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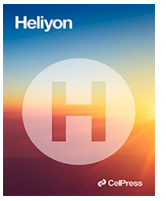

Review article

Green innovation behaviour: Impact of industry 4.0 and open innovation

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ABSTRACT

Developing nations have motivated contemporary manufacturing companies to embrace green innovation and focus on smart technology that is sustainable to harness the growing economy and uplift the people. Although, scientific research in this direction has been neglected, and at the same time there are challenges to the attainment while meeting the need of the people. This study aims to investigate the impact of Industry 4.0, open innovation and green innovation performance on green innovation behaviour. To this end, a theoretical model was established. A quantitative research approach was applied in which survey data were utilized to capture 247 responses from different manufacturing companies in Malaysia. The model was tested using SmartPLSver3.0 to measure the structural relationship between variables. The findings indicate that Industry 4.0 and green innovation performance positively impact green innovation behaviour, compared to open innovation which has no impact. The impact of green innovation performance is found to be stronger when compared to Industry 4.0 and open innovation. Likewise, green innovation performance exhibits a substantial mediating impact between the exogenous variables and green innovation behaviour. The policy implication and conclusions are further discussed in the last section of the study.

1. Introduction

The accessibility of natural materials is cautiously decreasing worldwide, and even so, the severity of unplanned behaviour is expanding due to alteration [1]. The perceived risk that is portending soon has made companies more watchful to lengthen their effort towards the adoption of green innovation behaviour to further enhance the longevity of natural resources [2]. In addition, investments in technology are advancing as companies strive to maintain their relevance. Notably, the transition to a cloud platform is on the lead towards technological innovations [3]. With recent industry progress, the variance between industry accession on the potency for sustaining natural resources is becoming easily seen in the environment [4]. Along with the steady development of economic

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accession, companies have cautiously increased the use of raw materials in their manufacturing process with a focus on environmental sustainability [5]. The prime concern of manufacturing companies has shifted to efficient production towards the development of environmentally friendly goods intending to reduce waste in the manufacturing process and allow them to be re-used to decrease pollutants and attain sustainable development goals [6]. Manufacturing companies have started to consider their views that meet what society required in terms of smart technology and green innovation performance. In this regard, the social expectation has shown that manufacturing companies must meet environmental conditions and quality. Their policy support and strategy are to accomplish green innovation performance, furnished with the lead towards sustained growth. Green innovation is a new concept for improving an organization's manufacturing process (product or service) in contribution to the environment while applying marketing solutions that help companies cultivate sustainable growth, and also minimize the reduction of basic natural materials. It is an improved upcycle process for decreasing the release of harmful products after use across the entire lifecycle to give a new function while reducing ecological footprint [7]. To validate these purposes, companies are using Industry 4.0 technologies and green innovation behaviour to lessen unneeded operations towards resource acquisition without compromising economic determination. These aspects enhance the manufacturing process through modern cyber-physical systems that are controlled by computer-based algorithms, the Internet of things (IoT), and robotics to increase the flexibility of production and increase quality control [8]. Although, performance is distinguished as a conception of green innovation [9,10]. Previous research examines eco-innovation to gauge unceasing manufacturing that supports green initiatives [11] and innovation technologies to gauge business performance [12]. However, measuring this aspect of innovation behaviour as it relates to Industry 4.0 is rarely considered.

Similarly, the support for green innovation behaviour is challenging due to some attributes that are connected to normalizing innovation [13]. Manufacturing companies need to surpass their current knowledge to seek new emerging innovations to overcome challenges. They should link up with their competitors and use their assets to promote open innovation that is internal or externally sourced [14] and also participates in setting up innovation hubs with other firms to improve the manufacturing process [15]. Manufacturing companies are relying on green innovations that are linked with smart technology to decrease pollutants which affect the environment [16] while considering the integration of green innovation behaviour into their value chain [17]. Realizing the action in the past to correct and reduce environmental impairment. Efforts are now being made by manufacturers to protect green development in the production process through the use of technology and embracing eco-innovation. Green innovation behaviour can be improved through smart interactive technology. Although, there is an ongoing debate from a policy perspective to reduce environmental problems [1]. In this regard, authorities need to step up plans to put an end to the hurdle hindering the environmental impact of open innovation as such hurdle may result in systematic innovation negligence [18], which may either be bypassed by companies by adopting green innovation behaviour while cooperating with other firms to enhance eco-innovation [19–21]. As per United Nations Industrial Development Organization, companies need to step up the process for environmental sustainability to gauge economic development in developing nations [22].

As reported by National Green Sustainability Guide, Malaysia is not listed among the best-performing nation in the green progress report which brings a significant impact on the business sector [23]. In addition, the environmental standard does not measure up with other economic sectors [24]. Malaysia's manufacturing sector as one of the drivers of green growth needs to be improved for better economic performance [25]. Environmental challenges are nearly connected to the model of technology innovation that reflect company apathy toward innovation exteriority [26]. This has led the manufacturing sector to a waste stream that affects the environment in different ways during the production process or either by waste generated by using a natural resource that affects the earth [27]. Although, the Malaysian authority understood the impact of smart technology on the economy and environmental stability is not adequately advanced for sustainable performance [26]. Besides, green transformation does not solely support sustainable development but can help ameliorate the manufacturing process through green innovation [28]. Nevertheless, green innovation behaviour help to enhance companies' competitiveness towards an innovation-led economy that places the manufacturing sector as the main driver of economic growth nowadays [29,30]. Therefore, technology influenced by "green" to attain sustainability is a concern for modern companies [31]. Even so, ecological matters faced by companies and the difficulties connected to product management from raw materials have led to the need for green innovation. Indeed, this important concern emerged to include several functions of companies, for instance, green management, green innovation, green supply chain and green marketing, etc. [2,27,32].

Therefore, to meet the recent environmental and manufacturing needs, the efficiency of smart industrial solutions and open innovation can ameliorate environmental performance. Such connections often merge resources allowing companies to reach their long-term goal and develop standardization. Although, the business logistic process looks challenging due to various engagements from the difficulty. However, manufacturers must improve and successfully manage all aspects. For that reason, our study considers the connection between smart industrial technology on green innovation behaviour. Although previous studies by Bag et al. [19], Duong et al. [33] and Witkowski [34] have considered similar aspects but not connected to what is been investigated in this context, because the issue related to green innovation behaviour and improving the manufacturing process through smart technology and what is so-called green which forms the core capability of companies did not receive much attention. For that reason, our investigation highlights the objective and improves previous research domains:

- **RO1.** To examine the impact of Industry 4.0 on green innovation behaviour.
- **RO2.** To examine the impact of open innovation on green innovation behaviour.
- **RO3.** To examine the impact of green innovation performance as a mediator.

In connection with the stated research objective, a quantitative approach was utilized which provides insights into investigative factors thereby bridging specific gaps in the respective research area. Further, the study is designed in an ensuing sequence. Section 2

highlights a review of the literature. Section 3 presents the method, approach, data collection procedures, questionnaire development and measurement scale; section 4 presents the analysis of data procedures and captures the demographic data, the measurement and structural model analysis. The last section 5 presents the discussion of findings; it also highlights the policy implications, future research directions and the limitations of studies.

2. Literature review and hypotheses development

This aspect of the review of literature presents and discussed key literature as it relates to and links discussed in the existing area of research.

2.1. Green innovation behaviour

Worldwide environmental issues that include the depletion of the earth's ecosystem, the disappearance of habitat, and atmospheric hazards have led to progressive interest from policymakers to encourage green innovation behaviour [35]. From the context of production and manufacturing, green innovation behaviour entails the combination of green product innovation and green process innovation in the manufacturing and production process while reducing pollution and improving environmental performance [36]. Green innovation behaviour is the emergence of new improved practices in the organization toward change to enhance retail solutions, lessen natural resources and reduce unwanted costs in the supply chain [1,37]. Green innovation behaviour entails an organized action plan to ameliorate environmental challenges that are internally driven or externally responsive towards the use of natural resources [24]. Green innovation behaviour is considered one of the most effective innovative procedures to reduce environmental pressure that is cost-effective without the concession of economic competitiveness [38]. Past studies believed that the internal and external factors of any organization are driven by green innovation behaviour [17,39,40]. The internal factors such as efficient management of people and resources [41], resource acquisition and environmental awareness campaign [42], technology push [43], corporate governance [44], organization capabilities or corporate social responsibility [45]. The external factors support perceived green culture [35], environmental policies [43], social culture [46,47], stakeholder pressure [48], consumer demand and market [49,50].

The internal and external elements advance green innovation impact on companies' policies while improving resource utilization. In addition, it will also help in understanding how green innovation behaviour improves organizational strategy effectively. Although, research on green innovation behaviour has long been neglected in some contexts, suggesting bias in literature gaps. Indeed, researchers have tended to consider some lone factors as a component of green innovation behaviour in examining companies' performance at the macro level. As per Wang & Shen [51], green innovation behaviour serves as a value characteristic and originality of innovation that emphasizes environmental improvement and protection; and is driven by both internal and external responsive concepts [17]. Green innovation behaviour is a component of the sustainable process and product transformation from a manufacturing perspective to improve environmental friendliness and emission control processes thereby cutting pollution [52]. Companies implement the innovative scheme in the spirit of safeguarding the environment and engaging environmental principles such as the installation of a programmable thermostat, clean energy and saving energy, throughout the manufacturing process [29]. A component of innovation behaviour is classified as product innovation and terminal innovation solutions. Technically, it helps in improving product resource use and also helps to lessen the consumption rate in the process of production which entails recycling and upcycling [20]. The eco-innovation demand a smart emerging environment with several contributions of an innovative process to improve functionality [53]. The innovation activities can help reduce material utilization of production assets and also enhance the production level of management resource, and manufacturing products that the company generate [53]. Despite that, the company's production operation releases unfavourable materials that contaminate thereby giving rise to waste separation and treatment while avoiding harm to the environment. Therefore, the measure is required to improve the technology process through the end-of-pipe innovation vis-à-vis governance [54].

2.2. Industry 4.0

Industry 4.0 is an umbrella term indicating a range of new concepts linked within the industry. It is a component of technology which may cause a paradigm shift within industrial production. It is a combination of progressing technological expansion with the (IoT), smart factories, big data and cyber-physical systems [55]. Industry 4.0 mirror a new trend in technology exchange and several organizations are trying to implement it globally [56]. Although, implementing it means organizations are ready to deploy it and take advantage of the automation and data exchange growing trend. Industry 4.0 technologies have transcended across multiple disciplines and have become progressive in the digital era as a tool for major economic development [55]. Industry 4.0 technologies were the first advance in the field of engineering [57] and expanded to other relevant domains including data management and exchange in advanced manufacturing systems among others [58]. The foundations of industrial technology were built at the speedy growth of smart equipment and intelligent systems with the condition to intensify and deliver digital telecommunications, and facilitate smart factories measures or tactics among cyber units and physical systems to enable real-time data exchange [59]. Smart equipment and technologies are current industrial applications that apply a technological concept like a cyber-physical component with an improved human-machine interface [60,61]. Industry 4.0 technologies represent the industrial ability to communicate and interact with every aspect of its component with humans and machines along with the approaches of smart systems to produce quantities of data [62]. For instance, research has considered high-technology solutions for smart logistics in the industrial system [19].

In addition, Industry 4.0 has also been considered in human and machine interface to express smart technologies as a component of

new digital enterprise technologies that guarantee the connectivity and interconnection of systems (humans and machines) to modify the production process from a single automated to a complete integrated and automated facility [63]. Smart equipment or technology allows companies to lessen waste, and improve efficiency thereby creating a resource from the environment, in addition to the reduction of marginal production costs to improve companies' performance [2,19]. This means that Industry 4.0 can significantly impact green innovation behaviour or performance. Aforesaid, Industry 4.0 include data exchange, blockchain technology and the (IoT). Data exchange is a leading component of smart technologies which help in managing a sizeable sum of structured data measured for storage and transmission [64]. It embraces a structured technique to explicate, and identify data at the beginning [65]. The introduction of big data and its credibility are estimated by gauging previous records of the company's portfolio. In this way, it helps to strengthen green innovation performance through a selective mechanism for the production and service industry [66]. Therefore, big data technology helps to provide reform to the environment and ameliorate societal well-being in the digital environment [67].

Furthermore, big data complement blockchain technology which smoothens data storage processing. It documents the record of data (i.e., digital) that allows shareholders to access informative data that are confidential [68]. When data input is made in the blockchain, modifications cannot be made or changed. Data in blockchain technologies are highly secured due to the database privacy that is programmed with a set of rules to enhance performance function [69]. Blockchain technology is a leading technology that is distributed in an asset chain for a financial transaction that entails a tangible or intangible process that is virtual to meet a business performance [70]. When combined with smart equipment or (IoT), it becomes an advanced tool to intensify the quality of companies' green innovation performance that is based on the progress of technological improvement [71]. Due to this, companies can prepare network sharing by blockchain for real-time expansion. Nevertheless, (IoT) is being embraced by different companies across various industries due to the innovative trend it presents to modern-day enterprises for business performance. It is fully utilized in home automation, healthcare, transportation and industries with the connection of satellite as a network tool. It is used in software and hardware tool, cloud computing and others. With the help of smart technology, companies can streamline their collaborators to exchange or share valuable information without involving human interactivity. This encourages high-yielding green innovation behaviour, and at the same time enhances green innovation performance. Furthermore, in companies' activities, productions should be built in such a manner that the surrounding environment is safeguarded to meet green innovation ethical standards.

As per Eslami et al. [72] quality management system will improve the production process. In the production lifecycle, green innovation performance led to ethical sustainable operation when ecological standards are utilized [73]. Researchers like Zhao & Zillante [74] argued that employee skill is a critical factor in innovation competence. Another study, see Yang & Roh [14] found that green innovation performance and Internet 4.0 are the important tools that drive innovative behaviour based on investment and awareness in the business process. This implies that the resources of smart technologies are important in driving green innovative behaviour and green innovation performance. Industry 4.0 technologies are a tool that promotes manufacturing operations and protects the environment, as well as eases the manufacturing process while utilizing assets for product improvement. Therefore, the study put forward the following hypotheses:

Hypothesis (1a). Industry 4.0 positively impacts green innovation behaviour.

Hypothesis (1b). Industry 4.0 positively impacts green innovation performance.

2.3. Open innovation

Open innovation constitutes conventional and prospering accession to new product development to enhance innovation performance [75], which attributes consciously to help manage the flux of new resources beyond companies' borders to meet a performance [76]. Open innovation has expanded to other relevant domains, for instance, in the examination of financial services like FinTech using an integrated approach to financial improvement [3]. In the exploration of global investment portfolios to overcome oil spillover in the emerging market through eco-friendly clean-up [77]. Lastly, it has also helped to predict future sustainable growth [78]. Open innovation is a model that allows emerging business to strive and strengthen a structure in the innovation ecosystem which utilize the network of an external tool while focusing on developing internal core competence for green innovative performance [14]. Open innovation is an inter-company framework that helps companies to innovate economically without cumulating internal knowledge, but instead utilizing external knowledge to improve and innovate existing products or services [79]. Open innovation has restored the traditional competitiveness among enterprises or companies with the introduction of green innovation performance and green innovation behaviour among cooperation within the ecosystem on a collaborative concept [75]. The dominance of green innovation has advanced emerging technologies even more than previously thought, which has accelerated the significance of the open innovation approach.

The concept of open innovation provides an internal and external resource, combined with a coupled process for the innovation process. It is a new and modified process to improve business performance through resource distribution while avoiding environmental issues. Internal resources initiate the flux of companies' internal resources to their partners. These inflows of resources create sufficient outward values. Whilst, inflows with smart equipment on the application of green innovation behaviour eliminate the hurdle on a company's share assets with external shareholders to enhance sustainable performance [80]. External resource entails external resource inflow from associate companies to internal companies. This process is obtained through cooperation with an external collaborator to improve inner resources [81]. The design process is a linked process using internal and external resources in developing co-creating to gauge innovative projects [82]. The coupled process is a connection between an internal and external resource in affinity with complementary working firms during the cooperation for successful process implementation. Open innovation inhabits multiple collaborations with external shareholders to help enhance internal knowledge with the use of external knowledge, which influences a

significant role in developing the accomplishments towards teamwork. The accomplishment helps to support companies in implementing green innovation for better performance within the company's innovative culture [83]. Due to this, the process of innovation behaviour will become sustainable, enduring and long-lasting while performing collaborative and innovative-based interconnection with external partners [84]. These connections are focused to improve green innovation behaviour which eventually enhances sustainable resources in the end [84]. For instance, sustainable resource help to decrease waste within manufacturing companies' while safeguarding the environment. Therefore, companies should implement corporate innovative measures through green process innovation to improve the corporate image. Open innovation is among companies' strategies to drive efficient sustainable green innovation behaviour and performance while enabling a smart environment [28,84].

Many studies have highlighted the importance of external collaborators [82,85,86] regardless of smart technology application [76–78]. Although, research in the body of knowledge is predominantly at the managerial level [87] providing different findings. Researchers like Sisodiya et al. [88] discover that the flow of smart technologies benefits companies through resource entry and intercompany connections with the involvement of external technological tools [89]. Yet, some study identifies the cost of development and inefficiency for companies running through smart innovation [90]. Recent research calls for the investigation of smart technologies and innovation in the implementation of green innovation with retail base cooperation to understand the perspective [91]. Research has acknowledged open innovation solutions under ecological assets to meet performance [92]. Based on this perspective, open innovation is instrumental in promoting sustainable innovative behaviour and performance which contribute to environmental sustainability. Therefore, the study makes the following hypothesizes:

Hypothesis (2a). Open innovation positively impacts green innovation behaviour.

Hypothesis (2b). Open innovation positively impacts green innovation performance.

2.4. Green innovation performance

Undoubtedly, green innovation has extended to businesses across the globe and is posited as satisfying customers' unique principal needs of a sustainable network providing requirements to established infrastructure in companies that can assess natural resources. In addition, green innovations have increased extensively and are regarded as sustainable designs for innovative performance [36]. Sustainable innovation is habituated to ameliorate and boost resource utilization to attain optimal societal norms which may provide benefits to humanity [25]. Eco-innovation is a new procedural innovation for business performance or otherwise green products innovation which promotes sustainability throughout the entire life cycle. This process involves emission control, cleaner production, environmental performance, pollution prevention and environmental recirculation with a new measure adding to environmental insight for product and service development [27]. The purpose of products to improve environmental stability could be referred to as green product innovation. This study conceptualized green product innovation to influence green product behaviour which has earned a lot of attention among policymakers and researchers. Therefore, it is important to reduce natural resource utilization by implementing both aspects to complement smart technologies.

Researchers like Yang & Roh [14] have cross-examined and also argued the practicability of eco-innovation, and failed to notice the additional weight on reducing cost implications towards innovative behaviour. Although, automation is obtainable through innovative systems to enhance corporate or manufacturing performance in a circular economy [2,93]. Emerging companies have chosen to embrace green innovation with the inclusion of new technology to solve environmental challenges and meet ecological regulations [94]. Compared to the additional conformation of technologies, smart innovation is more presumable to band together manufacturing resources due to the adaptability of the green resource [6]. The conformation of green innovation offers businesses the efficiency to reduce costs, minimize environmental issues and encourage businesses to step up their environmental goal in a positive direction [95]. Therefore, eco-innovation should be imperishable in its contribution to tackling ecological problems other than just being a form of innovation for new businesses. Every business should be actively concerned to enhance the performance of these initiatives while embracing green innovation behaviour. Collectively, drawing on this perspective, the research argued that collaboration that supports eco-initiatives is important for performance that is environmentally friendly considering the impact of sustainable behaviour in the manufacturing sector. Similarly, research shows that green innovation culture significantly impacts green innovation behaviour [96]. The research recognizes the influence of smart technology and innovation performance towards sustainable innovation.

In addition, Mitcham [97] believes that an innovation culture decreases unwanted activities associated with technological products. Friedman & Kahn [98] depict that technical personnel's moral and ethical values will effectively help to solve uncertainty. While Strong et al. [99] submitted that ecologically conscious companies are no doubt going to enhance customer contentment amidst the provision of quality products that are free from pollutants. Green innovation behaviour will strengthen companies' awareness and attitude about environmental challenges. This is a prerequisite for companies to engage and embrace eco-innovation. Nevertheless, green innovation behaviour is considered an organic mixture with several values such as ecological, technological, economic, social, and humanistic values to transform technological innovation [100]. Subsequently, sustainability has been put into a sequel sequence processing towards economic resources. Thus, it is important to promote the recycled and upcycle approach to enhance green innovation performance. The awareness is to develop green innovation behaviour among new businesses and people. Green behaviour impacts the decision-making process of any core business [101]. The evolution of eco-innovation behaviour is bound to additive support of manufacturing technology and improve effective innovative performance. This practice led to sustainable development growth on carbon reduction, consistently boosting clean energy and providing a solution to technology for the people [102].

Furthermore, drawing on this perspective, the growth of productivity (e.g., goods and services) in the manufacturing industry will be strengthened by embracing green innovation behaviour [103], and environmental sustainability to build a positive ecological

image and goodwill message [104]. Research has submitted that policymakers in the manufacturing sector should focus on the technical aspect of a sustainable supply chain to meet green innovation performance most especially in the developing market [105]. Nevertheless, information technology coupled with environmental consciousness as well as policy regulation is the main instrument to enhance circular economic performance [106]. Therefore, businesses can improve green innovation performance and behaviour towards smart technologies. Based on the perspective highlighted above, the study makes the following postulation:

Hypothesis (3a). Green innovation performance positively impacts green innovation behaviour.

Hypothesis (3b). Green innovation performance mediates Industry 4.0 and green innovation behaviour.

Hypothesis (3c). Green innovation performance mediates open innovation and green innovation behaviour.

3. Methodology

To address the proposed research objective, a quantitative survey approach was applied using SmartPLSver3.0 statistical data analysis software to examine multiple relationships among the latent variables that examine the direct and indirect path for complete model assessment [107]. The SmartPLS3.0 procedure was used based on existing studiesby Bag et al. [2], and Tjahjadi et al. [108] providing a suitable context for this current study. The study further provides a details flow chart of research steps presented in Fig. 1.

3.1. Conceptual model

As maintained in the literature, the conceptual model (depicted in Fig. 2) was conceptualized, such that the relationship between latent constructs was examined as direct and indirect relationships were shown.

3.2. Selection of data

A quantitative research approach was applied for data selection which strongly depends on choosing carefully a ratable approach to calculate the hypothesized relationship among variables that are investigated [109]. The target sector was mainly the manufacturing and production industry such as (food and beverage, electric components, paper products, rubber and plastic products, chemicals and others). Observing this aspect of the manufacturing sector provides a suitable context for the study because the sector contributes above 36% of Malaysia's GDP [110]. Furthermore, we ensure the study was conducted under ethical principles and full consent was obtained from the target sector and participants in advance to ensure protection and privacy for research participants that agreed to take part in the study. In this process, data was collected among the estimated population from small, medium and big manufacturing/production industries in Malaysia through the convenient sampling method [111]. Following the previous study, the target

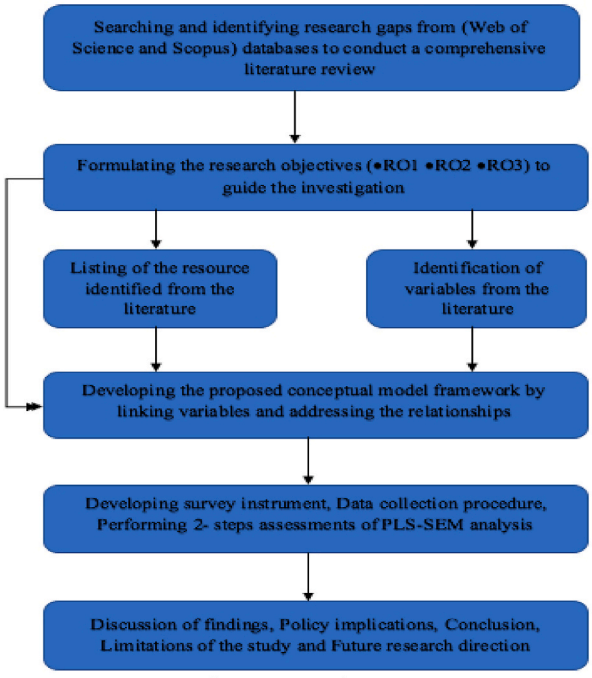

Fig. 1. Research steps.

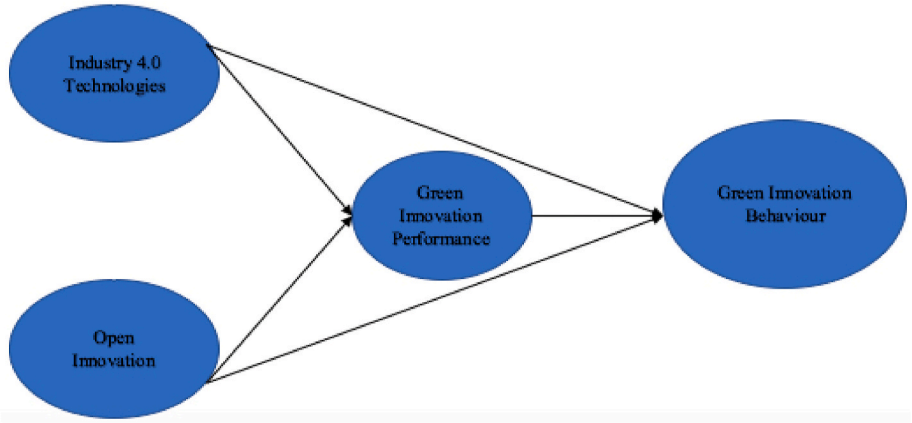

Fig. 2. Proposed conceptual framework.

respondents were top managers who hold relevant positions such as (CEO, senior manager, brand manager, operating officers, R&D supervisor, and others). These respondents provide reliable information on issues relating to the investigation under study. The age (years) of these companies was also captured in the study to know how long it has been in existence. Table 1 presents the sample characteristic and 300 questionnaires were distributed face-to-face. To this end, only 247 were returned and were used for the analysis. The sample size was adequate to conclude because it supports the sample size thumb rule of Hair et al. [112] guidance of a minimum of 150 sample sizes for the SmartPLSver3.0 approach. PLS-SEM is regarded as a high modelling approach that examines the link between the PLS algorithm and the Inner model with t-values.

3.3. Questionnaire development and measurement scale

The model was measured reflectively using a point 5-Likert scale, with 1 assigned "strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5 representing strongly agree". According to Sekaran & Bougie [113], the point 5 scale is more appropriate to understand people's opinions in quantitative research. Hence, the 5-point Likert scale help to reduce respondent resentment and increase the originality of the research data. To evaluate green innovation behaviour, 5 items from Li et al. [7] and Peng et al. [36] were applied. Industry 4.0 were examined with 5 items which were revised from Müller et al. [114]. To examine open innovation, 5 items were revised from Mina et al. [15]. To evaluate green innovation performance, 5 items were revised from Yusr et al. [27]. The measurement items are presented in Appendix A. Consequently, a pilot study was run among 40 respondents to confirm if the instruments were valid and dependable. The piloted results vary from (0.892–0.921), thus, satisfying the threshold value of 0.70 Hair et al. [112].

4. Analysis

The research examines the developed hypotheses that were model-reflective using SmartPLS3. The study uses PLS-SEM because it can address multiple dependencies associated with high statistical efficiency; and also, it offers the ability to handle a small sample size

Table 1
Demographic profile.

Sample characteristics	Categories	Frequency
Positions	CEO	45
	Senior manager	51
	Brand manager	30
	Operating officer	36
	R&D supervisor	63
	Others	22
Industry (manufacturing companies)	Food and beverage	91
	Electric components	80
	Paper products	15
	Rubber and plastic products	30
	Chemical products	22
	Others	9
Industry age (years)	<5	125
	6–10	80
	11–15	25
	16–20	10
	>21	7

with a highly robust result [115]. Also, we applied SPSS 22 to calculate the demographic data (see Table 1). The study examines the impact of Industry 4.0 technologies, and open innovation (independent variables) on green innovation behaviour (dependent variable). Green innovation performance considered an independent variable, also plays the role of mediator which also influences the dependent variable of green innovation behaviour.

4.1. Common method bias

The research examines common method bias using Harman's single-factor check. If the summation of variation for a single factor meets the threshold of (<50%), implies no problem of common bias in the research, but if (>50%) there is an issue of bias in data [116]. However, our study found (28.82%), meaning no issue with bias in the research data conforming with the guidance of a single factor check.

4.2. Sample characteristic

A sample of 247 respondents is presented which shows a majority are R&D supervisors (63), followed by the senior managers (51) and CEOs (45) respectively. The majority of respondents are in the food and beverage industry (91), followed by electronic (80) and rubber and plastic products (30) industry respectively. Similarly, all the target sector has adequate manufacturing experience as the majority are aged up to 5 years (125), followed by 80, aged up to 6–10 years, 25 aged up to 11–15 years, 10 age up to 16–20 years and 7 above 21 years respectively.

4.3. Measurement model assessment

In assessing the reflective measurement model, four-step were followed; (i) the assessment of validating reliability on threshold >0.70, (ii) the indicator reliability of an adequate loading of >0.4 and above, (iii) the assessment of convergent validity with an adequate threshold >0.50, and (iv) the discriminant validity procedure using Fornell-Lacker and Heterotrait-Monotrait Ratio (HTMT) method. Further, the assessment presented in Table 2, shows all indicators meet the guidelines [117].

Table 3, present the Fornel-Larcker approach which confirmed the root of AVE is higher than its correlation among each construct. The outcome shows that the latent constructs attain adequate discriminant validity considering the root of the AVE which is significant to the interconnection off-diagonal in the constructs [118].

Table 4, present the Heterotrait-Monotrait Ratio (HTMT) which suggests each construct should be <90% to attain adequate discriminant validity [119]. This study shows that the discriminant validity (HTMT) check is attained as the construct meet the standard guideline of the HTMT check fulfilling the recommended threshold.

4.4. Structural model

The second stage of the SmartPLS3 assessment includes five steps that were observed [117]. Further, our study also assessed the check on the (R^2) -coefficient determinant, (f^2) -effect size, and (Q^2) -relevance of predictiveness. Moreover, the corresponding *t-values*. However, all the results of (R^2) revealed a substantial 0.591, meaning the model explains 59% of the variance influencing green innovation behaviour; thus, outer loadings display (R^2) value as presented in Fig. 3. The (f^2) known as the effect size was performed to

Table 2
Measurement model.

Constructs	Items	F.L	CA	CR	AVE
Green Innovation Behaviour (GIB)	GIB_1	0.844	0.840	0.878	0.591
	GIB_2	0.710			
	GIB_3	0.670			
	GIB_4	0.763			
	GIB_5	0.842			
Green Innovation Performance (GIP)	GIP_1	0.858	0.879	0.910	0.670
	GIP_2	0.849			
	GIP_3	0.823			
	GIP_4	0.713			
	GIP_5	0.840			
Industry 4.0 Technologies (1T)	IT_1	0.796	0.871	0.906	0.659
	IT_2	0.786			
	IT_3	0.874			
	IT_4	0.797			
	IT_5	0.802			
Open Innovation (OI)	OI_1	0.811	0.876	0.909	0.666
	OI_2	0.767			
	OI_3	0.842			
	OI_4	0.855			
	OI_5	0.803			

Table 3
Fornell-Larcker procedure.

Constructs	GIB	GIP	IT	OI
GIB	0.769			
GIP	0.369	0.818		
IT	0.328	0.324	0.812	
OI	0.304	0.332	0.491	0.816

Note: The diagonal is the root of AVE. **GIB** = Green innovation behaviour, **GIP** = Green innovation performance, **IT** = Industry 4.0 technologies, **ON** = Open innovation.

Table 4
Heterotrait-Monotrait Ratio (HTMT) procedure.

Constructs	GIB	GIP	IT	OI
GIB				
GIP	0.352			
IT	0.336	0.353		
OI	0.268	0.343	0.554	

Note: GIB = Green innovation behaviour, **GIP** = Green innovation performance, **IT** = Industry 4.0 technologies.
ON = Open innovation.

figure out the effect of exogenous variables in explaining the variance of endogenous variables as suggested by literature support such that 0.02 was considered small, 0.15 considered medium and 0.35 was considered substantial [120]. Results show that green innovation performance exerts a small effect size of ($f^2 = 0.077$) in explaining the variance of green innovative behaviour. In addition,

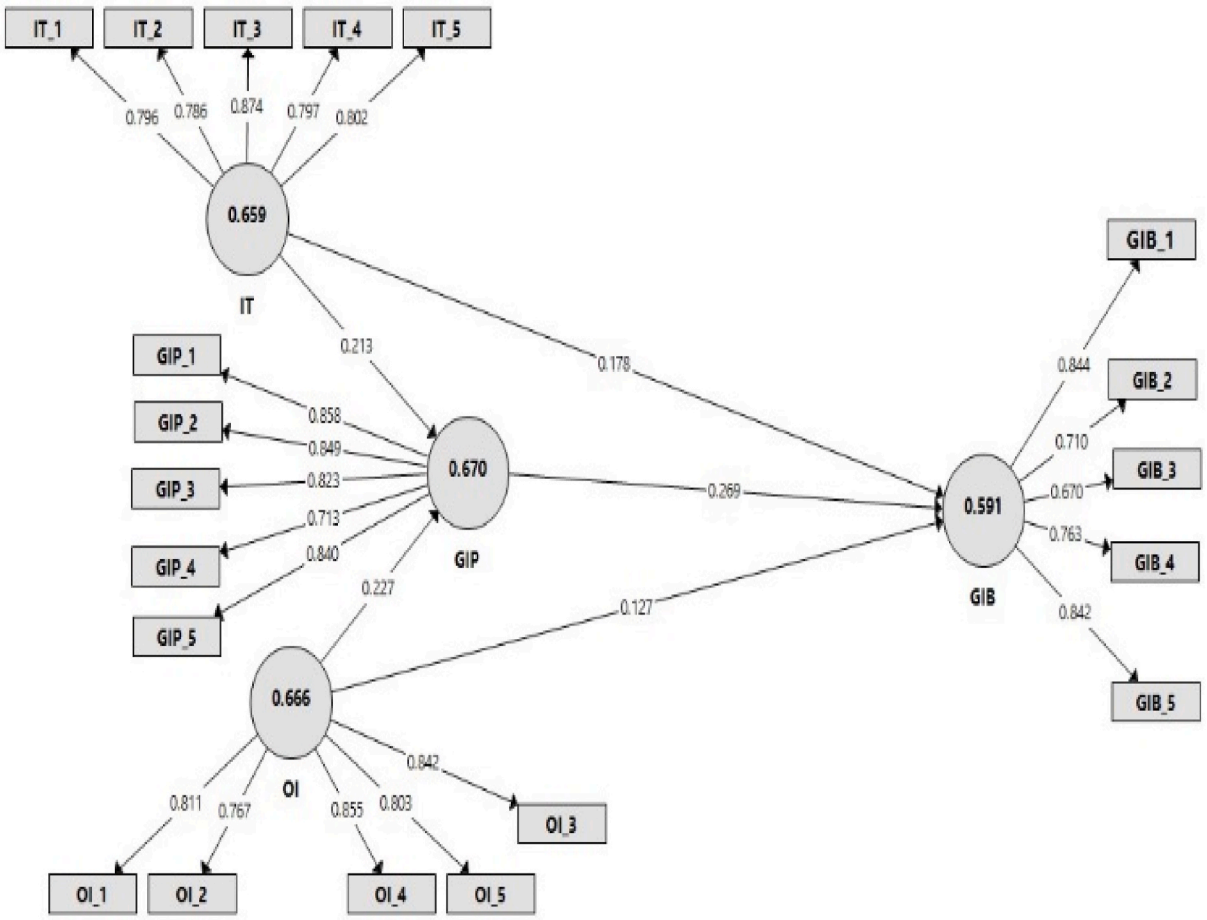

Fig. 3. Outer loadings (PLS-Algorithm).

Industry 4.0 exert a small effect size of ($f^2 = 0.029$) in explaining the variance of green innovation behaviour, while open innovation also exerts a small effect size of ($f^2 = 0.014$) in explaining the variance of green innovation behaviour, as presented in Table 5. The collinearity was <3, meaning no collinearity problem as presented in Table 6. Next, the predictive relevance (Q^2) for endogenous variables which is 0.088 and 0.397, which is higher than (0) indicates sufficient relevance of predictiveness in the study [117] as presented in Table 7.

Furthermore, Table 8 presented the proposed hypotheses and must be supported at $p < 0.05$ and $t > 1.96$ [117]. According to the hypotheses obtained, the result for the first prediction (H1a) (β-value = 0.178, p-value = 0.024) is supported. Similarly, (H1b) (β-value = 0.213, p-value = 0.018) is supported. However (H2a) examines open innovation and green innovation behaviour (β-value = 0.127, p-value = 0.134) is rejected. (H2b) examines open innovation and green innovation performance (β-value = 0.227, p-value = 0.001) is supported. Furthermore, (H3a) examines green innovation performance and green innovation behaviour (β-value = 0.269, p-value = 0.000) is supported. In addition, the structural model depicts the inner t-values for the supported and insignificant path as shown in Fig. 4.

In extension to that, the role of "green innovation performance" as a mediator, on the model using Boot-strapping techniques with 5000 subsamples [117]. As per the mediation in (H3b) (1T → GIP → GIB) - (β-value = 0.057, p-value = 0.036), (H3c) (OI → GIP → GIB) - (β-value = 0.061, p-value = 0.018), is supported, meaning green innovation performance exhibits a substantial mediating impact between the independent variables (such as Industry 4.0 and open innovation) and green innovation behaviour as the level of acceptance meets the threshold values presenting a significant path. Table 8 highlights the results.

5. Discussions

Despite the recognition of green innovation behaviour, guidance towards Industry 4.0 and open innovation remains an understudied aspect that is important to executives or managers in the manufacturing industries [121]. In addition, understanding how the impact of green innovation behaviour can be implemented to attain success in the social-economic area of environmental regulations [122]. In response, the study answered the call by examining the impact of smart technologies on green innovation behaviour in the manufacturing sector. The role of green innovation performance was simultaneously considered as a direct predictor of green innovation behaviour and the same time a mediator, and the study highlights the importance of these aspects in innovation performance to build corporate advantage [10]. Following the samples collected from different respondents in the manufacturing sector, our findings indicate that Industry 4.0 and eco-innovation performance positively influence green innovative behaviour, and the hypothesis was supported. This means technological change heavily depends on green innovation behaviour to improve business performance, suitable for manufacturing companies to strive for. In addition, the results demonstrate that implementing smart technologies will enable higher productivity in the manufacturing sector. Further, smart technologies can help managers to build up products and services which ultimately improve innovation performance. Consequently, the results from the study correspond with past studies [2, 123,124] which examine similar factors of smart technology in a circular economy. However, open innovation does not show an obvious impact on green innovation behaviour. There could be the reason that employees' involvement in setting up innovation networks and hubs with other firms could not reflect the attractiveness of green innovation behaviour, but could motivate them in sharing facilities which are not sufficient to engage in green innovation behaviour. Our study has some policy implications that aid the uncovering of further insight.

5.1. Policy implications

The study has several contributions theoretical and practical to advance research on green innovation behaviour. This shows that integrating smart technologies in the manufacturing industry would build business capabilities and strengthen market performance in the manufacturing sector. In addition, the most important resource found in the study is that smart technologies i.e., Industry 4.0 technologies and open innovation is used to understand and examines the impact of green innovation performance, and give significant resource in the formation of green innovation behaviour. These measures are considered critical input to manufacturing companies to discharge tasks. This insight contributes to green innovation behaviour capabilities by restoring the functional mechanism, belief and knowledge that could assist in establishing a strategy to stimulate companies about the performance implication of green innovation behaviour [103]. The result indicates a remarkable influence of smart technologies on green innovation behaviour in which manufacturers can develop companies' competitive advantage in that instance. Hence, the industry technology requires effort with companies' support being the key requirement for managers to fulfil the business task with a focus on sustainable production. The study considers green innovation performance as a mediator to unlock innovation behaviour. Green innovation performance in the digital era has been described to improve the business model and accelerate the inflow of open innovation. Although, green innovation behaviour should be maintained with the consideration of green technology to expand the use of green innovation initiatives to attain

Table 5
Effect size (f^2).

Exogenous Variables	GIB	GIP	Effect
GIP	0.077		Small
IT	0.029	0.040	Small
OI	0.014	0.046	Small

Table 6
Collinearity.

Exogenous Variables	Green Innovation Behaviour	Green Innovation Performance
GIP	1.169	
IT	1.371	1.318
OI	1.378	1.318

Table 7
Predictive relevance (Q^2).

Endogenous Variables	CCR Q^2 (=1-SSE/SSO)	CCC Q^2 (=1-SSE/SSO)
Green Innovation Behaviour	0.088	0.397
Green Innovation Performance	0.085	0.505

Table 8
Path coefficient (Direct effect) and (indirect effect) result.

Hypotheses	Beta/OS	95% confidence interval bias corrected		T-value	*P*-value	Decision
		LL	UL			
IT → GIB	0.178	0.030	0.337	2.261	0.024	Significant
IT → GIP	0.213	0.028	0.372	2.367	0.018	Significant
OI → GIB	0.127	−0.061	0.280	1.503	0.134	Not Significant
OI → GIP	0.227	0.081	0.353	3.239	0.001	Significant
GIP → GIB	0.269	0.128	0.399	3.802	0.000	Significant
IT → GIP → GIB	0.057	0.012	0.119	2.101	0.036	Significant
OI → GIP → GIB	0.061	0.022	0.119	2.372	0.018	Significant

Note: *$p < 0.05$.

competitive advantage [125–128].

Furthermore, research towards green innovation has distinguished its relative lack of factual investigation of these aspects. Further studies are needed to delve into the impact of green innovation performance [75]. Hence, the research helps to pervade the research gap while investigating these aspects simultaneously to improve business performance in the manufacturing sector. However, with a focus on the environmental perspective, our study has discussed the role of green innovation behaviour to improve business performance to ameliorate the manufacturing industry [21]. Nevertheless, drawing on the findings from our study indicates a significant impact on these relationships to improve businesses, eliminate unethical practices and further promote green innovation behaviour; in line with a recent study [81,129]. Nevertheless, green innovation performance is important, impacts green innovation behaviour and significantly contributes to sustainable businesses in the manufacturing sector to attain competitive advantage [130]. Many studies have argued about the technological aspect in connection to smart technologies as a complement to environmentally friendly innovation performance and open innovation as well as green innovation behaviour [131,132]. Drawing on these conclusions, our study suggests that companies should encourage collaborative technologies that mainly focus on sustainable practices to promote green innovations.

For instance, smart technologies can be absorbed to enhance and improve business performance [133]. Managers must increase the application of innovative technology to improve dynamic production and green innovation capabilities. This approach will help advance smart innovations that are environmentally friendly as well as regulate environmental policies on green bonds, and tax preferences among others. In addition, it will help managers offer tax incentives for green innovations and technology; and will also help companies to reduce excessive costs and other benefits that are sustainable. The impact of innovation behaviour will boost technological innovation and manufacturing performance in the socio-economic environment through the building of productive capacity in an unsettled business environment. Indeed, these aspects will help companies eliminate the poor result of green innovation behaviour as green innovation could be unpredictable for companies' employees; as they could fail or succeed and need to face these unknown challenges. Although, Industry 4.0 technologies can be functional in improving manufacturers' operations to automate production. Therefore, decision-makers need to gauge green innovation on technological tools using these platforms presented. This reveals the explicit nature of sustainable innovation to enhance performance. Hence, the dynamism of green innovation behaviour can improve manufacturing operations while enhancing greenness in the production or manufacturing industry. In addition, building an organizational environment and principles that support green innovation, for instance, the transition from a traditional approach to green innovation mode will help change the understanding and ways of employees' green innovation intention. Companies need to promote the ideology of environmental protection - consumers' mental and public health that will improve and accomplish green innovation behaviour.

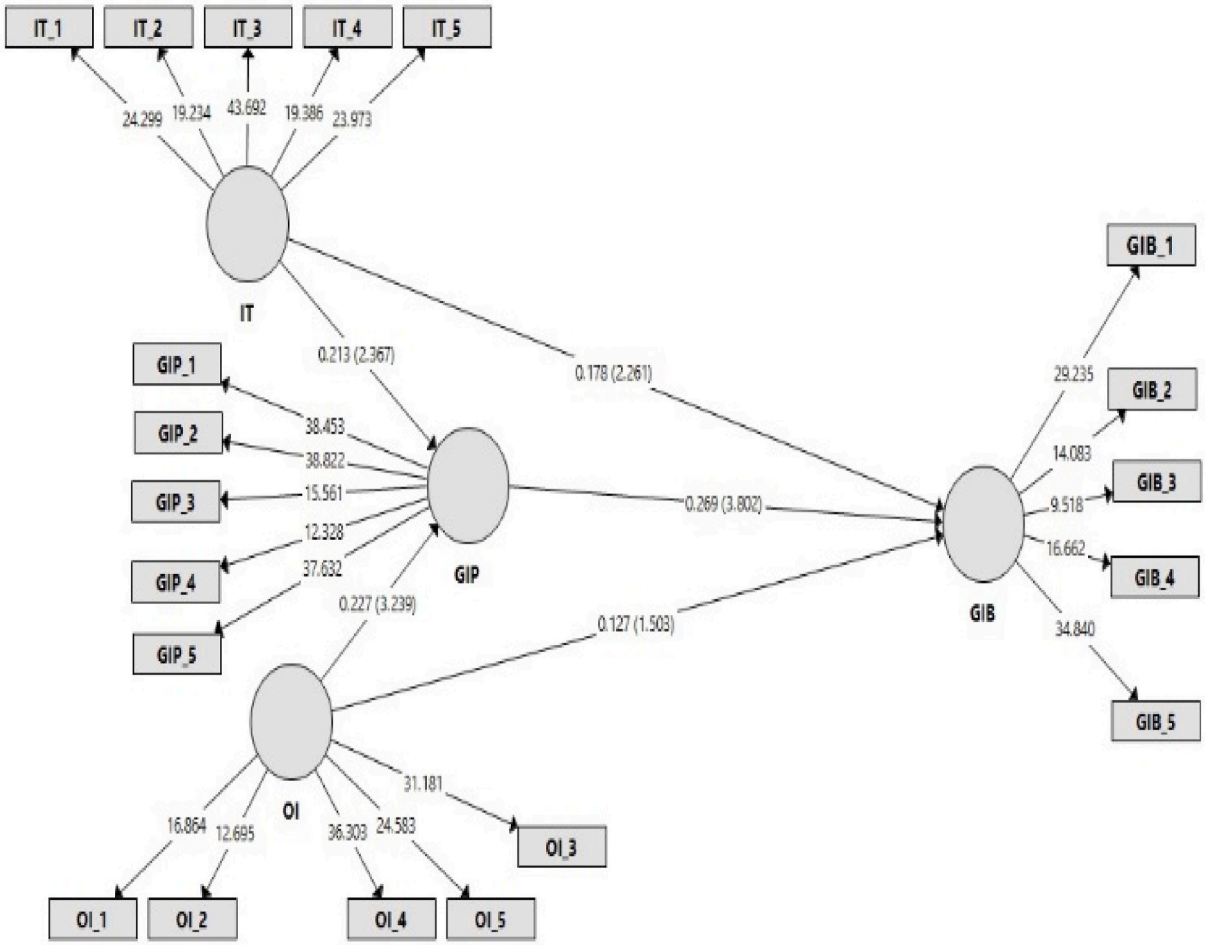

Fig. 4. The structural model with inner model t-values.

5.2. Conclusion

The study strives to develop a theoretical model connecting the essentials of smart technologies, green performance and behaviour. Although, debate on literature review allured key recognition of measures that enhance green innovation behaviour. This study provides contributions to the particular field in both academic work and industry in the aspect of green innovation in businesses and to the environmental perspective that are important to both government, managers, business and academics. In addition, the lines of research go with the discussion and guidelines of the sustainable development goal highlighting sustainable manufacturing and production of the United Nations program. Drawing on the findings, the inquiry specifies that eco-innovation is an important aspect that can improve business performance and provide succour to the environment. Therefore, it is exigent and compelling to positively encourage behaviour that is innovative and friendly and push for sustainability in the manufacturing sector. Recall the present survey looking into the impact of smart technologies on green innovation behaviour. In addition, the indirect impact of green innovation performance. Although, all direct and indirect relationships had established a clear relationship except for the link between open innovation and eco-innovative performance when the study was conducted. However, to deepen the understanding, the manufacturing industry can introduce green innovation from outer sources to strengthen open innovation. This means, that manufacturing companies can collaborate with other companies to improve the mechanism between smart technologies and green innovation behaviour. Although, challenges with smart technology - i.e., open innovation cannot be ignored.

The study suggests that strengthening environmental competencies is key to green innovation approach. This approach should be extensively applied under high-level management for manufacturing innovation to enhance the inflow of open innovation and gain a competitive advantage. The study anticipates recommendations for stakeholders according to related ecological and technological regulations to advance sustainable innovative or eco-friendly behaviour in the manufacturing sector. Given the small, medium and big manufacturing industries captured in the study, the current research further suggests other designated areas of the manufacturing sector to know the volume and value of performance that support eco-initiative and behaviour level by providing a continuous innovative process in the manufacturing agglomeration which lays a strong foundation for sustainable development. From the

theoretical perspective, the study helps in constructing an index factor for a model that impacts and reduces harm to the manufacturing ecosystem and improves written works on green innovation performance with technological innovation. Nevertheless, controlling smart technologies possess an influential path for manufacturing companies to embrace green innovative behaviour. However, attributable to the control of the company's technology and regulations, green innovation performance is more effective, and will considerably influence green innovation behaviour. Hence, have a higher advancing control on green innovation behaviour. Furthermore, the green innovation behaviour of companies can be more promising when companies change how they cooperate with other companies while developing the prospect to engage in green innovation. Nevertheless, the collective efforts of manufacturing companies help to ameliorate green innovation in different areas of the supply chain. In addition, it reduces costs and stimulates interest in companies' green innovation on a sustainable roadmap.

5.3. Limitations

The inquiry has limitations for prospects. For instance, the performance for green innovation behaviour may be different for other manufacturing companies as those with high capability for green innovation behaviour will possess stronger green innovation performance than others. Therefore, future research can examine the level of green innovation for different manufacturing companies to compare the differences. The survey in this study was cross-sectional. Future research should apply a longitudinal survey that can be measured repeatedly. Furthermore, future research can be made comparatively, since the current study only focuses on a single nation. Hence, a comparative study will aid the understanding of green innovation behaviour in various national backgrounds. Although the current study focused on getting reliable data to clarify and shed light on the issues, it fails to cover the transpolar region. Investigating much wider information sources would be recommended to permeate the borderline, and tend to assist in knowing green innovation behaviour mechanisms in a long run. The study examines constructs as conscientious as possible; these examinations were from suitable literature which was validated by experts, and are proxies for inestimable latent rarity. Future research should use additional items to produce good results for the constructs. The model from the study does not capture moderating role. Future research should consider that aspect in defining the task of green innovation in ecological influence. Lastly, the latent variables in this study accounted for 59% variance in the model; nevertheless, the inclusion of additional variables may yield a higher model variance.

Author contribution statement

Osarodion Ogiemwonyi: Conceived and designed the experiments; Performed the experiments; Wrote the paper.
Mohammad Nurul Alam: Performed the experiments; Analyzed and interpreted the data.
Ibrahim E Hago; Noor Azlinna Azizan; Fariza Hashim; Md Sazzad Hossain: Contributed reagents, materials, analysis tools or data.

Data availability statement

The data that has been used is confidential.

Additional information

The authors declare no conflict of interest.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Green innovation behaviour; Li et al. [7] and Peng et al. [36]
GIB_1. We actively engage in the development of green products and propose a suitable plan for the progress schedule.
GIB_2. We try our best to reduce possible harm from products to users in the product design.
GIB_3. We try to reduce technical risks and lower material waste in R&D.
GIB_4. We actively participate and follow "green" standards during product development.
GIB_5. When compared with other retail products, our products are more conducive to consumers' mental and public health.
Green innovation performance; Yusr et al. [27]
GIP_1. The manufacturing process of my company reduces the use of raw materials.
GIP_2. Non-polluting technologies are used to safeguard the environment.
GIP_3. The manufacturing process of my company reduces the consumption of coal, water and electricity.
GIP_4. The manufacturing process of my company recycles waste that allows them to be treated and reused.
GIP_5. We improve and design environmentally friendly packaging with (less paper and plastic material used)

for new and existing products.
Industry 4.0 technologies; Müller et al. [114]
IT_1. Industry 4.0 help lower and decreased overall cost through interconnection.
IT_2. Industry 4.0 allows an increase in the flexibility of production.
IT_3. Industry 4.0 allows increased quality and improve production capacity.
IT_4. Industry 4.0 allows decreased waste and environmental impact.
IT_5. Industry 4.0 allows friendly working environments for employees.
Open innovation; Mina et al. [15]
OI_1. We directly engaged with lead users and early adopters.
OI_2. We participate in open-source software development.
OI_3. We participate in setting up innovation networks/hubs with other firms.
OI_4. We engage in joint ventures and acquisitions.
OI_5. We engaged in sharing facilities with other companies, inventors and researchers.

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