Fostering low-carbon production and logistics systems: framework and empirical evidence

Abstract

This work proposes and empirically tests a new framework for evaluating the relationship between stakeholder pressures, the adoption of low-carbon operations practices and firms' carbon performance. It seeks to expand upon stakeholder theory and the natural-resource-based view (NRBV) to understand further the role of operations management in a low-cabrrbon environment. We conducted a survey of manufacturing companies located in Brazil. Our theoretical hypotheses were tested through the Partial Least Squares method with bias-corrected and accelerated (BCA) bootstrap confidence intervals. The key findings encapsulate a mixture of expected and unexpected research results: (i) stakeholder pressures influence both barriers and motivators for decarbonising operations management practices; (ii) a variety of barriers and motivators significantly affect the adoption of low-carbon operations management practices; (iii) developing positive relationships with stakeholders is important to overcome barriers from the external environment and enhance organisational competitiveness; (iv) low-carbon operations management has an overall effect on firms' carbon performance; However, unexpectedly: (v) firms seem to face difficulties in understanding stakeholder pressures when developing low-carbon products and logistics, due to a lack of awareness of the sources of barriers to the adoption of low-carbon management practices; (vi) in terms of stakeholders, competitors tend to exert significant pressure towards the adoption of low-carbon operations, while government does not; (vii) more research is necessary to better understand the apparent weak link between low-carbon logistics and firms' low-carbon performance. Thus, our findings offer new information for the sustainable production research community, as well as insights and directions to production research practitioners in supporting their planning and operations management.

Keywords: Sustainable Operations; Low-carbon Economy; Low-carbon Operations Management; Logistics; Green Supply Chain Management; Sustainable Manufacturing.

1. Introduction

Achieving more sustainable production has garnered the attention of the production research community and its leading scholars (Dolgui, 2018). The latest Paris Agreement, ratified in 2015, explicitly includes and reinforces the need for nations with emerging economies to adopt carbon reduction policies, an action which has the potential to influence the adoption of carbon reduction efforts by organisations throughout the world. Consequently, emerging economies have recently been facing pressure to transition towards a greener economy and to adopt globally recommended best practices in green operations (Mani et al., 2018; Seles et al., 2016; Teixeira et al., 2012). Research into the barriers and motivations that companies encounter when pursuing low-carbon operations management can play a vital role in supporting effective decision-making in regard to climate change (Henriques and Catarino, 2016; Herrmann and Guenther, 2017; Jeswani et al., 2008). To augment such research, scholars need to further investigate the role of operations in this field and develop a broader understanding in the context of both developed and emerging economies (Jabbour et al., 2019). This study introduces a framework with strong theoretical underpinnings to address that need.

Drawing on stakeholder theory (de Gooyert et al., 2017) and the natural-resource-based view (NRBV) of the firm (Hart and Dowell, 2011), this study sheds light on the role of stakeholders in firms' carbon performance and the adoption of low-carbon operations management practices, which include improvements in product design, management models, transformation processes and equipment with the goal of minimising carbon emissions and energy consumption (Du et al., 2015), within the context of the Brazilian economy. The research offers insights into operations and carbon reduction, and fills gaps identified in the existing literature.

The existing literature reports divergence in stakeholders' roles and organisations' consequent responses to climate change in a decarbonised economy (Penz and Polsa, 2018). While the literature suggests many benefits of climate change strategies (Hoffman, 2005;), it also documents the difficulties of implementing decarbonising initiatives (Herrmann and Guenther, 2017; Eisenack et al., 2014). For example, recent industry reports suggest that there is no harmonised and homogenous pattern of organisational responses to climate change across Latin America (CDP, 2015), Asia, North America, and Europe (CDP, 2014). Therefore, it appears that organisational actions to combat the consequences of climate change have not been standardised, likely due to difficulties in the implementation of low-carbon initiatives (Paul et al., 2017). The existence of a variety of barriers to and motivations for pursuing a decarbonised production system (Tsalis and Nikolaou, 2017) may explain the different organisational responses to the consequences of climate change; further research is therefore necessary to understand organisational barriers and motivations towards decarbonised production systems.

Recent studies have reported that pressure from stakeholders drives some organisational responses to climate change (Liu, 2018; Cadez et al, 2018; Littlewood et al., 2018; Damert et al., 2017; Abreu et al., 2017). The question is whether such pressure from stakeholders' triggers motivations and barriers towards the adoption of low-carbon operations practices. Therefore, this article concerns the following research questions: (a) have stakeholders influenced barriers and motivations for the adoption of low-carbon operations practices? (b) have barriers and motivations created by stakeholders influenced the adoption of low-carbon operations practices? and (c) has the adoption of low-carbon operations practices affected organisational low-carbon performance?

To date, research into low-carbon operations, which involve designing products with a low-carbon footprint and carbon-efficient manufacturing and logistics processes, has focused on specific practices, such as low-carbon supply chains (Damert et al., 2018; Luo et al., 2017). There are few comprehensive studies that simultaneously include products, processes, and logistics (Böttcher and Müller, 2015). The majority of empirical studies are geographically limited, with a particular emphasis on China (e.g. Luo et al., 2017), India (e.g. Dubey et al., 2016) and Germany (e.g. Böttcher and Müller, 2015).

Stakeholder theory and the NRBV have the potential to provide insights to further the understanding of low-carbon operations management. Research in this field can benefit from this joint theoretical underpinning because organisational motivation for the adoption of sophisticated sustainable management practices — such as low-carbon operations management — may be triggered by stakeholder pressure and the search for competitive advantage, and the principles of NRBV can explain the differences in companies' responses to environmental issues (Penz and Polsa, 2018).

This work proposes an original theoretical framework integrating constructs that have previously been studied only separately, namely stakeholder pressure, barriers, motivators, low-carbon operations practices and firms' carbon performance. Empirical evidence from Brazilian companies sheds additional light on these relationships. The aforementioned fragmentation in the existing research is due to articles tending to limit themselves to identifying motivations and/or barriers to the adoption of low-carbon operations initiatives (Chu and Schroeder, 2010; Ng et al., 2013, Liu, 2012; 2014; Zhenggang et al, 2017), or to analyse solely the effects of stakeholders and/or motivators on initiatives to reduce CO_2 emissions (Boiral et al., 2012; Palsson and Kovács, 2014; Böttcher and Müller, 2015; Lee and Kim, 2015; Yafei et al., 2018). These studies also focus predominantly on high-income countries, while evidence from emerging economies remains a relatively open question.

The key contribution of this article is the unification of theoretical angles and constructs that have been fragmented in previous literature, combined with insights from Brazil, a top-10 economy which is an industrial powerhouse in Latin America and promises to maintain a presence among the top global economies for decades to come (Jabbour et al., 2013). In this vein, our article aims to advance and enrich recent literature on low-carbon operations (Jabbour et al., 2019; Deng, Lv, Huang, Wan, & Li, 2020; Qin, Han, Wei, & Xia, 2020), by identifying essential implications that scholars should consider, especially when considering emerging economies. Furthermore, this article highlights robust, practical insights and implications for production research practitioners. In this regard, we provide helpful directions concerning the dynamics as managers adopt strategies to improve low-carbon operations production and their accompanying logistics systems.

This study is organised as follows. After this introductory section, the theoretical framework and hypotheses are presented in Section 2. Following this are the research methodology in Section 3, analysis of results in Section 4, and discussion in Section 5. Finally, conclusions are presented in Section 6, and the implications for multiple beneficiaries of the research are highlighted along with the limitations of this study, which may inform future research.

2. Theoretical framework and development of hypotheses

2.1. Stakeholder Theory, Natural Resource Based View Theory and low-carbon operations management practices

Stakeholders constitute any group or individual that may affect or be affected by an organisation's goals (Freeman, 1984). Stakeholder theory links external environmental changes to organisations' need to dynamically adjust their routines and strategies in response to their stakeholders, in order to avoid underperformance (Freeman, 1984). Stakeholders can paradoxically present a source of both risk and cooperation for organisations and, consequently, can be either a motivation or a barrier for organisational decisions and operations. Thus, stakeholders must be considered when making strategic decisions (Savage et al., 1991). The level of pressure exerted by these groups can vary (de Gooyert et al., 2017), and organisations can advance from a reactive to a proactive environmental management approach by managing and building relationships with stakeholders (Baranova and Meadows, 2017).

Stakeholder theory has been utilised to connect the themes of sustainable business management and climate change. According to Daddi et al. (2018), stakeholder theory has supported the understanding that stakeholder pressure influences carbon disclosure, and that organisational responses to climate change rely on the importance of stakeholders.

Low-carbon operations management includes the integration of carbon efficiency into the planning, execution, and control of business processes to gain competitive advantage. Low-carbon operations embrace the development of low-carbon products, production and logistics processes (Böttcher and Müller, 2015).

Low-carbon products aim to reduce the amount of carbon emissions throughout the development and consumption stages of products, including more energy-efficient product design, which reduces these emissions throughout a product's life cycle (Lee, 2012; Wesseling et al., 2017). Low-carbon processes include the development of energy-efficient processes to reduce greenhouse gas emissions and the measurement and maintenance of a carbon inventory for processes (Tang and Zhou, 2012; Furlan Alves Matos, et al., 2017). Low-carbon logistics relate primarily to modes of transport, one of the largest sources of atmospheric emissions due to the consumption of fossil fuels (Tang and Zhou, 2012; Haddad-Sisakht and Ryan 2018, 2018). Logistics managers can reassess modes of transport and maximise the use of shipping space in order to minimise their carbon footprint (Dey et al., 2011; Han et al., 2017).

Palsson and Kovács (2014), for instance, find that stakeholder theory helps in understanding organisations' motivations for reducing carbon emissions in transport activities. A summary of motivations and barriers to low-carbon operations management can be found in Table 1. In each study cited, stakeholders (e.g. employees, shareholders, government, customers, and competitors) were found to play a significant role, due to the fact that stakeholders are environmental change "forcers" (Valero-Gil et al., 2017). For example, Garcés-Ayerbe et al. (2012) suggest that proactive environmental strategies, which include low-carbon operations, are the result of organisational efforts to meet stakeholders' environmental demands. This means that stakeholders are a source of motivation for low-carbon operations. However, climate change actions may be limited in contexts in which some regulatory bodies are less stringent (Amran et al., 2016; Chu and Schroeder, 2010), which means that experiencing less pressure from stakeholders may act as a barrier to low-carbon operations management initiatives. Barriers to low-carbon operations must be identified in order to be overcome, and all parties and their actions, including single stakeholders, are responsible for creating and reducing barriers to climate change initiatives (Eisenack et al., 2014).

The studies shown in Table 1 further support stakeholder theory. Not only does stakeholder pressure increase organisations' motivation to adopt certain environmental practices, but it may also reduce barriers (Delgado-Ceballos et al., 2012). For example, managers can utilise stakeholder pressure to argue for resources needed to implement environmental policies or to build knowledge in an organisation. The more that managers consider high environmental stakeholder pressure to improve processes, enhance resources, and even increase competitive advantage (Valero-Gil et al., 2017), the greater barriers can be overcome.

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Considering the above, it can be hypothesised that:

H1a – Stakeholder pressure negatively influences barriers to the adoption of low-carbon operations

H1b – Stakeholder pressure positively influences motivations for the adoption of low-carbon operations

More recent studies, for instance, have reported that pressure from stakeholders drives some organisational responses to climate change (Liu, 2018; Cadez et al., 2018; Littlewood et al., 2018; Damert et al., 2017; Abreu et al., 2017); however, these studies have only tested the influence of stakeholder pressure on organisational carbon management or carbon strategies. There is a lack of analysis of the influence of stakeholder pressure on the adoption of the three low-carbon operations management practices mentioned above, namely low-carbon products, low-carbon processes, and low-carbon logistics, which represent different organisational responses due to stakeholder pressure. Thus, this article tests the following hypotheses.

H1c – Stakeholder pressure influences the adoption of low-carbon products

H1d – Stakeholder pressure influences the adoption of low-carbon processes

H1e – Stakeholder pressure influences the adoption of low-carbon logistics

The NRBV argues that firms' internal resources and sustainable management capabilities should be developed to improve organisational competitiveness (Hart and Dowell, 2011). By investing in environmental improvements, organisations can enhance their sustainable performance, which is similar to the fundamental principles of the resource-based view of the firm (Barney, 1991). Environmental resources and capabilities may be key factors in overcoming external environmental barriers and improving organisational competitiveness (Martín-de Castro et al., 2016). The NRBV argues that there are three key strategic capabilities: pollution prevention, product stewardship, and sustainable development (Hart and Dowell, 2011). Developing resources and capabilities for carbon emissions reduction is an important competitive response in the transition to a low-carbon economy (Gallego-Alvarez et al., 2015).

The adoption of low-carbon operations management practices can be seen as a strategic capability to respond to stakeholder pressure regarding climate change. Low-carbon processes and low-carbon logistics relate to a firm's pollution prevention strategy, because they aim to increase the efficiency of processes, including carbon efficiency. Low-carbon products relate to the product stewardship strategy, since they change product design features based on a life-cycle perspective. Thus, it can be argued that based on the NRBV, the adoption of low-carbon operations practices provides an organisational response to stakeholder pressure related to the consequences of climate change. In addition, the adoption of low-carbon operations practices may vary, because the level of pressure exerted by stakeholders can also vary (de Gooyert et al., 2017).

Some studies have discussed the role of stakeholders in influencing organisational responses to climate change. According to Sprengel and Busch (2011), organisational responses and strategies to reduce CO_2 emissions do not tend to differ according to the source of stakeholder pressure. Betts et al. (2015) seem to partially agree with Sprengel and Busch (2011), suggesting that stakeholder pressure is experienced differently by different companies due to individual features of the sector to which they belong. However, according to the NRBV, companies' responses in terms of environmental management practices do not vary depending on stakeholder pressure. It seems that there is conflicting understanding in terms of the effect of stakeholder pressure on organisational responses to reduce CO_2 emissions; González-Benito and González-Benito (2006) and Hyatt and Berente (2017) both state that organisational responses to stakeholder pressure differ according to the profile of the relevant stakeholder. Therefore, while stakeholder pressure consistently leads to the adoption of environmental practices by organisations, different stakeholders may apparently drive different environmental responses in organisations. This article contributes to further understanding this last statement.

Based on the assumptions emerging from the previous hypotheses – i.e., that stakeholder pressure creates barriers and motivations for the adoption of low-carbon operations practices, namely low-carbon products, low-carbon processes, and low-carbon logistics – and on the fact that environmental resources and capabilities may be key factors in overcoming external environmental barriers and improving organisational competitiveness (Martín-de Castro et al., 2016) the following set of hypotheses are proposed:

H2a – The perception of barriers to low-carbon operations negatively affect the adoption of low-carbon products

H2b – The perception of barriers to low-carbon operations negatively affect the adoption of low-carbon processes

H2c – The perception of barriers to low-carbon operations negatively affect the adoption of low-carbon logistics

H3a – The perception of motivations for low-carbon operations positively affect the adoption of low-carbon products

H3b – The perception of motivations for low-carbon operations positively affect the adoption of low-carbon processes

H3c – The perception of motivations for low-carbon operations positively affect the adoption of low-carbon logistics

2.2. Low-carbon operations management practices and carbon performance

The rationale for the adoption of carbon reduction initiatives and practices is to reduce environmental damage and improve overall company performance, based specifically on carbon performance (Damert et al., 2017). Carbon performance, an element of environmental performance measurement, means the reduction of carbon emissions associated with organisations' main processes, involving the consumption of energy, carbon emitted, and use of carbon-intense materials per unit of product produced (Böttcher and Müller, 2015). Interestingly, the relationship between corporate adoption of environmental practices and actual environmental performance has not been studied as extensively as has the relationship between adoption of environmental practices and financial performance. The reason for this dearth of studies is that organisations have always been primarily interested in financial performance; additionally, environmental performance and carbon emissions data are much more limited than financial performance data (Doda et al., 2016).

In this matter, there is some ambiguity in the relationship between low-carbon operations and carbon performance (Damert et al., 2017). Few studies have addressed the impact of low-carbon operations practices on the reduction of GHG emissions (Doda et al., 2016). An important aspect of assessing this relationship is determining whether it is worthwhile for organisations to make significant investment in such efforts. It has also been posited that organisations may adopt certain practices as a 'greenwashing' effort, to improve their image, but that resultant environmental performance is not always forthcoming, since the focus in such cases is on the signal to the marketplace (e.g. see Wang and Sarkis, 2017). Therefore, further studying the relationship between carbon operations practices and carbon performance benefits the literature of the field by advancing understanding of whether stakeholder pressure is effective in terms of stimulating carbon operations practices and in turn improving organisational carbon emissions reduction (Damert et al., 2017).

Existing studies are conflicted in terms of low-carbon operations, carbon performance and organisational size (Zuraidah et al., 2014). For example, small manufacturers may focus more on process improvements rather than product redesign, which may be mandated by customers (Zailani et al., 2012). Another assumption regarding low-carbon operations, carbon performance and company size is that large firms are likely to adopt carbon strategies or carbon management initiatives when under positive pressure from stakeholders (Liu, 2018).

Thus, based on previous statements regarding the relationship between low-carbon operations practices and carbon performance, it can be hypothesised that:

H4 – Adoption of low-carbon products has a positive effect on firms' carbon reduction performance

H5 – Adoption of low-carbon processes has a positive effect on firms' carbon reduction performance

H6 – Adoption of low-carbon logistics has a positive effect on firms' carbon reduction performance

Although the aforementioned hypotheses H4-H6 may be considered non-specific statements, they also have the potential to provide some important insights for the emerging state-of-the-art literature on this topic. Figure 1 depicts a representation of the complex relationships among stakeholders, barriers, and motivations for low-carbon operations management, the adoption of low-carbon operations practices, firms' carbon performance, and firms' size.

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3. Research design and methodology

3.1. Constructs, measures and scale development

A questionnaire was created based on measures adapted from previously validated studies (Table 2). The most closely related studies on each topic were taken into consideration, according to searching in the Scopus database. Thus, Liu's (2014) and Böttcher and Müller's (2015) articles came to represent the main pillars of the research questionnaire used in this study, in terms of the items and scales of measurement used, as well as questions. The decision to use the same questions and scales as Liu's (2014) and Böttcher and Müller's (2015) research was taken since these authors have already tested these items of measurement in studying barriers, motivations, low-carbon operations management, and carbon performance constructs. Variables from Liu's (2014) article are used to describe barriers, while the motivations for low-carbon operations management are based on Böttcher and Müller's (2015) indicators. The stakeholder construct includes customers, government, competitors, employees, suppliers, and media (Clarkson, 1995). Low-carbon operations management (low-carbon products, low-carbon processes, and low-carbon logistics) and carbon performance constructs were also based on Böttcher and Müller's (2015) indicators. A five point Likert-scale was used to measure all items.

The original questionnaire was pre-tested (Synodinos, 2003) with both academics considered experts in the area of sustainable operations management and managers representative of the intended respondents, following the procedure suggested by the literature (e.g. Darroch, 2003). Regarding the group of academics who pre-tested the questionnaire, five were PhD holders and five PhD candidates. Regarding the pre-testing managers, two experts were consulted. The pre-testing phase resulted in a number of improvements to the clarity of certain questions; no questions were dropped at this stage.

Table 2 summarises the constructs, items and scale of measurement.

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3.2. Sampling and data collection procedures

The sample country selected for this research is Brazil. Brazil is especially pertinent, as a developing economy which has proposed to reduce its greenhouse gas emissions by 37% by 2020 as part of the COP 21 agreement (Marcondes and Canto, 2015). This represents a bold and risky commitment for a developing country, whose economy might be negatively affected by such an initiative. This agreement therefore shows that Brazil is committed to reducing carbon emissions, and industry will be central to this goal.

Since the complete population size relevant to this study is necessarily unknown, we used the following criteria to identify the target population: (a) companies which manufacture mechanical capital goods, due to the potential environmental degradation caused by their products – these companies may have to adapt their products and processes in order to comply with legal and stakeholder environmental requirements; and (b) companies who are members of the Brazilian Machinery Builders' Association (ABIMAQ) and the National Union of the Component Industry for Auto Parts (Sindipeças). Based on these criteria, we identified 2137 eligible companies as our target population. We then contacted these companies to ask for their agreement to participate in the survey. We received approval from 882 companies for their voluntary participation, constituting our sampling frame. We used a non-probability sampling method, selecting our sample non-randomly based on the responses we received. This method is considered appropriate when each element of the sample population does not have the same chance of being chosen as part of the sample. In addition, the use of non-probability sampling is commonly used because it saves time and costs when faced with a large number of population elements (Sekaran and Bougie, 2016).

After the final version of the questionnaire was established, invitations to participate in the research were sent via email to the environmental managers or holders of similar positions in each company of the sampling frame. This respondent profile was selected because environmental managers, in general, are the individuals responsible in their organisation for proposing environmental management policies, implementing environmental management systems and developing environmental reports (Arnaut et al. 2012). Thus, environmental managers are required to collect data on environmental indicators (e.g. carbon emissions) for their organisational processes and to interact with other organisational areas in order to collect such data. Therefore, environmental managers are best qualified to respond to questions related to low-carbon operations management. The email sent to respondents included a web link to access the online version of the questionnaire. We followed up with participants via telephone calls two weeks after the initial email. The survey was conducted over 5 months, from late 2014 to mid-2015, the data was analysed during 2016 and this article was written during 2017. The time frame used in this research is suitable for comparing the findings in terms of the relationships between stakeholder pressure, barriers to and motivations for the adoption of low-carbon operations management practices, and the consequences for organisational carbon performance, both before and after the agreement reached in COP 21, which occurred in 2015. It was therefore possible to check whether the organisations studied have changed their pathway towards a low-carbon economy due to the COP 21 agreement.

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The profile of the companies studied in terms of size is as follows: 8 micro-sized, 20 small-sized, 38 medium-sized and 25 large-sized. All the companies involved have been awarded ISO 9001 and 14001 certifications. Table 2 depicts the sample distribution features in further detail. The sample size obtained proved to be sufficient, taking into account the following parameters. According to Hair et al. (2017), this sample size is sufficient to run a model with statistical power of 0.80 and R-square of 0.25 at the 5% significance level; with 6 independent constructs in use, the minimum sample size required was 51. We also reinforced our results using the G*power software, and obtained a minimum sample size of 77. Additionally, the sample size in this research is similar to that used in other established works in the green production research area. For example, Klassen and Whybark (1999) used a sample of around 70 respondents, Holt and Ghobadian (2009) 60 respondents and Rao (2002) 52 respondents. Additionally, there are other relevant studies which use a smaller sample size than that used in this work (Gavronski et al., 2008). Based on the work of Hair et al. (2019), the use of small sample sizes in partial least squares-structural equation modelling (PLS-SEM) can be justified when the level of statistical power has been ascertained. Thereby, PLS-SEM can provide unbiased estimation and tend toward the true values. It should be recognized that the greater the sample size used (e.g. 200 cases), the smaller the standard error values produced will be; therefore, the PLS estimation results will be more precise. However, the difference may be very small, as noted by Hui and Wold (1982), meaning that the conclusions drawn will remain unbiased.

We conducted non-response bias testing, comparing respondents who returned the questionnaire early and late. For this we used t-testing, comparing the two groups (early and late responders) by looking at the significance of Levene's test and equality of means. Table 4 shows a significance value of > 0.05 for the two groups of respondents in the constructs tested, indicating that non-response bias is not a potential threat to our results.

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3.3. Data analysis procedures

We have chosen to use the Structural Equation Modeling (SEM) approach in this study, which is considered the second generation of multivariate analysis. SEM enables us to examine the relationships between unobserved variables and to test more complex relationships in the realm of quantitative research. In addition, SEM offers a sophisticated approach compared to classical methods such as multiple regression or path analysis. With SEM, analysis can be carried out simultaneously without intervention. Therefore, taking its advantages into account, SEM is a suitable approach for this study. We chose to use variance-based SEM (VB-SEM) through partial least squares-structural equation modelling (PLS-SEM) for our data analysis. PLS-SEM provides a flexible approach and is superior when modelling multiple construct interactions about which there is relatively scarce theoretical knowledge (Noonan and Wold 1986; Wold 1986). PLS-SEM is especially useful for the exploration of new theoretical and conceptual frameworks (Henseler 2018), and is particularly effective in the examination of complex relationships between variables; covariance-based SEM (CB-SEM) and traditional regression methods are more limited in this area (Latan 2018; Ramli et al. 2018). However, certain assumptions should be considered when using the PLS model, such as the absence of model misspecification and multicollinearity between predictor variables.

The data analysis method used in this research contains three sub-processes. The first was to assess the measurement model in order to ensure the reliability and validity of each indicator. The second involved assessing the structural model through examination of the coefficient of determination (R^2), Q^2 predictive relevance, effect size (f^2) and goodness of fit model. Finally, in the third stage, we tested our hypotheses using a 95% confidence interval.

4. Results

4.1. Measurement model assessment

Our analysis results are reported following the general reporting standards proposed by Latan (2018) for studies using PLS-SEM. First, we analysed the measurement model to ensure that the indicators of each construct were valid and reliable. Here, we tested convergence and discriminant validity as well as construct reliability. Convergent validity was measured using factor loading, for which the values should equal 0.70, and the average variance extracted (AVE) should equal 0.50. For discriminant validity, we employed the approach called the heterotrait-monotrait (HTMT) ratio. This approach is considered better than the Fornell-Lacker criterion, and HTMT is able to overcome the bias embedded in measurements (Hair et al., 2017). The HTMT value must be less than 0.90 for each construct. As for measuring the reliability of the constructs, we selected ρ_c and ρ_A as the most appropriate measures. It is recommended that the ρ_c and ρ_A value must be greater than 0.70. We used the SmartPLS 3 program (Ringle et al., 2015) to analyse the model. As Latan (2018) suggests that authors should disclose the specific settings used in the PLS algorithm, we selected the weighting scheme (path) with the maximum number of iterations at 300. In terms of bootstrapping, we chose a bias-corrected and accelerated (BCa) bootstrap, with a resampling number of 5,000 to obtain structural model results. Table 5 below show the overall measurement model results.

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Table 5 above shows the results of convergent validity and construct reliability. The value of the loading factor, the average variance extracted (AVE), and reliability derived from the analysis of the measurement model for all variables are as follows: loading factor > 0.708, ρ_c/ ρ_A > 0.70 and AVE > 0.50 which meets the recommended requirements (Benitez et al., 2020). However, some measurement model indicators were retained, with the loading factor value being < 0.70. As stated by Hair et al. (2017, p. 114), the value of the loading factor shows the explained variance in a construct. Therefore, if the AVE value is already greater than 0.5, an indicator with low loading values can remain in the construct to ensure content validity. The results of the measurement model analysis are shown in Figure 2 below.

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Table 6 shows the results regarding discriminant validity and correlation between constructs. From these results, it can be seen that stakeholder pressure and motivation have the strongest correlation, at 0.641, followed by low-carbon operations and carbon performance, with 0.625 and 0.498, and finally barriers and low-carbon operations, with -0.347, -0.409 and -0.319, respectively. The results of the discriminant validity analysis (values above the diagonal line), conducted using the HTMT approach, shows that all HTMT values of the constructs are < 0.90, indicating that the required rule of thumb is met.

4.2. Common method bias assessment

We also assessed the data for common method bias, one of the most important issues discussed in social science research over the past three decades. This bias generally arises from methodological and response variances that affect the correlation between variables measured using the same method (Doty and Glick, 1998; MacKenzie and Podsakoff, 2012). This problem is often associated with self-reporting techniques involving data collection from questionnaire surveys and potential measurement errors. Some researchers suggest methods by which scholars can control this bias (Malhotra et al., 2017) in order to avoid inaccurate results, such as inflated or deflated correlations. Inflation results in a wrongly identified strong relationship between variables and/or support for a theory (type I error), while deflation leads to the relationship between variables being perceived as weak and/or prompting a rejection of the theory (type II error). To redress this issue, we used the full collinearity approach as provided by Kock (2017) in PLS-SEM, by looking at the average variance inflation factor (AFVIF) value. The analysis results show that the AFVIF values obtained < 3.3, indicating that common method bias poses no threat to our results (see Table 7).

4.3. Structural model assessment

After confirming that all the indicators of the variables were reliable and valid (see Figure 2 above), the next step involved assessing the results of the structural model and testing the hypotheses. Since the PLS-PM algorithms use the iteration method following multiple regression series, path coefficient interpretation in PLS-PM is equal to the standardisation of regression coefficients. Similarly, interpretation may be applied to adjusted r-square, variance inflation factor (VIF), effect size (f^2) and predictive relevance (Q^2) (Hair et al., 2017; Latan, 2018).

Before we illustrate the results of our analysis in this second step, it should be noted that we tested the collinearity of the structural model. To assess collinearity, we used the same measure as in multiple regression. VIF values of < 3.3 are recommended, with values < 5 still remaining acceptable for all variable predictors in the model (Hair et al., 2017; Latan, 2018). The results of the analysis in Table 7 show that there is no collinearity problem interfering with the results. Furthermore, we evaluated the structural model by looking at the coefficient of determination (R^2 or adjusted R^2), f^2 and Q^2. The coefficient of determination measures the predictive power of the model and represents the amount of variance in the endogenous variable that can be explained by all exogenous variables. A coefficient of determination above 0.20 is considered high in some disciplines, but values between 0.25 and 0.50 are considered valid.

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Table 7 indicates that the R-square and Adj. R-square values generated by each endogenous construct are entirely acceptable. These values suggest that the ability of the predictor variables to explain the outcome variables approaches the substantial level (Field, 2016; Wooldridge, 2020). The resulting effect size values of each predictor variable in the model range from 0.01 to 0.69, thus falling across the small to large categories. The value of the variance inflation factor (VIF) generated for all the independent variables in the model is < 3.3, which indicates that there is no collinearity problem between the predictor variables. The Q^2 predictive relevance value indicates excellent endogenous variables, i.e. values > 0, meaning that the model has predictive relevance.

4.4. Testing hypotheses

We tested our hypotheses in view of the coefficient parameter and the significant value generated from the 95% bias-corrected confidence interval of each independent variable. We tested the hypotheses using the one-tailed rather than two-tailed test. Testing hypotheses using a one-tailed test is more appropriate when the hypothesised direction is clear, so as to minimize type II errors (Field, 2016; Wooldridge, 2020). The results of the testing of hypotheses are presented in Table 8 below.

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As shown in Table 8, almost all the path coefficients provide significant value (at the 5% level). Based on this analysis, stakeholders have a significant positive effect on motivations and a significant negative effect on barriers. From the analysis results, we may obtain coefficient values (β) for the relationships between Stakeholders → Barriers, Stakeholders → Motivations and Stakeholders → GOProc of -0.244, 0.641 and -0.074

respectively, with 95% bias-corrected and accelerated (BCa) < 0.05. This means that H1a, H1b, and H1d are supported. Furthermore, the values of the coefficient (β) for the relationships barriers → low-carbon operations (products, processes and logistics) are -0.288, -0.275 and -0.280 respectively, with 95% bias-corrected and accelerated (BCa) < 0.01. This means that H2a, H2b, and H2c are supported.

The relationships between motivations → low-carbon operations (products, processes and logistics) also yield significant results, with coefficient values (β) of 0.405, 0.363 and 0.233 respectively, with 95% bias-corrected and accelerated (BCa) < 0.05. This means that H3a, H3b, and H3c are supported. Finally, for the relationships between GOProd → carbon performance and GOProc → carbon performance, the coefficient values (β) obtained are 0.207 and 0.521 respectively, with 95% bias-corrected and accelerated (BCa) < 0.01. This means that H4 and H5 are supported. However, H6 is not supported.

4.5. Additional testing

We also tested for endogeneity bias, which posed another threat to our results. This endogeneity testing was intended to maintain the robustness of our analysis results. Endogeneity bias generally arises from the selection of non-random sample, and may manifest through bidirectional relationships between variables or as a result of the effect of omitted variables (Ketokivi and McIntosh, 2017; Peel, 2018). Endogeneity bias distorts the PLS algorithm and threatens the validity of the results. To clarify this issue, we used the Heckman test to obtain propensity scores in assessing endogeneity with the help of the Stata program. We found that the significance obtained from both models remained the same (see Table 9), which indicates that endogeneity bias is not a potential threat to our results.

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PLEASE INSERT TABLE 9 HERE

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5. Discussion

Underpinned by stakeholders' theory (de Gooyert et al., 2017) and the natural-resource-based view (NRBV) of the firm (Hart and Dowell, 2011), this study sheds light on the role of stakeholders in firms' carbon performance and the adoption of low-carbon operations management practices (processes, products, and logistics) in the context of an emerging economy (Brazil). Overall, this research offers findings which are both expected and unexpected based on the current literature and relevant theory, and adds insights into the application of stakeholders' theory to low-carbon operations management by highlighting that competitors tend to influence the transition to low-carbon operations more significantly than other important stakeholders, which adds to the debate on the role of stakeholders in operations management (de Gooyert et al., 2017). We also add some new insights to the NRBV theory by suggesting that, while the majority of low-carbon operations practices tend to relate positively to firms' performance, this may not be always the case for low-carbon logistics, which requires more reflection from academics working in this area (Hart and Dowell, 2011).

Precisely, this work encapsulates five main results that contain both expected and unexpected discoveries. The main findings of the research are: (a) stakeholder pressure exerts influence on both barriers and motivations for adopting low-carbon operations management practices; (b) stakeholder pressures, especially from competitors, tend to impact low-carbon processes, while significant evidence has not been found for the same type of impact on low-carbon products and low-carbon logistics; (c) both barriers and motivators tend to influence the adoption of low-carbon operations management practices; (d) the adoption of low-carbon operations management affects the carbon performance of the organisations studied, although low-carbon logistics proved to be an exception; and (e) the larger the size of the firm, the more intense the adoption of low-carbon processes and logistics.

Stakeholders influence the barriers and motivations for the adoption of low-carbon operations management practices. Consequently, organisations should manage their relationships with stakeholders in order to mitigate the barriers to the adoption of low-carbon operations management practices, following Delgado-Ceballos et al. (2012) who suggest that integration with stakeholders can alleviate internal barriers. Additionally, organisations should monitor the demands of customers and government in terms of low-carbon products, processes, and logistics in order to maintain good relationships with these stakeholders, as is explained further in the following paragraphs. A positive stakeholder relationship increases performance and allows stakeholders to act as a source of support for low-carbon strategies (Baranova and Meadows, 2017). This finding reinforces the need to further explore the complex relationship between stakeholder theory and operations management (de Gooyert et al., 2017).

The findings of this work go beyond recognising that stakeholders are relevant to implementing environmental practices (Sarkis et al., 2010), also incorporating the complexity of dealing with low-carbon practices. We found that stakeholders affect the adoption of low-carbon processes; however, stakeholders are most concerned with low-carbon processes and tend not to be involved in practices around low-carbon products and logistics. Generally, it is manufacturing and transformative production processes which create the most significant risks to the environment. Because of this, stakeholders tend to be more sensitive to environmental issues such as emissions and other forms of pollution, which emerge during manufacturing (Jabbour, 2010).

Additionally, the survey results show that, quite unexpectedly, competitors were acknowledged as the most prominent stakeholders in influencing low-carbon operations initiatives. As a result, we can conclude that the organisations studied have been driven by competitors pursuing low-carbon operations management, and specifically low-carbon processes, which are likely to result in an increase in operational efficiency (e.g. due to the use of energy/carbon efficient equipment) and competitiveness. This finding is a novel insight of this article. Previous literature has identified customers and government as the most relevant stakeholders in terms of adopting environmental practices (Liu, 2012, 2014; Zailani et al., 2012; Palsson and Kovács, 2014; Lee and Kim, 2015, Weber and Cabras, 2017). Furthermore, according to Hoogendoorn et al. (2015), Lee and Kim (2015) and Zailani et al. (2012), government stakeholders tend to influence the adoption of low-carbon production practices, while suppliers primarily influence the adoption of low-carbon processes (Zuraidah et al., 2014). In summary, competitors prompt organisations to adopt low-carbon processes, which can potentially improve operational efficiency and competitiveness. Thus, improved low-carbon processes are a particular source of competitive distinction. Additionally, different types of stakeholders can influence the adoption of different low-carbon operations practices as a corporate response to climate change. Therefore, this article contributes to the debate addressed by González-Benito and González-Benito (2006), Sprengel and Busch (2011), Betts et al. (2015), and Hyatt and Berente (2017) and reinforces the idea that NRBV theory can explain differences in companies' responses to environmental issues (Penz and Polsa, 2018) by means of the adoption of low-carbon operations practices.

The findings from our survey demonstrate that barriers and motivations impact the adoption of low-carbon operations practices. The major barrier identified was a lack of social and consumer context for the reduction of CO_2 emissions. In terms of reduction in carbon emissions, the most important stakeholder for the organisations surveyed was competitors, which can be considered an unexpected research result, suggesting that the search for enhanced competitiveness can drive firms towards the adoption of low-carbon operations. The main barrier and motivation both align with the results of Ng et al. (2013), and the main motivation also aligns with the findings of Böttcher and Müller (2015). The results show that customer stakeholders are not the main influencers for low-carbon operations initiatives; however, a lack of social and consumer context for the reduction of CO_2 emissions is related to customers' behaviour. Thus, the organisations studied seem to have experienced difficulty in identifying customer stakeholders as a barrier to the adoption of low-carbon operations practices. The consequence of such a lack of awareness of the source of barriers is that critical stakeholders may not be adequately managed. According to Baranova and Meadows (2017), building environmental capabilities through stakeholder engagement is fundamental for continuity and the success of sustainable business strategies, especially in the context of transitioning to a low-carbon economy. Moreover, Gallego-Allvarez et al. (2015) state that developing resources and capabilities is relevant for the reduction of carbon emissions. Consequently, through the NRBV perspective, developing strong relationships with stakeholders is important to overcome barriers from the external environment and enhance organisational competitiveness (Martín-de Castro et al., 2015).

The adoption of low-carbon operations management practices assists organisations in pursuing improved carbon performance, especially in terms of reducing the CO_2 emissions of processes and products. Surprisingly, no significant relationship between low-carbon logistics practices and carbon performance was identified (H6). We may begin to explore this finding through the following tentative explanations; however, this outcome certainly deserves further investigation. First, the adoption of low-carbon logistics seems to be a considerably complex process, which requires more variables to capture its complexity than the three variables used in this work, which was inspired by Böttcher and Müller (2015). Additionally, previous literature has found that low-carbon logistics initiatives can leverage firms' environmental and financial performance, supported by inter-organizational integration, which is in turn reinforced by collaboration, knowledge transfer and information sharing (Qian, Wang, Liu, & Zhang, 2019). Legislation and regulation can play an important role in explaining the adoption of low-carbon logistics practices (Laosirihongthong, Adebanjo, & Choon Tan, 2013); however, this is not the focus of our current research framework. Furthermore, the adoption of low-carbon logistics can suffer from significant barriers regarding lack of awareness, policies and regulatory voids, lack of knowledge and skills, adequate infrastructure and poor efficiency in the way complex logistics systems are designed (He, Chen, Liu, & Guo, 2017).

The positive general relationship between low-carbon operations and carbon performance is a signal that stakeholder pressure is effective in terms of transforming pressure into carbon operations practices and in turn into organisational carbon emissions reduction (Damert et al., 2017). This article contributes to the debate on the positive link between low-carbon operations and improved carbon performance, for instance, Doda et al. (2016) and Damert et al. (2017). This article has raised three important insights: (a) different types of stakeholders can influence the adoption of different low-carbon operations practices as a corporate response to climate change; (b) lack of awareness of the source of barriers to the adoption of low-carbon management is critical because stakeholder relationships may not be adequately managed, and developing strong relationships with stakeholders is important to overcoming barriers from the external environment and enhancing organisational competitiveness; and (c) enhancing the environmental capability of suppliers (Genovese et al., 2013) may improve carbon performance comprehension. In summary, building environmental capability through stakeholder engagement is fundamental for continuity and the success of sustainable business strategies, which may include reconfiguring support and supply networks (Dolgui, Ivanov, & Sokolov, 2020; Ivanov & Dolgui, 2020) during and after severe events (Dolgui & Ivanov, 2020; Queiroz, Ivanov, Dolgui, & Fosso Wamba, 2020). On one hand, these insights are essential to the production research field, as they foster the scholarly debate on integrating variables from diverse theories to gain a deeper understanding of low-carbon operations from different angles. On the other hand, the insights could provide directions for managers and practitioners as they adopt low-carbon operations by employing sustainable strategies and considering the influence of the network stakeholders.

5.1 Implications of the findings of this research

Our research has potention implications for academics, practitioners, industrial policy decision-makers and environmental regulators:

- Research findings can be relevant in the context of a low carbon economy, and recent discussions on green deals, and net zero production systems.
- First, this work adds original discussion to the debate on adopting low-carbon operations, extending the literature (Böttcher and Müller, 2015) by testing a complex framework and providing a mixture of expected and unexpected findings.
- For academics, our findings regarding the relevance of competitors in exerting pressure towards the adoption of low-carbon operations, as well as the lack of a positive relationship between low-carbon logistics and low-carbon performance requires further investigation and reflection;
- For organisational managers, it adds that stakeholders can act not only as motivators for low-carbon operations, but also as barriers. This implies the necessity of a comprehensive map of stakeholders for each organisation aiming to adopt low-carbon operations practices. This finding also extends the literature on stakeholder pressures by clarifying that stakeholders can act as both motivators and barriers.
- For supply chain managers working in multi-tiered supply chains, it is important to recognise how 'competition' spreads across multiple tiers (upstream and downstream multi-tiered supply chains) and how competitors who are engaged with multiple supply chains at the same time can exert their influence.
- Environmental regulators and industrial policy makers will need to pay additional attention to and create specific support for SMEs adopting low-carbon operations management, as the size of the firm can affect the adoption of these practices.
- Industrial policy makers do not need to be afraid of pushing forward the transition towards a low-carbon economy, as there is evidence of synergy between low-carbon operations and firms' carbon performance. However, this process can be highly complex and attention must be paid to the relationship between low-carbon logistics and firms' carbon performance.

6. Conclusion

This work tests a complex framework aiming at understanding the relationships among stakeholder pressure, low-carbon operations, motivations, barriers, and firms' carbon performance in a sample of Brazilian companies. This research suggests that: (a) stakeholder pressures influence both barriers and motivations for decarbonising operations management practices; (b) stakeholder pressures, especially from competitors, tend to impact low-carbon processes, although their influence on low-carbon products and low-carbon logistics is weaker; (c) both barriers and motivators tend to influence the adoption of low-carbon operations management practices; (d) the adoption of low-carbon operations management affects the carbon performance of firms, although low-carbon logistics was an exception; and (e) the larger the firm size, the more intense the adoption of low-carbon processes and logistics.

Thus, these findings contribute to production research literature by demonstrating how to apply aspects of various traditional theories to the field and providing empirical outcomes from an emerging representative economy. Additionally, our work suggests that production research scholars should gain a more in-depth understanding of the barriers and the actor's influence on low-carbon operations projects.

In addition to the managerial and practitioner lens, the findings can be a driver for production managers to support low-carbon operations strategies. In this sense, our work and its outcomes suggest that production managers should gain a deeper awareness of the barriers and motivations related to decarbonising operations practices. In the same line of thought, identifying and managing pressures from stakeholders is also essential. Lastly, production managers should consider the dynamics and complexities of the supply network (Dolgui, Ivanov, & Sokolov, 2020; Ivanov & Dolgui, 2020) in their projects. This is fundamental to avoid/minimise errors, rework, and increased costs during low-carbon operations projects as they often require network reconfiguration due to environmental changes.

At the same time as pushing the state-of-the-art literature forward, this work also has certain limitations that should be recognized. First, the research portrays the reality of a specific sample of firms operating in a specific country – Brazil – in the Latin American context. If the context were altered, different research results and insights may be found. The sample of companies considered in this work could have been bigger, so it is possible to suggest the conduction of future research with bigger sample. Thus, additional research efforts should be made in order to enhance the body of knowledge on low-carbon operations, particularly regarding the unexpected results around low-carbon logistics. It is important to develop further scales to measure low-carbon operations management and the potential implications of this construct on firms' performance. Although this work has adopted the perspectives of Liu's (2014) and Böttcher and Müller's (2015) items, it is relevant to keep developing further alternative scales for the topic. Additionally, further examination of the role of the environmental capability of suppliers in improving understanding of carbon performance would be worthwhile. In this work, it is recognized that hypotheses H4, H5 and H6 may be considered somewhat generic, and it is therefore strongly suggested that future research look further into the relationships between low-carbon operations and firms' performance. It is also relevant to further investigate why H6 was rejected; possible explanations for this outcome, which deserves to be explored further, are: (a) the majority of firms in the sample have not yet fully adopted the practices represented by our scale to measure low-carbon logistics with a clear mission to reduce their emissions (e.g. measurement of carbon emissions from transportation processes; consolidation of shipments to reduce carbon emissions; use of carbon-efficient technologies and modes of transportation); (b) it is possible that the scale used herein, inspired by Böttcher and Müller (2015), is not fully adapted to the characteristics of logistics in a country as complex and vast as Brazil; (c) even though companies may have adopted low-carbon logistics practices (Böttcher and Müller, 2015), their emissions per unit of output (example, PCO1, PCO2) can still be high, revealing a weak link between low-carbon logistics and the scale used to measure low-carbon performance of firms; (d) as explained above, the effectiveness of low-carbon logistics depends on collaboration, regulation and other antecedents, which may be not yet be fully developed in Brazil. Undoubtedly, the rejection of H6 deserves further investigation.

Another productive avenue of future research would be to verify whether the organisations studied, or others located in Brazil, have changed their pathway towards a low-carbon economy following the COP 21 agreement. Therefore, the findings of this article may provide a parameter of comparison to understand the effectiveness of stakeholder pressure and the development of environmental capabilities. Finally, we should point out the potential for social desirability bias, which may occur in any sustainability-related research (Roxas and Lindsay 2012).

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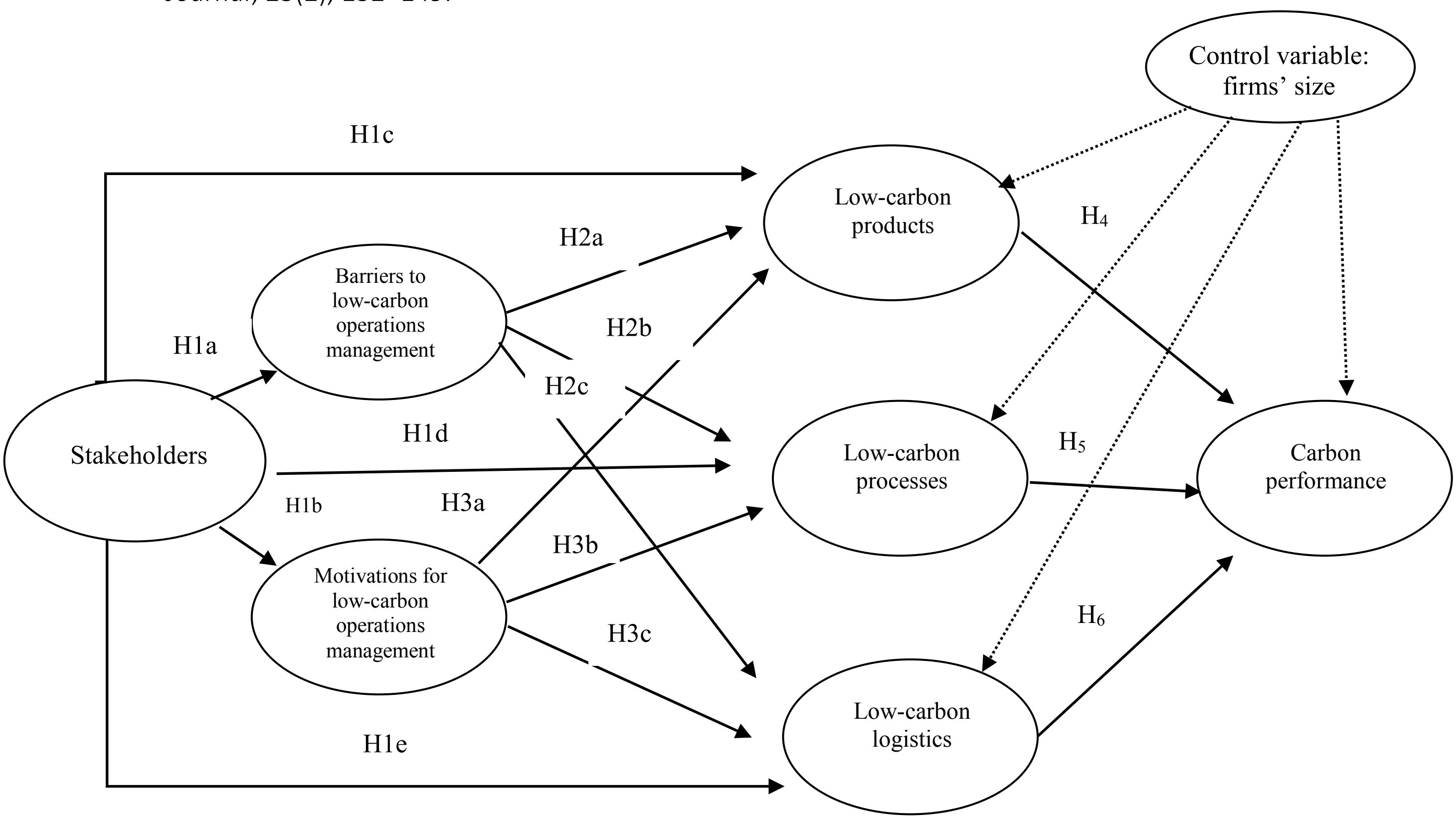

Figure 1. Research Framework and Hypotheses

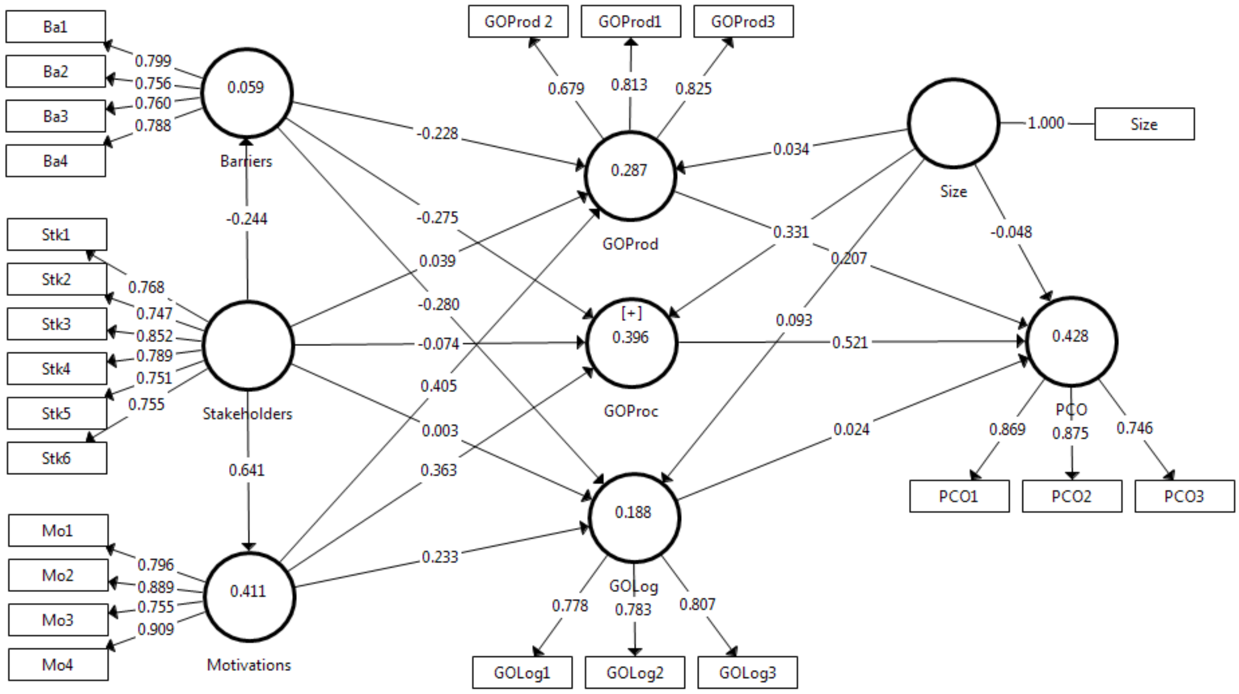

Figure 2. Evaluation of the Measurement Model

Table 1.

Selected Examples of Motivations and Barriers to Organisational Low-carbon Actions

Research	Motivations	Barriers
Okereke (2007)	• Profit • Credibility and influence in the development of climate policies • Risk aversion • Ethical considerations	• Lack of policy • Uncertainty of governmental actions • Uncertainty about the market
Jeswani et al. (2008)	• Cost savings • Corporate goals • Commitment management • Regulatory compliance	• Lack of knowledge • Lack of availability of technology • Absence of governmental policies • High cost • Lack of financial resources
Chu and Schroeder (2010)	• Competitive advantage • Reputation • Leadership of organisational management • Reduction of risk • Regulatory pressure	• Lack of legal requirements • Lack of capacity and knowledge • Lack of management support
Boiral et al. (2012)	• Market opportunity • Reduction of production costs • Increased value for shareholders	• N/A

	• Requirement of customers • Access to capital	
Ng et al. (2013)	• Reduction of costs • Increase of market prospects.	• Lack of environmental market awareness • Limited budget • Customer attitudes • Top management
Liu (2014)	• N/A	• Structural • Regulation • Cultural • Contextual
Galbreath (2014)	• N/A	• Lack of perception of risks caused by climate change • Lack of clarity about the economic benefits generated by processes/products changes
Palsson and Kovács (2014)	• Profit • Competitiveness • Market advantage • Customer requirements • Investor requirements • Social responsibility • Environmental awareness of employees	• N/A
Böttcher and Müller (2015)	• Improvement of image • Market opportunity • Cost reduction • Differentiation among competitors • Rewarding customers • Access to funds	• N/A

Table 2.

Summary of Constructs and Indicators of the Research

Construct (inspired by)	Indicators	Questions and Scales
Stakeholders (Clarkson, 1995)	• Customers (Stk1) • Government (Stk2) • Competitors (Stk3) • Employees (Stk4) • Suppliers (Stk5) • Media (Stk6)	*Managers were asked to what extent their organisation's efforts to reduce* *carbon emissions were affected by each of those stakeholders* *Level of influence:* from no influence to strong influence (5 point Likert-scale).

Barriers (Liu, 2014)	• There is a social and consumer context that does not encourage the reduction of CO_2 emissions by the company (Ba1) • There is an internal organisational culture that does not encourage the reduction of CO_2 emissions where I work (Ba2) • There is a political and governmental context that does not encourage the reduction of CO_2 emissions where I work (Ba3) • It is difficult to include the topic of reducing CO_2 emissions where I work (Ba4)	*Managers were asked about the barriers to carbon emission reduction within their organisations.* *Level of agreement:* from totally disagree to totally agree (5 point Likert-scale).
Motivations (Böttcher and Müller, 2015)	• Image improvement (Mo1) • Marketing opportunity (Mo2) • Cost reduction (Mo3) • Differentiation from competitors (Mo4)	*Managers were asked about the motivations for carbon emission reduction within their organisations.* *Level of motivation:* from not motivating to totally motivating (5 point Likert-scale)
Low-carbon products (Böttcher and Müller, 2015)	• Use of life cycle assessment (carbon footprint) (GOProd1) • Use of renewable and/or recycled raw materials (GOProd2) • Reduction of carbon emissions in utilization phase (GOProd3)	*Managers were asked about which low-carbon products, processes, and logistics practices their organisations have adopted.*
Low-carbon processes (Böttcher and Müller, 2015)	• Measurement of carbon emissions in production processes (GOProc1) • Use of energy/carbon efficient equipment (GOProc2) • Use of low-carbon/carbon-free energy sources (GOProc3)	*Level of adoption:* from no adoption to completely adopted (5 point Likert-scale)
Low-carbon logistics (Böttcher and Müller, 2015)	• Measurement of carbon emissions of transportation processes (GOLog1) • Consolidation of shipments to reduce carbon emissions (GOLog2) • Use of carbon-efficient technologies and modes for transportation (GOLog3)	

Carbon performance (Böttcher and Müller, 2015)	• Energy use (per unit of output) (PCO1) • Carbon emissions (per unit of output) (PCO2) • Use of carbon-intensive materials (per unit of output) (PCO3)	*Managers were asked about their perception on their organisations' carbon emission reduction over time.* *Level of improvement:* from decrease a lot to improve a lot (5 point Likert-scale)

Table 3.

Sample Distribution

Features	Percentage
Micro-sized (1-19 employees)	9%
Small-sized (20-99 employees)	22%
Medium-sized (100-499 employees)	42%
Large-sized (more than 500 employees)	27%
ISO 9001 Certified company	75%
ISO 14001 Certified company	54%

Table 4.

Non-Response Bias Test

Constructs	Sig. Levene's Test	Sig. t-test for Equality of Means
Stakeholders	0.112	0.296
Barriers	0.113	0.091
Motivations	0.306	0.727
Low-carbon Products	0.192	0.118
Low-carbon Processes	0.560	0.190
Low-carbon Logistics	0.181	0.061
Carbon Performance	0.103	0.111

Table 5.

Construct Indicators and Measurement Model Results

Latent Variables	Items/Indicators	FL	AVE	ρ_c	ρ_A
Stakeholders	Stk1	0.768			
	Stk2	0.747			
	Stk3	0.852	0.605	0.902	0.882
	Stk4	0.789			
	Stk5	0.751			
	Stk6	0.755			
Barriers	Ba1	0.799			
	Ba2	0.756	0.602	0.858	0.807
	Ba3	0.760			
	Ba4	0.788			

Motivations	Mo1	0.796			
	Mo2	0.889			
	Mo3	0.755	0.705	0.905	0.868
	Mo4	0.909			
Low-carbon Products	GOProd1	0.813			
	GOProd2	0.679	0.601	0.818	0.682
	GOProd3	0.825			
Low-carbon Processes	GOProc1	0.666			
	GOProc2	0.854	0.621	0.829	0.720
	GOProc3	0.830			
Low-carbon Logistics	GOLog1	0.778			
	GOLog2	0.783	0.623	0.832	0.697
	GOLog3	0.807			
Carbon Performance	PCO1	0.869			
	PCO2	0.875	0.692	0.870	0.791
	PCO3	0.746			

FL = factor loading; AVE = Average variance extracted; ρ_c = Composite Reliability; ρ_A = Dijkstra-Henseler's rho_A.

Table 6.

Correlations and Discriminant Validity Results

Construct	Mean	S.D	1	2	3	4	5	6	7
Barriers	3.13	1.07	1	0.438	0.506	0.428	0.226	0.350	0.274
GOLog	2.03	1.29	-0.347*	1	0.787	0.823	0.390	0.549	0.293
GOProc	2.58	1.33	-0.409*	0.527*	1	0.832	0.559	0.834	0.355
GOProd	2.32	1.23	-0.319*	0.570*	0.549*	1	0.608	0.702	0.459
Motivations	2.99	1.27	-0.178	0.302	0.424*	0.477*	1	0.262	0.735
PCO	3.46	0.59	-0.302*	0.406	0.625*	0.498*	0.216	1	0.209
Stakeholders	2.46	1.06	-0.244*	0.238	0.286	0.361	0.641*	0.168	1

*Correlation is significant at the 0.05 level (2-tailed). Below the diagonal elements are the correlations between the construct values. Above the diagonal elements are the HTMT values.

Table 7.

Structural Model Results

Constructs	R^2	Adj. R^2	f^2	Q^2	VIF	AFVIF
Stakeholders	–	–	0.063 – 0.699	–	1.755	–
Barriers	0.059	0.049	0.065 – 0.112	0.051	1.123	–
Motivations	0.411	0.405	0.039 – 0.135	0.406	1.711	–
GOProd	0.287	0.253	0.044	0.255	1.711	–
GOProc	0.396	0.368	0.247	0.370	1.923	–
GOLog	0.188	0.150	0.001	0.152	1.640	–
PCO	0.428	0.401	–	0.404	–	0.185

Table 8.

Relationships between Variables

Structural path	Coef(β)	Std. deviation	*p*-values	95% BCa CI	Conclusion
Stakeholders → Barriers	-0.244	0.109	0.013	(-0.411, -0.050)*	H1a supported
Stakeholders → Motivations	0.641	0.079	0.000	(0.481, 0.749)**	H1b supported
Stakeholders → GOProd	0.039	0.121	0.372	(0.000, 0.089)$^{n.s}$	H1c not supported
Stakeholders → GOProc	-0.074	0.082	0.042	(-0.210, -0.002)*	H1d supported
Stakeholders → GOLog	0.003	0.112	0.489	(0.000, 0.001)$^{n.s}$	H1e not supported
Barriers → GOProd	-0.228	0.102	0.012	(-0.392, -0.054)**	H2a supported
Barriers → GOProc	-0.275	0.086	0.001	(-0.399, -0.110)**	H2b supported
Barriers → GOLog	-0.280	0.104	0.003	(-0.432, -0.086)**	H2c supported
Motivations → GOProd	0.405	0.162	0.006	(0.097, 0.645)*	H3a supported
Motivations → GOProc	0.363	0.139	0.004	(0.127, 0.583)*	H3b supported
Motivations → GOLog	0.233	0.141	0.049	(0.125, 0.483)**	H3c supported
GOProd → PCO	0.207	0.093	0.013	(0.062, 0.355)**	H4 supported
GOProc → PCO	0.521	0.090	0.000	(0.375, 0.667)**	H5 supported
GOLog → PCO	0.024	0.066	0.360	(0.000, 0.060)$^{n.s}$	H6 not supported

Note: ** and * statistically significant at the 1 percent and 5 percent levels, respectively; n.s is not significant

Table 9.

Endogneity Test

Structural path	Coef(β)	Std. deviation	z	Conclusion
Stakeholders → Barriers	-0.153	0.068	-2.23*	Not different
Stakeholders → Motivations	0.548	0.069	7.87**	Not different
Stakeholders → GOProd	0.203	0.157	1.29	Not different
Stakeholders → GOProc	-0.267	0.080	-3.34**	Not different
Stakeholders → GOLog	0.172	0.163	1.05	Not different
Barriers → GOProd	-0.148	0.063	-2.35**	Not different
Barriers → GOProc	-0.263	0.086	-3.06**	Not different
Barriers → GOLog	-0.120	0.044	-2.70**	Not different
Motivations → GOProd	0.304	0.063	4.81**	Not different

Motivations → GOProc	0.316	0.069	4.56**	Not different
Motivations → GOLog	0.218	0.071	3.04**	Not different
GOProd → PCO	0.257	0.046	5.54**	Not different
GOProc → PCO	0.283	0.039	7.16**	Not different
GOLog → PCO	0.190	0.146	1.30	Not different

Note: ** and * are statistically significant at the 1 percent and 5 percent levels, respectively.