such as planning, execution and control of the system (de Sousa Jabbour et al., 2018; Zhou et al., 2022) but it is a forward step to contribute for achieving COP26 commitments by ensuring global net-zero emissions by 2030 (Dwivedi et al., 2022).

Over the last two decades, there has been a paradigm shift in the global economic landscape. Due to significant Gross Domestic Products (GDP) and increasing populations, emerging economies like China and India now play a key role in global growth and provide greater investment opportunities for business (Tamvada et al., 2022; Singh et al., 2022). The emerging economies are now performing well in terms of improving customer service, generating employment and reducing poverty (Mathivathanan et al., 2018). However, the emerging economies are also major greenhouse gas emitters, leading to threats of climate crisis if industries are not able to address these concerns (Singh and Singh, 2018; Zahan and Chuanmin, 2021). According to 2018 United Nations Environment Programme, carbon emissions from fossil fuels and industrial processes make a major contribution to emission and global climate change (UNEP, 2018). This means LCO are the ideal for all industrial operations in all countries, from an environmental point of view (Saint Akadiri et al., 2020).

In India, the automobile sector has become one of the major pillars of the economy (Mathivathanan et al., 2018). The industry has taken up an aggressive stance as society recognises the negative impact it has had on the environment. The performance of the Indian automobile industry in meeting environmental targets has been well below satisfactory levels, which may in part be due to the lenient regulatory framework that governs these companies (Luthra et al., 2018; Nizam et al., 2020) but is also assumed to be due to the perceived barriers to change which make low-carbon operations difficult to achieve. The automobile industry is also actively involved in many sustainability programmes to make their businesses more sustainable; the zero-carbon mission initiative is one of them. In this sense, an effective institutional level framework is very important to LCO adoption (Chen et al., 2020). Such a framework can assist business to create adaptive and responsive capacities to manage potential hurdles and implement policies in pursuit of LCO (Luo et al., 2017). This further helps the industry to achieve the goals of lower greenhouse gas (GHG) generation and higher business sustainability (Kedia, 2016).

The environment pollution threat is rising; taking this threat seriously, the Indian government introduced the 'National Electric Mobility Mission' to promote the use of electric vehicles (Kumar and Padmanaban, 2019). Under this scheme, the Indian government is trying to provide financial support to all parties involved with vehicle use and production. This initiative demonstrates government support in limiting the use of traditional resources and improving

public health. However, the concepts of cleaner production and low carbon emission technology are still far from full acceptance in the automotive sector in India (Suresh et al., 2010; Mathivathanan et al., 2018; Shayganmehr et al., 2021). As will be shown, research that can guide companies on LCO is somewhat undeveloped in the literature (Furlan et al., 2017; de Sousa Jabbour et al., 2019).

Driven by the urgent need to improve operations from the environmental perspective, this research seeks to address two key questions. Firstly, what are the key barriers to LCO that are perceived by the managers? Secondly, how can these barriers be examined according to their priority and organised in terms of their causal relationships? Understanding the nature of the barriers will facilitate future interventions to allow progress to be made.

The study therefore aims to analyse the barriers to adopting LCO in the automobile industry in India. The following research objectives are set out:

- (i) To identify and validate the barriers to LCO;
- (ii) To assess the priority ranking of the barriers to LCO;
- (iii) To identify the causal relationships between listed barriers to LCO;
- (iv) To recommend relevant suggestions to overcome the barriers to LCO.

After studying relevant literature, the key barriers to LCO were identified. To confirm these barriers, Exploratory Factor Analysis (EFA) was conducted (Field, 2009). A dataset of 127 responses from the Indian automobile industry was used for empirical analysis. Best Worst Method (BWM) was used to prioritise the validated barriers based on their importance weights (Rezaei, 2015; Rezaei et al., 2016). The DEMATEL method was used to establish the causal relationships between barriers (Hsu et al., 2013; Govindan et al., 2020).

Following the introduction, the literature describing the existing background knowledge for the work is given in Section 2. The research methodology and the analysis with results are provided in section 3 and 4. The findings and discussion are given in Section 6 and 7. Finally, Section 8 covers the concluding remarks and directions for future research.

2. Literature Review

We present the literature in two main areas – a conceptual background on LCO and related barriers and identifying the open questions for this research.

2.1 LCO and related barriers

Carbon emission management has become a significant subject at corporate and decision-making level (Tang et al., 2015; Shen et al., 2018; Stefanelli et al., 2021; Zheng and Ge, 2022). Scholars and practitioners across the globe now accept the need to tackle carbon emissions at both macro and micro levels. The acceptance of LCO practices can assist different industrial sectors, as has begun to be seen in sectors such as automobile manufacturing, in efforts to eliminate negative impacts on the environment. There are three key operational areas where carbon management practices are of paramount importance:

- *Products*: Manufacturers need to engage in low carbon products to generate low carbon emissions and utilize energy, material and resources effectively (Fahimnia et al., 2015; Liu et al., 2017). The parts produced for an automobile company can also be made low carbon using contemporary approaches like Big Data (Seles et al., 2018).
- *Manufacturing*: A proactive approach towards manufacturing can assist managers to improve their operational capabilities to achieve LCO (Micheli, and Mantella, 2018). The adoption of LCO can also facilitate manufacturers in analysing impacts of carbon cap and trade mechanisms in manufacturing and remanufacturing decisions (Chang et al., 2015). The use of the contemporary environmentally friendly processes can further support the implementation of LCO to produce sustainable products (Dong et al., 2018). This would also help manufacturers in improving product stewardship for low carbon management and high sustainable business development (Wong et al., 2012; Tamvada et al., 2022).
- *Supply chain (SC)*: There is an increased attention to ecological consciousness in the design and operation of SCs. The SC is a key element in the automobile industry, responsible for delivering of parts to the major manufacturers. In automotive industry, the SC has a complex structure. Therefore, managers need to examine the issues of GHG generation and sustainability in a SC context (Tang et al., 2015). Currently, the automobile industry generates huge amounts of pollution and emits hazardous gases in its various stages of production, distribution, and disposal of automotive components. The automotive sector accounts for 17% of global GHG emissions (United Nation Climate Change, 2018). To reach a potential USD 1 trillion market for electric vehicles, the industry also has to make huge changes in their supply chain design (United Nation Climate change, 2018). Successful implementation of LCO is associated with a robust supply chain or logistics arrangement regardless of the company managing it (Jabbour et al., 2015; Ji et al., 2017; Singh et al., 2022). For example, manufacturers can engage with their stakeholders for higher environmental performance and select suppliers who are conscious to environment

sustainable manufacturing (Wong et al., 2012; Liu et al., 2019) and using LCO practices, to cut down emissions.

We acknowledge that a fourth area, the emissions from motor vehicles during their use, is of vital importance from carbon reduction in general. However, for this paper we regard the design and use of vehicles as beyond the operations management arena and confine ourselves to the emissions from production operations.

Carbon Trust reported (2006) that evaluating carbon practices across supply chains can help manufacturers to minimise the carbon emissions in each activity of product life. This would further lead to cost savings and improve operational efficiency. In 2009, McKinsey and Company provided a quantitative basis and trade-off between carbon emissions reduction and cost (McKinsey and Company's 2009). Since then, many studies have been conducted in different perspectives. Böttcher and Müller (2013) examined how the drivers and practice of LCO play a significant role in cutting carbon emissions, but the study did not look at barriers to LCO. Furlan et al. (2017) studied the importance of LCO for organisational sustainability. In their empirical study, they conducted interviews with many experts, tried to create a link with the SC, and suggested the future scope of research in low carbon and supply chain management. They mentioned the need for work evaluating adoption of LCO practices from an operational context. In 2017, Bai et al. (2017) developed a framework for a zero-carbon logistics support practice and provided relational practices to show organisations and their ancillary suppliers how to develop robust chains and work towards zero-carbon targets. Srivastav et al. (2018) examined how organisations throughout the world are undergoing a low carbon transition to improve their societal and environmental gains and called for research in integrating low carbon transition with supply chain design. de Sousa Jabbour et al. (2018) performed a systematic literature review and discussed the importance of LCO in an industrial context. They classified barriers as technology issues, policy, governance, market and the economic.

Meyers et al. (2016) conducted an audit base study of six EU nations to evaluate product specific energy consumption and means to limit carbon emissions. Cost effectiveness, technology and governance related to management were the major barriers for them to reduce carbon emissions. Meath et al. (2016) supported the same barriers. Liu and Song (2017) discussed the pre-requisites and contracting model in the zero-carbon support mechanism by taking two cases for installing zero carbon practices in the context of the textile logistics from China. This work highlighted several obstacles - scarcity of energy sources, infrastructure, lack

of clean technology etc. in adopting the management practices required for zero carbon emission. In addition to this, [De Wolf et al. \(2017\)](#) discussed the importance of governance in LCO practices.

The concept of LCO and the development of sustainable environmental initiatives needs strong organisational commitment ([Liu et al., 2018](#)). However, there are several problematic issues, such as lack of political commitment, weak policy mechanism and high set up costs; these may obstruct the smooth implementation of LCO in a company ([Vagnoni and Moradi, 2018](#)).

[de Sousa Jabbour et al. \(2018\)](#) suggested companies to identify barriers to LCO. A further empirical investigation is needed so that companies are able to overcome these barriers and adopt LCO more easily. No study is available in the current literature that examines the priority ranking and causal relationships of barriers to LCO in a developing economy context. [Hall et al. \(2020\)](#) investigated the applicability of innovative business models to achieve low carbon entrepreneurship and management in the energy system in United Kingdom.

[Bai et al. \(2017\)](#) show that there is a lack of research to understand the importance of LCO practices to counter industry greenhouse gas emissions. The initiatives taken by the government and the automobile companies in India are not strong enough to achieve a proper adoption of LCO ([Mathivathanan et al., 2018](#)). Although several attempts have been made by researchers all over the world to understand low carbon practices ([Suresh et al., 2010](#)), no proportionate successes or results have been achieved so far. The lack of awareness among the automobile companies also adds to the existing literature gaps for LCO ([Gouldson and Sullivan., 2013](#); [Long et al., 2016](#); [Singh et al., 2022](#)).

2.2 Research needs

This research seeks to reveal the barriers to LCO in the context of the automobile industry. This involves identifying the barriers, ranking their importance, and identifying any causal relationships between barriers, in order to be able to make suggestions for approaches that may be used to overcome the barriers and move towards LCO. Considering the importance of emerging economies, we focus on India as an example.

The barriers were identified from literature and prioritised using EFA and BWM-DEMATEL.

Aligned with the objectives of our study, we use the term “barriers” for any situation, problem or difficulty whether perceived or real that deters a manager from planning and implementing LCO.

To find the exhaustive list of barriers, we searched the literature using the following keywords: barriers, obstacles, hurdles, low carbon emission, low carbon operation management. The various data bases such as Scopus, Science Direct, EBSCO, Emerald, Wiley, Taylor and Francis were searched and by considering only peer reviewed journal and English language articles, 43 articles were selected using the systematic literature review approach of [Tranfield et al. \(2003\)](#) and [Centobelli et al. \(2017\)](#) considering the scope and aim of this study. A forward and backward snowball approach was used for final screening. The barriers related to adoption of LCO distilled from the previous studies (see Table 1). These were used as the basis of the main research that will be described in the next section.

Table 1: Barriers to LCO from literature

No.	Barriers	Sources
1	Cost effectiveness	Liu and Song (2017) ; van Doren et al (2018) ; Dissanayake et al (2020) ; Singh et al. (2022)
2	High set up cost	Hsu et al. (2013) ; Furlan et al. (2017) ; de Sousa Jabbour et al. (2018) ; Victor-Gallardo et al. (2022)
3	Low credit rating	Furlan et al. (2017) ; De Jesus and Mendonça (2018) ; Arent et al. (2022)
4	Lack of market gain	Xodo (2011) ; Gray et al. (2017) ; Zhao et al. (2018) ; Chapungu et al. (2022)
5	Lack of low carbon competitiveness	Hsu et al. (2013) ; Tang et al. (2015) ; Kedia (2016) ; Fragkos et al. (2017) ; Zhao et al. (2018) ; Dissanayake et al (2020)
6	Commercialization	Fragkos et al. (2017) ; Melville et al. (2017) ; Liu et al. (2022)
7	Lack of motivation for low carbon focused procurement	Hsu et al. (2013) ; Zimmer et al. (2015) ; Zhao et al. (2018) ; Vimal et al. (2022)
8	Lack of awareness	Gouldson & Sullivan (2013) ; Tang et al. (2015) ; Long et al. (2016) ; Muduli et al. (2020) ; Singh et al. (2022)
9	Lack of supporting finance by financial Institutions	Zimmer et al. (2015) ; Li et al. (2020) ; Ohene et al. (2022)
10	Less mobilized private fund for LCO related activities	Suresh et al. (2010) ; Polzin (2017) ; Melville et al. (2017) ; de Sousa Jabbour et al. (2018)
11	Information asymmetry	Mulugetta and Urban (2010) ; Liu and Song (2017) ; Polzin (2017)
12	Environmental regulations	Mulugetta and Urban (2010) ; Tan et al. (2017) ; Singh et al. (2022)
13	Resources unavailability	Lee et al. (2017) ; Callaway et al. (2018)

14	Air quality	Golub et al. (2009); Bush et al. (2017)
15	Issues related to energy transition from fossil fuels	Hsu et al. (2013); Shen et al. (2018)
16	Lack of renewable energy options	Polzin (2017); Callaway et al. (2018); Kim et al. (2020)
17	Lack of political commitment	van Doren et al. (2018); Victor-Gallardo et al. (2022)
18	Lack of renewable energy sources	Ahlborg and Hammar (2014); Polzin (2017); van Doren et al (2018)
19	Lack of specific laws	Bush et al. (2017); Geels et al. (2018)
20	Lack of low carbon supply chain management	Tan et al. (2017); Shen et al. (2017); Emodi et al. (2017); Singh et al. (2022)
21	Lack of testing nodes in LCO practices	Suresh et al. (2010); Li et al. (2017)
22	Lack of proper policy mechanism	Bush et al. (2017); Rosenbloom et al. (2018); Chen et al. (2020)
23	Lack of potential vendors	Evans and Karvonen (2014); Vimal et al. (2022)
24	Slow vehicle electrification	Emodi et al. (2017); Vagnoni and Moradi (2018)
25	Lack of capacity building and green training	Golub et al. (2009); Babatunde and Perera (2017)
26	Scarcity of energy sources	Meyers et al. (2016); Liu and Song (2017); Babatunde and Perera (2017)
27	Lack of low carbon technology	Luo et al. (2017); Meyer and Xin (2017); Shen et al. (2018)
28	Lack of operational efficiency	He (2016); Hall et al. (2017); Geroe (2022).
29	Carbon risk assessment	Li et al. (2017); Vagnoni and Moradi (2018)
30	Lack of carbon governance	De Wolf et al. (2017); Liu et al. (2018)
31	Lack of performance assessment	He (2016); Hall et al. (2017); Singh et al. (2022)
32	Lack of top management commitment	Evans and Karvonen (2014); De Wolf et al. (2017); Rosenbloom et al. (2018); Vimal et al. (2022)
33	Lack of green motivation	Hsu et al. (2013); Liu et al. (2018); Sindhwani et al. (2022)

3. Research Methodology

The methodology adopted for this research is shown in Fig.1.

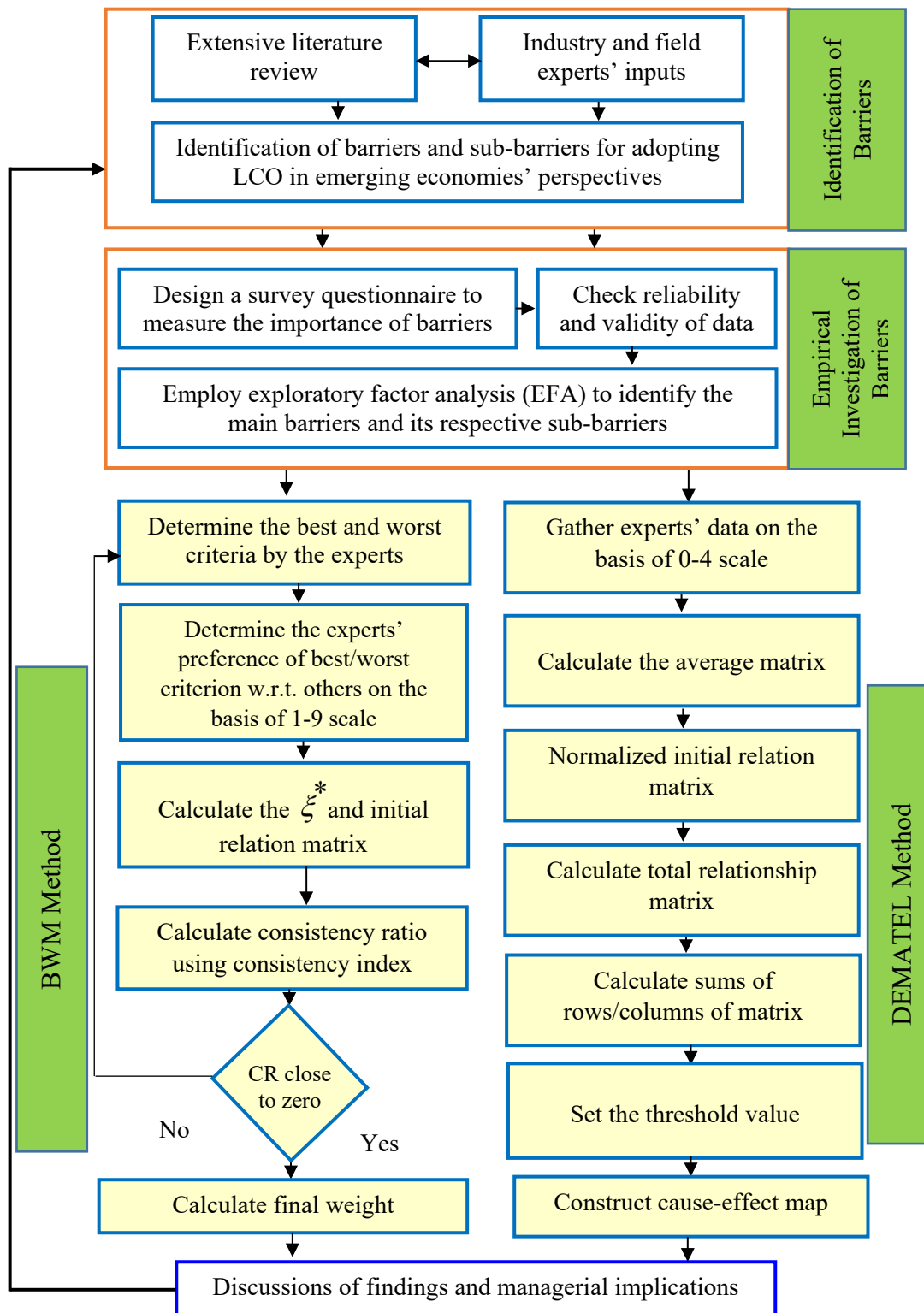


Fig. 1 Research methodology

An empirical investigation provides theoretical foundation to the problem and using both qualitative and quantitative approaches give more strength to theoretical foundation (Bryman, 1988; Newman and Benz, 1998; Kothari, 2004). Empirical research aims to provide knowledge

through direct and indirect experiences of respondents. In this work, an effort is made to identify and evaluate the barriers to adopting LCO in the automotive industry. The barriers listed from literature need to be confirmed by respondent's opinions in terms of their applicability. Therefore, the research team collected data from large, middle and small companies in the emerging Indian automobile industry using both online and offline modes of data collection. In this way, we empirically validated the barriers to adopting LCO. Moreover, we further determined the relative weights and cause-effect relationship of barriers and their respective sub-barriers. Checks were made for bias, and the Cronbach alpha (Nunnally, 1978; Hair et al., 2010) was used for the reliability and validity of data. To classify the barriers into various categories, EFA (Field, 2009) was employed.

BWM was applied to reveal the relative significance of the barriers. BWM is able to solve decision-making problems with multiple criteria. This method has some unique advantages, for instance, more consistent results, it provides flexibility to the decision maker to select the best (high effect) and worst criteria (less effect) among all and provides more reliable results in less time due to the smaller number of pair-wise comparisons (Rezaei, 2015). BWM is a well-established method and have used in various domains (Torabi et al., 2016). However, the BWM method does not have the capability to map the relationships among barriers. For this aspect, the DEMATEL method is best suited and has the capacity to generate inter-relationships among them (Hsu et al., 2013; Govindan et al., 2016; Kazançoglu et al., 2020). It is a well-established method to know the cause-effect interrelationship in the form of digraph and is widely used by researchers in various domains (Rahman and Subramanian, 2012).

3.1 Data collection and development of questionnaire

To check the statistical establishment of all barriers, an empirical investigation was carried out. A questionnaire (see Appendix A) was designed and a pre-tested the survey instruments with senior professionals with strong exposure to LCO in the automobile sector was conducted. As a result, some of questions were re-worded to bring more clarity and avoid confusion. The survey was administered to Indian automobile companies with a covering letter specifically mentioning that the respondent and organization details will be kept strictly confidential. Initially, convenience sampling method was used for data collection but after discussions, some participants, helped the research team to reach more participants through their references to other companies. The questionnaire, along with the cover letter, was sent to 350 operation managers in different large, medium and small size companies. After two weeks, a reminder mail sent. The research team was able to collect 158 respondents' data. After careful

investigation, 127 responses were used; these were complete in all aspects and were considered as an acceptable sample size for analysis (Hair et al., 2010).

4. Data analysis and results

Various statistical tools were used to evaluate the data collected in this research; other details are given below. The respondent details are given in Table 2.

Table 2: Profile of the participants

Characteristics		Total	Percentage (%)
Qualification	Graduation	77	60.63
	Masters	41	32.28
	Doctorate	2	1.57
	Others, please specify...	7	5.51
Work experience	Less than 5 years	10	7.87
	5 to 10 years	55	43.31
	11 to 15 years	44	34.65
	16-20 years	15	11.81
	Above 20 years	3	2.36
Background	Senior Manager	10	7.87
	Manager	32	25.20
	Middle Manager	47	37.01
	Supervisor	28	22.05
	Other, please specify...	10	7.87
Participants from	Large size firm (Annual turnover exceed 10 crore INR equivalent to 115M US\$)	47	37.01
	Medium size firm (Annual turnover between 5 – 10 crore INR equivalent to 57 – 115M US\$)	61	48.03

	Small size firm (Annual turnover more than 25 lakh INR but does not exceed 5 crore INR equivalent to between 2.8 - 57M US\$)	19	14.96
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4.1.1 Measurement of biasness

In the process of data collection, biased opinions of respondents may affect the responses. Therefore, the following measures were considered to deal with biased responses of respondents in validating the barriers (Tittle and Hill, 1967):

- i. We kept the responses of experts as anonymous (Podsakoff et al., 2003).
- ii. We conveyed the aim and objectives of the research to the respondents. They were asked to give their most relevant response. With this procedure, we were able to record their most consistent response and further limit the chances of biasness in their responses (Podsakoff et al., 2012).

Harman's one-factor test was used to test for common method bias (Harman, 1976; Podsakoff et al., 2003). The result of the unrotated factor solution with a single factor is 19.83 which is less than 50 % of variance, showing the common bias problem is not significant. To compare between early and late responses, and offline and online data, a t-test was employed (Podsakoff et al., 2012) and no significant difference at $p > 0.05$ was observed.

4.1.2 Reliability and Validity checks

To check the accuracy of respondent data, reliability tests help to assess the 'goodness' of a measure (Field, 2009). To check convergent validity, the factor-loading concept is used; the value obtained is greater than 0.5, which is acceptable (Field, 2009). Cronbach's alpha α is commonly applied to judge reliability (Nunnally, 1978). The overall Cronbach alpha value is 0.788, which is acceptable (Field, 2009). The factor loading of each item is greater than 0.5, which shows the internal consistency of the instruments used (Nunnally, 1978) and convergent validity of the instruments. After establishing the factor structure of LCO barriers using EFA, the factor-wise (main barrier) Cronbach alpha value is calculated; the range of 0.750 - 0.944 justifies the convergent validity of the instruments (Hair et al., 2010).

4.1.3 Exploratory factor analysis (EFA)

EFA is the technique used most frequently among all the multivariate models to establish the factor structure (Bryman and Bell, 2015). Without loss of information, EFA helps us find factors structure of dimensions (Hair et al., 2010), therefore, EFA is employed to identify the factor structures of all the identified barriers to adopting LCO. Both the EFA technique and the reliability tests were conducted. The collected data is fulfilled the criteria for applying EFA, for instance, The KMO significant value is 0.787 which is higher than 0.6 (Bryman and Bell, 2015). Bartlett's Test of Sphericity is also significant at $p < 0.01$), and the obtained sampling adequacy value is greater than 0.50 for each barrier (Hair et al., 2010). Through EFA, all listed barriers were classified into seven categories (see Table 3); total variance is 74.16%. The factor loading of each barrier under its respective category is in the range of 0.611 - 0.935 that are greater than 0.60. The commonalities range is 0.504 to 0.889, also above the acceptable limit of 0.40 (Field, 2009). The barriers 'air quality' and 'lack of testing nodes in LCO practices' were dropped from further analysis because of low loading as per the acceptable level 0.60 (Hair et al., 2010).

Table 3: EFA analysis results

Barriers	Sub-barriers (Code)	Loading	Commonalities	Cronbach α
Economic (EB)	Cost effectiveness (EB1)	0.883	0.807	0.929
	High set up cost (EB2)	0.856	0.789	
	Supporting finance (EB3)	0.854	0.756	
	Lack of motivation for low carbon focused procurement (EB4)	0.797	0.678	
	Low credit rating (EB5)	0.793	0.758	
	Less mobilized private fund for LCO related activities (EB6)	0.752	0.738	
Market (MB)	Lack of low carbon competitiveness (MB1)	0.825	0.695	0.862
	Commercialization (MB2)	0.809	0.655	
	Lack of awareness (MB3)	0.793	0.625	
	Lack of market gain (MB4)	0.739	0.680	
	Information asymmetry (MB5)	0.729	0.715	
Environmental /resources (EnB)	Environmental regulations (EnB1)	0.935	0.504	0.899
	Lack of renewable energy options (EnB2)	0.933	0.891	
	Resources unavailability (EnB3)	0.891	0.900	
	Issues related to energy transition from fossil fuels (EnB4)	0.622	0.838	
Policy/ regulatory (PB)	Lack of political commitment (PB1)	0.810	0.723	0.750
	Lack of resources to electrify renewable energy (PB2)	0.786	0.708	

	Lack of proper policy mechanism (PB3)	0.767	0.696	
	Lack of specific carbon law (PB4)	0.738	0.724	
Infrastructure (IB)	Lack of low carbon supply chain management (IB1)	0.833	0.652	0.796
	Slow vehicle electrification (IB2)	0.787	0.551	
	Lack of capacity building and green training (IB3)	0.719	0.687	
	Scarcity of energy sources (IB4)	0.611	0.726	
Operational (OB)	Lack of low carbon technology (OB1)	0.918	0.889	0.944
	Lack of operational efficiency (OB2)	0.918	0.833	
	Lack of potential vendors (OB3)	0.900	0.826	
	Carbon risk assessment (OB4)	0.896	0.865	
Organizational Governance (OGB)	Lack of top management commitment (OGB1)	0.856	0.819	0.860
	Lack of carbon governance (OGB2)	0.836	0.791	
	Lack of performance assessment (OGB3)	0.836	0.819	
	Lack of green motivation (OGB4)	0.753	0.652	

4.2 Priority ranks of barriers using BWM

Prof. Rezaei developed BWM in 2015 (Rezaei, 2015) to solve decision-making problems. BWM is based upon pairwise comparisons of the selected best/worst barrier to the other barriers (Rezaei et al., 2016). Compared to other MCDM methods, BWM is more consistent and provides more reliable results (Govindan et al., 2020). Below are the following steps in BWM:

Step 1: The barriers need to be recognized through critical review of literature and expert inputs. For this step, data was collected from a decision-making team of fifteen experts. These experts have a minimum of ten years' work experience in production planning, control and related domains. The authors made arrangements for personal interaction with experts and explained the objectives of the study. Details of the team of experts related to their education, experience and responsibilities are considered during data collection.

Step 2: A questionnaire was designed (as shown in Appendix A) based on a 1-9 scale. The result of best-to-others preference is given as follows:

$$A_B = (a_{B1}, a_{B1}, \dots, a_{Bn}), \quad (1)$$

where a_{Bj} corresponds the significance of the best barrier B (high effect) over barrier j .

Similarly, the preference of each of the other barriers over the worst barrier (least effect), using 1 for the worst barrier (less effect) and 9 for the most significant is defined. The others-to-worst preference is given as follows:

$$A_w = (a_{1w}, a_{1w}, \dots, a_{nw})T, \quad (2)$$

where a_{jw} corresponds the significance of the barrier j over the worst barrier W .

Furthermore, the experts were asked to give their assessment for each barrier compared with the barriers that they thought were the most and least important. Results are shown in Table 4 -Table 5.

Table 4: Best to other barriers to adoption of LCO

Experts	Best	E	M	En	P	I	O	OG
DM1	E	1	6	9	5	2	3	4
DM2	P	3	2	5	1	4	6	8
DM3	O	2	5	6	4	6	1	3
DM4	P	4	7	6	1	3	2	5
DM5	OG	8	3	4	6	2	5	1
DM6	P	5	9	3	1	6	2	4
DM7	M	6	1	2	5	3	9	4
DM8	E	1	5	8	6	2	4	3
DM9	I	3	5	2	6	1	4	7
DM10	I	2	4	6	3	1	6	5
DM11	O	8	2	5	3	4	1	6
DM12	E	1	9	4	3	5	2	6
DM13	OG	5	8	3	6	2	4	1
DM14	OG	6	2	5	3	8	4	1
DM15	I	4	2	7	5	1	3	6

Table 5: Worst to other barriers to adoption of LCO

Experts	Worst	E	M	En	P	I	O	OG
DM1	O	7	6	2	5	3	4	1
DM2	En	5	3	1	6	2	7	4
DM3	P	2	4	7	1	6	4	3
DM4	En	3	5	1	4	7	2	6

DM5	M	4	1	6	3	5	2	7
DM6	I	6	2	4	7	1	3	5
DM7	E	1	7	3	6	2	4	5
DM8	En	4	2	1	7	3	5	6
DM9	O	5	7	3	2	4	6	1
DM10	O	4	7	6	2	5	3	1
DM11	P	7	4	2	1	6	3	5
DM12	O	3	6	2	5	7	4	1
DM13	O	7	3	5	2	4	1	6
DM14	I	7	2	5	3	1	6	4
DM15	O	6	2	5	4	3	1	7

Step 3: Calculate the weight of each barrier. Based on the study of [Rezaei \(2015\)](#), to determine the optimal weights of the barrier, the maximum absolute differences $\{|w_B - a_{Bj}w_j|, |w_j - a_{jw}w_w|\}$, for all j should be minimized. The problem statement is written as:

$$\min \max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jw}w_w|\}$$

subject to

$$\sum_j w_j = 1, \tag{3}$$

$$w_j \geq 0 \text{ for all } j$$

The linear programming formulation can be used to solve this problem:

$$\text{Min } \xi$$

Subjected to

$$|w_B - a_{Bj}w_j| \leq \xi, \text{ for all } j$$

$$|w_j - a_{jw}w_w| \leq \xi, \text{ for all } j$$

$$\sum_j w_j = 1$$

$$w_j \geq 0 \text{ for all } j \tag{4}$$

The Eq.4 must have a unique type of solution.

The optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ are noted after solving the above linear programming problem. The following formula is used to measure the consistency of the responses:

$$\text{Consistency ratio (CR)} = \frac{\xi^*}{\text{Consistency index (CI)}} \quad (5)$$

Appendix B1 illustrates information about the consistency index. From this, it can be inferred that the lower the ‘consistency ratio’, the higher the reliability of the comparisons (Rezaei et al., 2016).

Using Eq. (5), the consistency of each expert matrix is checked; all values are close to zero. The consistency ratio and ξ^* values for all fifteen experts are shown in Appendix B2 of Appendix B. After using all steps of the BWM method, the weight of each barrier is calculated for each expert’s matrix. In the final step, the average weight is calculated for all the experts’ matrices. The final weights and ranks are shown in Table 6. The same step is followed to collect the weights of the sub-barriers. Table 6 shows the weight, local rank as per weight, final weight, based on the calculation of each sub-barrier, with its main barrier weight; the global rank is given accordingly.

Table 6: Final rank of barriers to LCO adoption

Barriers	Relative weight/ (Rank)	Sub-barriers	Relative weight	Local rank	Global weight	Global rank
EB	0.249/ (1)	EB1	0.310	1	0.077	2
		EB2	0.180	3	0.044	7
		EB3	0.090	5	0.022	21
		EB4	0.080	6	0.019	26
		EB5	0.120	4	0.029	15
		EB6	0.220	2	0.054	5
MB	0.123/ (5)	MB1	0.240	2	0.029	15
		MB2	0.280	1	0.034	11
		MB3	0.090	4	0.011	30
		MB4	0.150	3	0.018	27
		MB5	0.240	2	0.029	15
EnB	0.089/ (7)	EnB1	0.280	2	0.024	20
		EnB2	0.200	3	0.017	28
		EnB3	0.380	1	0.033	12
		EnB4	0.130	4	0.011	30
PB	0.133/ (4)	PB1	0.270	2	0.035	10
		PB2	0.170	3	0.022	21
		PB3	0.390	1	0.051	6
		PB4	0.170	3	0.022	21

IB	0.159/ (2)	IB1	0.380	1	0.060	3
		IB2	0.160	4	0.025	19
		IB3	0.270	2	0.042	8
		IB4	0.190	3	0.030	14
OB	0.153/ (3)	OB1	0.380	1	0.058	4
		OB2	0.220	3	0.033	12
		OB3	0.150	4	0.022	21
		OB4	0.250	2	0.038	9
OGB	0.094/ (6)	OGB1	0.340	1	0.094	1
		OGB2	0.150	4	0.014	29
		OGB3	0.290	2	0.027	18
		OGB4	0.220	3	0.020	25

4.3 Determining causal relationships between barriers

DEMATEL can build a cause-effect structure of attributes (Gabus and Fontela, 1972;). DEMATEL is able to divide all attributes into two groups, cause and effect. This helps the researcher to visualise relationships among attributes and construct cause-effect models (Govindan et al., 2020). The steps involved for conducting DEMATEL along with the analysis of study are explained below.

Step 1: The same team of experts were asked to assess the relationships among the n barriers ($i, j = 1, \dots, n$) on a scale from 0 to 4 (0 = no influence to 4 = very high influence). The opinions of experts were translated into a direct relation matrix. Next, the average direct relation matrix (A) is formed using Eq. (4) as shown in Table 7.

$$A = a_{ij} = \frac{1}{p} \sum_{k=1}^p x_{ij}^k \text{ where } p \text{ is number of experts, } i, j = 1, \dots, n \quad (4)$$

Table 7: Average matrix for the barriers to LCO

Barriers	EB	MB	EnB	PB	IB	OB	OGB
EB	0.000	1.428	1.642	1.428	1.357	1.392	1.607
MB	1.500	0.000	1.678	1.464	1.678	1.285	1.392
EnB	1.678	1.678	0.000	1.642	1.392	1.535	1.285
PB	1.571	1.428	1.035	0.000	1.214	1.500	1.571
IB	1.500	1.535	1.500	1.500	0.000	1.535	1.535
OB	1.214	1.357	1.250	1.535	1.464	0.000	1.464
OGB	1.392	1.785	1.321	1.785	1.785	1.321	0.000

Step 2: The matrix normalization is obtained applying Eqs. (5 and 6) as shown in Table 8.

$$U = k \times A, \quad (5)$$

$$k = \min \left(\frac{1}{\max_i \left(\sum_{j=1}^n a_{ij} \right)}, \frac{1}{\max_j \left(\sum_{i=1}^n a_{ij} \right)} \right), i, j = 1, 2, \dots, n. \quad (6)$$

Table 8: Normalized initial direct-relation matrix

Barriers	EB	MB	EnB	PB	IB	OB	OGB
EB	0.000	0.152	0.174	0.152	0.144	0.148	0.171
MB	0.159	0.000	0.178	0.155	0.178	0.136	0.148
EnB	0.178	0.178	0.000	0.174	0.148	0.163	0.136
PB	0.167	0.152	0.110	0.000	0.129	0.159	0.167
IB	0.159	0.163	0.159	0.159	0.000	0.163	0.163
OB	0.129	0.144	0.133	0.163	0.155	0.000	0.155
OGB	0.148	0.190	0.140	0.190	0.190	0.140	0.000

Step 3: Compute the total relation matrix (T) using Eq. (7):

$$T = U(I - U)^{-1} \quad (7)$$

Define r as $n \times 1$ and c as $1 \times n$, these are obtained from Eqs. (8 and 9) as below:

$$r = [r_i]_{n \times 1} = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1} \quad (8) \quad c = [c_i]_{1 \times n} = \left[\sum_{i=1}^n t_{ij} \right]_{1 \times n} \quad (9)$$

Where t_{ij} is total relation matrix, for $i, j = 1, 2, \dots, n$.

The relation matrix is computed in Table 9 with impact result of LCO adoption shown in Table 10.

Table 9: Total relation matrix (T) pertaining to the barriers to LCO

Barriers	EB	MB	EnB	PB	IB	OB	OGB
EB	2.351	2.563	2.399	2.594	2.485	2.412	2.498
MB	2.523	2.465	2.435	2.632	2.543	2.436	2.515
EnB	2.577	2.657	2.321	2.688	2.561	2.495	2.547
PB	2.364	2.428	2.226	2.327	2.412	2.476	2.3669

IB	2.542	2.626	2.439	2.656	2.412	2.476	2.5470
OB	2.329	2.415	2.236	2.460	2.355	2.150	2.350
OGB	2.599	2.713	2.488	2.747	2.6380	2.522	2.371

Table 10: Impact results of LCO adoption

Barriers	<i>r</i>	<i>c</i>	<i>r + c</i>	<i>r - c</i>	Impact
EB	17.306	17.287	34.594	0.018	Cause
MB	17.551	17.870	35.421	-0.319	Effect
EnB	17.848	16.547	34.396	1.300	Cause
PB	16.351	18.107	34.459	-1.756	Effect
IB	17.701	17.338	35.040	0.363	Cause
OB	16.297	16.787	33.085	-0.490	Effect
OG	18.180	17.297	35.478	0.883	Cause

Step 4: Draw the digraph. For this, the threshold value (α) is calculated using Eq. (10),

$$\alpha = \frac{\sum_{i=1}^n \sum_{j=1}^n [t_{ij}]}{N} = 2.474 \quad (10)$$

where N illustrates the number of elements in matrix T . All values greater than the threshold value (2.474) were retained and italicized in the matrix T in Table 10; the rest of the values were eliminated. The network relationship map (NRM) is conducted e.g., the value of t_{12} (2.563) $>$ α (2.474); that shows the strength of the relationship, for instance, economic barrier to market barrier means EB affects MB. This means that EB impacts MB in adopting LCO practices in automotive industry in India. Further to this, for instance, OB is not influencing other barriers as all values are below than threshold value for OB.

Similarly, all the relationships based on threshold value and matrix T are constructed as visualised in Fig.2.

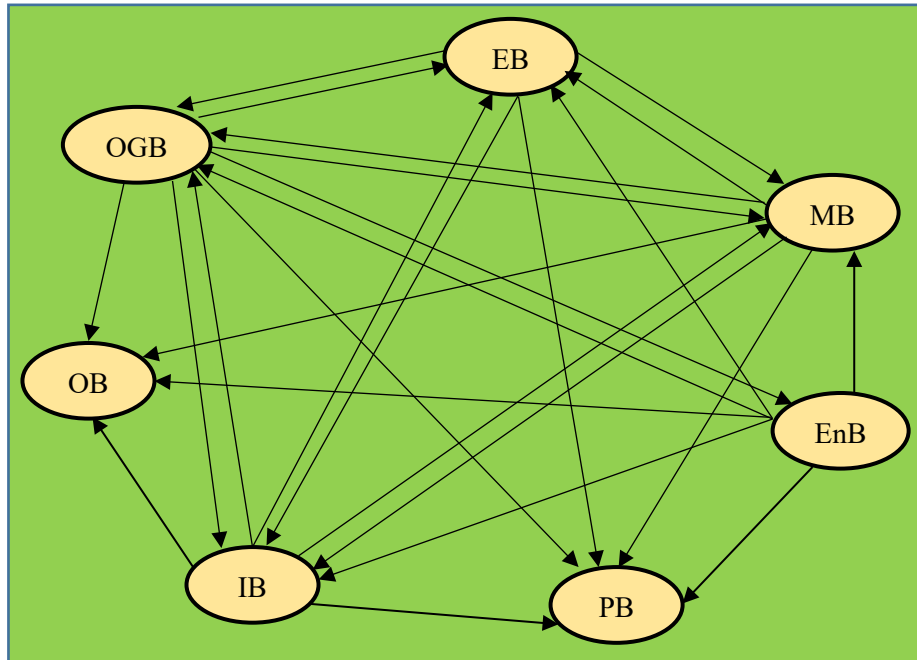


Fig.2 Network relationship map of the main barriers

As per DEMATEL analysis the barriers ‘Economic’, ‘Economic’, ‘Environment’, ‘Infrastructure’ and ‘Organization Governance’ are the cause group barriers (as shown in Table 10). The barriers are ‘Market’, ‘Policy/regulatory’, ‘Operational’ and ‘Organization Governance’, are in effect group, meaning that these barriers are influenced by others. Fig.2 represents the causal relationship among the barriers. The same steps are followed for sub-barriers and the result are presented Table 11, with network maps visualized in Fig.3.

Table 11: Impact results of LCO adoption of sub-barriers with each barrier of LCO

Barriers	Sub-barriers	$r + c$	$r - c$	Impact
EB	EB1	22.804	-0.870	Effect
	EB2	22.261	-1.025	Effect
	EB3	23.025	0.102	Cause
	EB4	22.874	-0.424	Effect
	EB5	22.259	0.420	Cause
	EB6	22.506	1.797	Cause
MB	MB1	13.542	-1.059	Effect
	MB2	13.883	0.432	Cause
	MB3	13.601	-0.306	Effect
	MB4	13.934	-0.965	Effect
	MB5	15.519	0.501	Cause
EnB	EnB1	15.722	-0.511	Effect
	EnB2	15.297	1.713	Cause
	EnB3	15.015	-0.514	Effect
	EnB4	15.722	-0.511	Effect
PB	PB1	17.815	-1.152	Effect
	PB2	17.016	0.127	Cause
	PB3	17.962	0.146	Cause
	PB4	17.054	0.878	Cause
IB	IB1	12.458	0.132	Cause
	IB2	11.265	-0.515	Effect
	IB3	10.959	1.305	Cause
	IB4	12.459	-0.921	Effect
OB	OB1	14.068	0.639	Cause
	OB2	13.924	1.499	Cause
	OB3	13.464	0.519	Cause
	OB4	14.214	-0.340	Effect
OGB	OGB1	16.590	0.740	Cause
	OGB2	17.530	-1.155	Effect
	OGB3	17.662	0.151	Cause
	OGB4	16.908	0.264	Cause

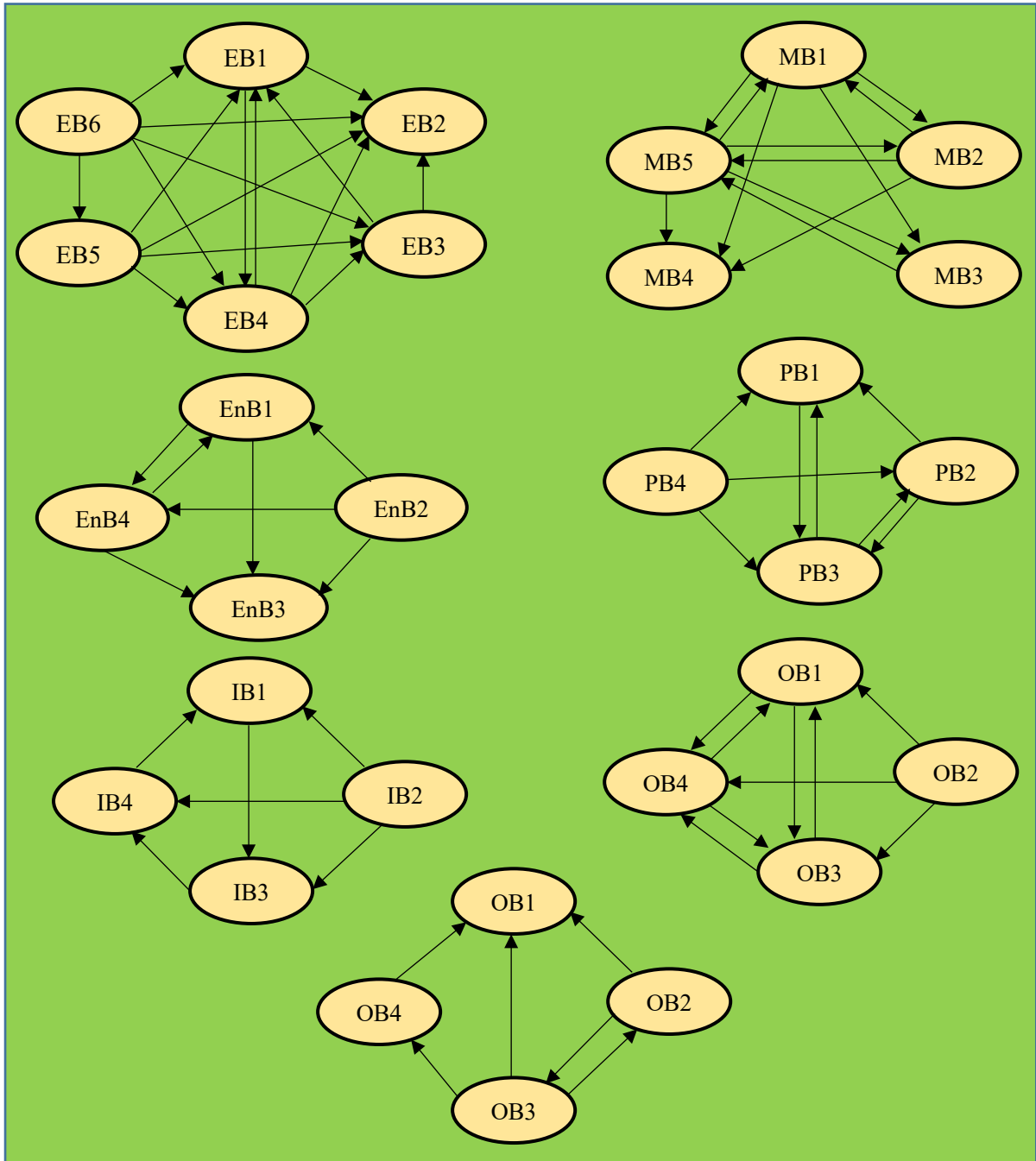


Fig.3 Network relationship digraph of the sub-barriers

5. Results and findings

From the BWM analysis, the priority order of these barriers is Economic (EB) – Infrastructure (IB) – Operational (OB) – Policy/regulatory (PB) – Market (MB) – Organizational Governance (OGB) – Environmental/resources (EnB). From DEMATEL analysis, among all the main barriers, Economic, Environmental/resources, Infrastructure and Organizational Governance

belong to the cause group. Market, Policy/regulatory and Operational belong to the effect group.

From this analysis, all the priority factors fall under cause group except operational barriers. This may be because 'operational' barrier is an internal barrier and effected by many external factors, at the same time highly important for the entire process system.

The analysis shows that 'economic' barrier with weight score of 24.9% is the main cause barrier followed by infrastructure. Policy/regulatory is one of the main priority barriers but it is an effect group barrier. It is because of inadequate administrative capacities to facilitate coordinated efforts towards government's initiatives to achieve low carbon emission targets. For instance, initiatives such as 'Demonetization', 'Make in India' were highly promising but not very successful and even created uncertainty among all types of businesses and investors. India is an emerging economy; therefore, strong steps are required to implement low carbon initiatives which can impact policy positively.

Each category of barrier has its respective sub-barriers, which have also been prioritised based on their priority weights. The cause-effect relationship models among barriers have also been constructed. The results obtained are described more fully in the following sub-sections.

5.1 Economic barrier category

Economic barrier category ranks first and belongs to the cause group barrier. The result indicates that it is the main obstacle in adoption of LCO in the Indian automobile industry and the most influential barrier to others. There are six sub-barriers under this category; their priority ranking is given as cost effectiveness (EB1) - less mobilized private fund for LCO related activities (EB6) - high set up cost (EB2) - low credit rating (EB5) - lack of supporting finance (EB3) - Lack of motivation for low carbon focused procurement (EB4). The sub-barriers EB3, EB5 and EB6 belong to the cause group; EB1, EB2 and EB4 are in the effect group. Among all cause group sub-barriers, less mobilized private fund for LCO related activities (EB6) has the highest (r-c) value of 1.79, signifying that it has the greatest influence on the other sub-barriers. Among all sub-barriers, the most weighted is cost effectiveness followed by lack of investment with scores of 31 and 22 respectively.

5.2 Infrastructure barrier category

Infrastructure barrier category is prioritized next among all barriers with relative weight of 15.9. This entails four specific sub-barriers; their priority ranking is: lack of low carbon supply chain management (IB1) - lack of capacity building and green training (IB3) - scarcity of energy sources (IB4) - slow vehicle electrification (IB2) with weight scores of 38, 27, 19 and

16 respectively. Among all sub-barriers, IB1 and IB3 fit to the cause group; IB2 and IB4 fit to the effect group. The cause group barrier ‘lack of capacity building and green training’ has the highest influence score of 1.305; this signifies that capacity building and green training is the main influencing barrier in this category, followed by lack of low carbon supply chain management with a score of 0.132.

5.3 Operational barrier category

Operational barrier category is the third most important priority rank with a weight score of 15.3. This category has four sub-barriers. The rank in importance of these barriers is: lack of low carbon technology (OB1) - carbon risk assessment (OB4) - lack of operational efficiency (OB2) - lack of potential vendor (OB3) with weight scores of 38, 25, 22 and 15 respectively. The barriers lack of low carbon technology (OB1), lack of operational efficiency (OB2) and lack of potential vendor (OB3) belong to the cause group; carbon risk assessment (OB4) is in the effect group.

5.4 Policy/regulatory barrier category

‘Policy/regulatory’ barrier category has the fourth ranking among all the main categories of in barriers. This main barrier category contains four sub-barriers. In terms of priority, these are lack of proper policy mechanism (PB3) - lack of political commitment (PB1) - lack of resources to electrify renewable energy (PB2) and lack of specific law (PB4) with weight score of 39, 27, and 17. The barriers PB2, PB3 and PB4 fit to the cause group while PB1 is in the effect group. Among all cause group sub-barriers, lack of specific law (PB4) has the maximum highest (r-c) value of 0.878, meaning that PB4 has utmost effect on the other sub-barriers.

5.4 Market barrier category

The fifth ranked barrier category is market barrier with a weight score of 12.3. This main barrier overarches five specific sub-barriers and priority rank is; commercialization (MB2) - lack of low carbon competitiveness (MB1) and information asymmetry (MB5) - lack of market gain (MB4) - lack of awareness (MB3) with weight score of 28, 24, 15 and 9 respectively. The barriers MB2 and MB5 belong to the cause group with values 0.432 and 0.501 respectively; this signifies that information asymmetry is the most influential barrier to all sub-barriers.

5.6 Organizational governance barrier category

The organizational governance barrier category is ranked sixth with a weight score of 9.4. This main barrier category contains four sub-barriers. The sub-barrier lack of top management commitment (OGB1) is ranked first followed by lack of performance assessment (OGB3) with

the weight score of 34 and 29 respectively. The sub-barriers lack of green motivation (OGB4) and lack of carbon governance (OGB2) are ranked third and fourth respectively. The barrier lack of top management commitment belongs to the cause group with the highest influence score of 0.740 followed by lack of green motivation with a value of 0.264.

5.7 Environmental/resources barrier category

The last ranking is the environmental barrier category with a weight score of 8.9. This main category of barrier contains four sub-specific barriers. Arranged in terms of priority, these are resources unavailability (EnB3) - environment regulations (EnB1) - lack of renewable energy options (EnB2) - issues related to energy transition from fossil fuels (EnB4) with weight score of 38, 28, 20 and 13 respectively. The barrier EnB2 belongs to the cause group, indicating that this barrier has the highest influence of the entire system with a value of 1.713.

6. Discussion

Economic barrier category - The result indicates that it is the main obstacle in adoption of LCO in the Indian automobile industry and the most influential barrier to others. [de Sousa Jabbour et al. \(2018\)](#) also support in their study that economic barrier is the main obstacle in the adoption of LCO and achieving net-zero emissions. Many researchers have reported that 'economic barriers' is one of the key challenges in adoption of LCO ([Jabbour et al., 2016](#); [Furlan et al., 2017](#); [De Jesus and Mendonça, 2018](#)). According to the research of [Fahimnia et al. \(2015\)](#) and [Liu and Song \(2017\)](#), they suggested tax rebate/subsidy and incentive mechanism are important economic mechanism to attain the low-carbon mission. [Furlan et al. \(2017\)](#) reported that financial support investment can motivate the LCO.

Infrastructure barrier category - The infrastructure is important to support low carbon practices in an industry in the literature, [de Sousa Jabbour et al. \(2018\)](#) also highlighted the importance of infrastructure in LCO adoption. [Huang et al. \(2016\)](#) also proposed that infrastructure transforming are essential steps in adoption of LCO. [Tan et al. \(2017\)](#) and [Emodi et al. \(2017\)](#) also suggested that the lack of low carbon SCM is among the most weighted sub-barriers as logistics and commercial transportation is among the prime contributors to rising carbon emission. This effect is explained in terms of quantum and volume as transportation vehicles emit more carbon than other sources. Energy inefficiency is another reason for the slow implementation of LCO as the proper energy volumes required to establish the framework for zero carbon vehicles is still not at optimum levels. [Seles et al. \(2018\)](#) suggested that firms react

to the climate issues by investing in training, R&D in addition to effective planning of capacity planning through co-operation with other organizations.

Operational *barrier category* - The study of [Hall et al. \(2017\)](#) and [Shen et al. \(2018\)](#) suggested that an efficient operational system is of paramount importance for an industry to adopt LCO effectively and achieving net-zero emissions.. [Shen et al. \(2018\)](#) found in their research due to increased industrialisation and greater demands of customers, business organizations may struggle with the issue of operational inefficiency. Therefore, it is very important for automobile companies must support sustainable environment initiatives by using the latest low carbon technology to reach a desired outcome of robust environmentally friendly models to overcome the issue of operational inefficiency. A welcoming approach to embracing more technologically innovative ideas would help implementation of LCO. Companies should also harness the intellectual ideas which often surface during discussions or meetings and take them to the implementation stage to seek solutions to the relevant problems they are faced with. [Ball and Lunt \(2018\)](#) suggested that lean tools and techniques can help industry to reduce waste and improve operational efficiencies in adopting LCO.

Policy/regulatory *barrier category* - The research carried out by [Micheli and Mantella \(2018\)](#) reported that the policy/regulatory barrier is one of key concern in in adopting LCO and other researchers like [Luthra et al. \(2016\)](#); [Micheli and Mantella \(2018\)](#) are also supported our finding. However, [Black et al. \(2015\)](#) showed that policy is a causal factor, which is in contrast to findings of our study. The reason was as they used secondary data in their study and so the consistency of results depends on how much old the data used by them. India is an emerging economy and most business decisions are affected by political influence in the country. Therefore, it is necessary that government and regulatory authorities must implement carbon control policies and specific regulations to motivate the industry to implement LCO in their organizations. [Bush et al. \(2017\)](#) suggested that political stability is very much required not only to motivate the industry to implement LCO but also to develop strong policy mechanisms to achieve zero carbon neutrality. While, [Luthra et al. \(2016\)](#) proposed that the weak policy mechanism and lack of political commitment towards making a sustainable development are the most influential political barriers, it has been observed that the enthusiasm of the policy makers is weak with a lack of strong motivation.

Market barrier *category* – The Indian automobile industry is facing tough competition in the market at both international and domestic levels, as per literature this finding has been supported by [Rehmatulla and Smith \(2015\)](#). The industry manufactures products while considering customer needs and demands. Therefore, the involvement of stakeholders in a value chain is not only of paramount importance for business sustainability but it is necessary to adopt LCO given current environmental awareness in society. [Jabbour et al. \(2015\)](#) suggested that the involvement of all stakeholders will help business organizations to take strategic decision such as to switch to renewable sources and invest in the development of LCO. In another study, [Luthra and Mangla, \(2018\)](#) stated that information asymmetry plays a vital role in achieving a specific goal. Information asymmetry involves how the industry spreads information regarding any green initiative so that all stakeholders know their roles and responsibilities. [Gouldson et al. \(2013\)](#) and [Long et al. \(2016\)](#) stated that stakeholders' awareness and their active participation play an important role in pushing industries to adopt LCO. To make gains in the market, management should encourage private investors and provide asymmetry information about green initiatives that are planned. In this way they are able to not only increase the brand reputation of the organization, but also to maximum their profit. Thus, information asymmetry plays a vital role in achieving a specific goal.

Organizational governance *barrier category* - [Liu et al. \(2018\)](#) proposed that it is very important to have not only management commitment but also dedicated organisational governance to achieve low carbon emissions, which also supported by [Hsu et al. \(2013\)](#), while [Seles et al. \(2018\)](#) suggested that organizations with better governance support voluntarily disclosing their actions regarding the mitigation of GHGs in promoting LCO. [Meyer and Xin \(2017\)](#) supported in their research that top management commitment is necessary to develop a sustainable business environment management should also welcome intellectual ideas from both within the organisation and outside the organisation to promote their green initiative plans. [Hsu et al. \(2013\)](#) suggested that company management may encounter challenges when adopting LCO because of lack of awareness of the work force. Motivational steps should be taken. For instance, IBM invited presentations from employees on energy and environment practice at work. This signifies that management commitment towards the environment and society is most important for adoption of any green initiative like LCO.

Environmental/resources barrier category - The business organizations' employee find difficult to adopt LCO due to non-awareness of new environmental regulations. Thus,

awareness about new environment regulations is also very important among employees to effectively adopt LCO, as also supported by [Furlan Matos Alves et al. \(2017\)](#). Thus, managers should consider issues emanating from the environmental regulations. This suggests that a lack of renewable energy options is acting as a major hurdle in constraining the implementation of LCO. For example, to reduce fossil fuel use, more available renewable energy options would help. In line with this, industry could achieve zero carbon missions through effective adoption of renewable sources ([Tan et al., 2017](#); [Callaway et al., 2018](#)). It often happens that firms want to adopt green ideas but a lack of resources prevents them from doing so.

The findings of this research are further compared with the previous works (see Table 12).

Table 12: Comparison of findings with the previous works

Barrier category	Results in agreement with	Results in contrast with
Economic	de Sousa Jabbour et al. (2018) ; Gaur et al. (2021)	-
Infrastructure	de Sousa Jabbour et al. (2018) ; Gaur et al. (2021)	-
Operational	Shen et al. (2018) ; de Sousa Jabbour et al. (2020)	-
Policy/regulatory	Luthra et al. (2016) ; de Sousa Jabbour et al. (2018) ; Micheli and Mantella (2018) ; Gaur et al. (2021)	Black et al. (2015)
Market	Rehmatulla and Smith (2015) ; de Sousa Jabbour et al. (2018) ; de Sousa Jabbour et al. (2021)	-
Organizational governance	Hsu et al. (2013) ; de Sousa Jabbour et al. (2018) ; Kannan et al. (2022)	-
Environmental/resources	Furlan Matos Alves et al. (2017) ; de Sousa Jabbour et al. (2020)	-

7. Implications for managers and policymakers

In this study, we empirically identified and investigated the barriers to adopting LCO. Moreover, we further determined the relative weights and cause-effect relationship of barriers and their respective sub-barriers. The study finding makes significant contributions in both theoretical and practical perspectives for adopting LCO initiatives and provides fruitful insights for managers and policy-makers.

7.1 Implications and theoretical contributions

The contributions of this research are threefold. First, the study attempts to identify the barriers and their respective sub-barriers empirically in the context of the automobile sector, which concentrates on adopting a zero-carbon emission paradigm, and which has started thinking about relevant environmentally friendly initiatives to reduce carbon pollution (Luthra et al., 2018; Praveena and Aris, 2021).

Second, the unique and the topmost theoretical contribution is to provide the clear picture of best (strongest) and worst (weakest) and cause-effect interrelationship among the LCO oriented barriers and their respective categories. The best and worst category of the barriers helps the managers to know their priority rank and/or relative importance (using BWM) which further help them to focus accordingly to overcome these barriers (Shen et al., 2017) and improve operational carbon efficiency in their company. The DEMATEL approach provides fruitful insights for the managers to understanding the cause-effect interrelationship among the barriers (Shieh et al., 2010). Managers needs to give higher attention to causal group barriers to stabilise effect group barriers for adopting LCO practices successfully.

7.2 Implications and practical contributions

The external factors (e.g. energy transition, stakeholder pressure, economic pressure etc.) are forcing the industry to adopt a zero-carbon emission paradigm. Because of this pressure and their commitment towards environment and society, all types of industries have started thinking about relevant environmentally friendly initiatives to reduce carbon pollution. The outcomes of this study give a clear picture about barriers of adoption of LCO and provides suggestions and recommendations to adopt LCO in an industrial context.

- Government is a key stakeholder in managing carbon emission related issues. Thus, in case of an emerging economy like India, government should motivate automotive industry managers to reduce environmental pollution and attain a low carbon goal (Singh et al., 2022). The Indian automobile industry is lacking in emission free practices

due to lack of infrastructure; therefore, management should think about the development of infrastructure for the adoption of LCO. The Indian government should take steps to establish appropriate supportive policies in this regard and should invite private investors to try to create better infrastructure.

- From an organisational context, managers may also explore some novel initiatives for LCO adoption. Initiatives like credit mechanism, venture capital, finance mechanism etc. may encourage successful adoption of LCO to enhance zero carbon emission practices. Stakeholders' awareness and their active participation play an important role in pushing industries in the automobile sector to adopt LCO. Thus, management should encourage and involve different stakeholders (external as well as internal) to not only decrease their greenhouse emissions, but also to increase their organizational brand image. These may also include awareness programs for stakeholders as well as support for local innovation ideas.
- For implementing LCO successfully, the industry should create long-term policies. They should adopt certification from various standards such as ISO 14064 and PAS 2050 and implement carbon-auditing processes (McKinnon, 2010). This would encourage engagement with businesses to reduce carbon emissions and natural resource energy consumptions (Vimal et al. (2022)). Managers should seek to reduce fossil fuel use in automotive sector, more available renewable energy options can help to achieve this. An effective use of renewable energy can assist automotive industry to adopt LCO.
- The automobile industry in India is lacking in emission-free practices due to lack of infrastructure, facilities etc. Therefore, management should think about the development of infrastructure and facilities for successful adoption of LCO in Indian automotive context. In line with this, automobile companies must support sustainable environment initiatives (green, circular economy, lean, sustainability) by using the latest low carbon technology to reach a desired outcome of robust environmentally friendly models Vimal et al. (2022). In doing so, it helps to promote uses of low carbon technology while making the operational system more efficient and flexible. Technological advancements and big data management facilitate automotive managers in lowering carbon emissions and building a sustainable society (El-Kassar and Singh, 2018).

- The automobile industry in India is facing tough competition in the market at both international and domestic levels. Developing skills among the workforce is important to promote green initiative plans in business. Initially, company management may encounter challenges when adopting LCO because of lack of awareness of the workforce. In this sense, management may initiate training and development programs among employees. In addition, among employee, awareness about new environment regulations is also very important.

8. Conclusions

Low carbon management has become one of the topical areas of discussion for the academic community. Scholars and practitioners across the globe have accepted the need for zero carbon emission or carbon neutrality implementation at both macro and micro levels. In this study, an attempt is made to evaluate the barriers to LCO in developing economies like India by examining the automobile industry.

[de Sousa Jabbour et al. \(2019\)](#) posed a research question ‘*What are the barriers that could inhibit companies’ adoption of low carbon operation management practices?*’ They concluded that an empirical investigation is required so that companies are able to overcome these barriers and are able to adopt LCO effectively. This paper is an attempt to develop studies in this direction and to provide unique contributions in the context of both theoretical and methodological viewpoints.

This research applies BWM and DEMATEL methods to establish the priority and reveal the causal relationships of barriers. The priority rank of identified categories of barriers is given as economic barriers – infrastructure barriers – operational barriers – political barriers – market barriers – organizational governance barriers – environmental barriers. Further in this analysis, the barriers economic, environmental, infrastructure and organisational governance belong to the cause group; market, political and operational barriers fall into the effect group.

From findings, the economic is the main obstacle in adoption of LCO in the Indian automobile industry and the most influential barrier to others followed by Infrastructure. Therefore, it is an indication that the industry needs support from the Indian Government in term of tax rebate/subsidy and incentive to attain the low-carbon goal and build the infrastructure to support low carbon practices. No doubt the specific law is required to motivate the industry to implement LCO in their organizations but the political stability is very much required not only

to motivate the industry to implement LCO but also to develop strong policy mechanisms to achieve zero carbon neutrality. A welcoming approach of automobile companies would support sustainable environment initiatives by using the latest low carbon technology to reach a desired outcome of robust environmentally friendly models to overcome the issue of operational inefficiency.

It is true that the industry manufactures products while considering customer needs and demands but the involvement of stakeholders in a value chain is not only of paramount importance for business sustainability but it is necessary to adopt LCO given current environmental awareness in society. It is very important to have not only management commitment but also dedicated organisational governance to achieve low carbon emissions that top management commitment is necessary to develop a sustainable business environment, but management should also welcome intellectual ideas from both within the organisation and outside the organisation to promote their green initiative plans. Awareness about new environment regulations is also very important among employees to effectively adopt LCO. The study also suggests that a lack of renewable energy options is a major hurdle in implementing LCO.

This research offers several directions for further research. The listing of barriers was done through literature and experts' feedback. There could be some more categories of barriers and its respective barriers to LCO, but we restricted the literature-based barrier list to most applicable to Indian automotive sector. Some barriers may become outdated with time, and some new challenges may emerge with time and advancements in technology. This study is limited to the automobile industry; the study context may be extended to other industrial sectors in future. In future, research studies can be conducted in the context of managing carbon emissions in a circular economy. Further research may be conducted to measure the internal capabilities of an organisation in the adoption of LCO and its impact on organisational performance.

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Appendix-A

Phase 1 - Questionnaire

This research is about evaluating the barriers in adopting LCO practices in Indian automobile industry. We identified the barriers through literature and experts' inputs. Please respond to confirm the barriers using five-point Likert scale (5 = Strongly Agree to 1 = Strongly Disagree).

Please tick (√) in appropriate box

Barriers	Strongly Agree 5	Agree 4	Natural 3	Disagree 2	Strongly Disagree 1
Cost effectiveness					
High set up cost					
Low credit rating					
Lack of market gain					
Lack of low carbon competitiveness					
Commercialization					
Lack of motivation for low carbon focused procurement					
Lack of awareness					
Lack of supporting finance by financial Institutions					
Less mobilized private fund for LCO related activities					
Information asymmetry					
Environmental regulations					
Resources unavailability					
Air quality					
Issues related to energy transition from fossil fuels					
Lack of renewable energy options					
Lack of political commitment					
Lack of resources to electrify renewable energy					
Lack of specific laws					
Lack of low carbon supply chain management					
Lack of testing nodes in LCO practices					

Lack of proper policy mechanism					
Lack of potential vendors					
Slow vehicle electrification					
Lack of capacity building and green training					
Scarcity of energy sources					
Lack of low carbon technology					
Lack of operational efficiency					
Carbon risk assessment					
Lack of carbon governance					
Lack of performance assessment					
Lack of top management commitment					
Lack of green motivation					

Phase 2 - Evaluating the barriers using BWM-DEMATEL

Priority rank of main barriers using BWM

We attempt to distinguish the priority of barriers in LCO practices in Indian automobile industry. In this sense, please provide the most significant barrier from the seven barriers as mentioned in table below. For this, it is suggested to use number between 1 and 9 for providing their response.

The Most Important Barrier	Economic	Market	Environmental/ Resources	Policy/ regulatory	Infrastructure	Operational	Organizational Governance

Next to this, please provide the least significant barrier from the seven barriers as mentioned in table below. For this, it is suggested to use number between 1 and 9 for providing their response.

The Least Important Barrier	
Economic	
Market	
Environmental/resources	
Policy/regulatory	
Infrastructure	
Operational	
Organizational Governance	

Causal relationships among barriers using DEMATEL

We also attempts to define the causal relationships among barriers in LCO adoption. Thus, please provide your response evaluating the causal relationship among the barriers using the following scale: 4 = Very high influence, 3 = High influence, 2 = Low influence, 1 = Very low influence, 0 = No influence.

Please mark your response in a suitable box

		Compare the influence of one barrier over another																																	
Main barriers → Main barriers ↓	Economic	Market					Environmental/ resources					Policy/ regulatory					Infrastructure					Operational					Organizational Governance								
	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0											
Economic	0																																		
Market						0																													
Environmental/resources											0																								
Policy/regulatory																0																			
Infrastructure																					0														
Operational																										0									
Organizational Governance																															0				

Appendix-B

Appendix B1. Consistency Index (CI)

<i>a_{BW}</i>	1	2	3	4	5	6	7	8	9
<i>Consistency index (max ξ)</i>	0	0.44	1	1.63	2.3	3	3.73	4.47	5.32

Appendix B2: Consistency ratio and ξ^* for each expert

Experts	A_{BW}	ξ^*	CR
DM1	9	0.09	0.019
DM2	8	0.08	0.029
DM3	6	0.12	0.025
DM4	7	0.13	0.032
DM5	8	0.10	0.048
DM6	9	0.08	0.034
DM7	9	0.09	0.035
DM8	8	0.11	0.023
DM9	7	0.13	0.029
DM10	6	0.16	0.023
DM11	8	0.12	0.036
DM12	9	0.11	0.021
DM13	8	0.10	0.045
DM14	8	0.15	0.046
DM15	6	0.11	0.032