



# Eco-innovation, sustainable business performance and market turbulence moderation in emerging economies

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## ABSTRACT

The study purports to empirically draw out the prominence of eco-innovation in achieving sustainability in business performances, which is further tested by the moderation of turbulent market conditions on the relationship. In contrast to previous eco-innovation research, a nascent methodology involving a dual-stage hybrid analysis and an emerging Artificial Intelligence (AI) technique, deep learning was used to analyze 683 viable responses from Ghanaian manufacturing firms.

Some intriguing conclusions were discovered where the dimensions of sustainable business performance are achievable vis-à-vis the implementation of product, process, and organizational eco-innovation. Notably, a manufacturing firm's environmental performance can be considerably improved by implementing the triumvirate of product, process, and organizational eco-innovation. Subsequently, a firm can improve its social performance by R&D investment in eco-innovations, novel green management practices and staff sensitization on eco-innovation. Lastly, market turbulence (technology and environmental turbulence) in the form of technological advancements, intense market competition, changing household demand and taste amplifies the positive effect of product and organizational eco-innovation on the economic dimension of sustainable performance.

Theoretically, a newly integrated theoretical framework, which incorporates eco-innovation, contingency and RBV theory, could aid in determining the relative importance of specific determinants, thereby providing significant contributions to eco-innovations effect on the sustainability of business performance.

## 1. Introduction

As the circular economy transpires into a new paradigm for sustainability, eco-innovation is becoming recognized as a critical mechanism for transitioning manufacturing processes. Nascent technologies, competition, and market demand for ecologically friendly business practices have become necessary sustainability components. But firms must determine whether their involvement in eco-innovation improves their sustainable business performance. However, this cannot occur in isolation and require a coherent response from households, firms-investors, and governments. Consequently, eco-innovation and sustainability studies have become a frequent topic of discussion in recent years [1,2]. Despite extensive research into the relationship between

eco-innovation and sustainability, the relevant literature, mostly from developed economies, has produced inconsistent findings [3–5] and does not fully address management concerns regarding eco-innovation and sustainable business performance. Inadvertently, these shortcomings concerning this subject remain unaddressed in emerging and developing economies with low-tech sectors [3].

For instance, a substantial body of literature indicates a positive relationship between eco-innovation and sustainability [6–8], while others indicate negatively insignificant or U-shaped relationships [9, 10]. Secondly, the literature on emerging African economies is limited in this area [11–13]. As a result of these contradictory findings, eco-innovation and its relationship with sustainability and the dearth of empirical studies in emerging economies ala Africa remain a matter of

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discussion, hence the demand for additional research.

Prior research often failed to distinguish clearly between various eco-innovation types [14]. For example, studies indicate that numerous eco-innovation types (e.g., process, product & organizational eco-innovation) represent a unique precursor [15,16] with performance implications [1,17]. As a result, studies on eco-innovation have produced inconsistent conclusions. Identifying a peculiar type of eco-innovation is critical to broaden our understanding and provide more precise results [1]. As a result, this research concentrates on eco-innovation types (product, process and organizational) as specific indicators of sustainable business performance.

Moreover, the contradictory findings reported in prior works may be related to the fact that sustainable business performance is measured differently in various countries [7,18]. The choice of appropriate metrics can impact sustainable business performance and eco-innovation relationships, as each of these metrics has distinct pros and cons. A one-fit all measurement model may also not be applicable as countries are at different economic spectrums worldwide. Per Ch'ng et al. [1] and Nilashi et al. [19], we adopt the triple bottom line proposed by Eklinton [20], which predicates sustainability measurement and usage both in research and making decisions. Corresponding to this notion, organizations must equitize economic, social, and environmental parameters to achieve sustainable business performance. Their study develops more appropriate indicators for examining the relationship between eco-innovation and sustainability. Most studies examining this relationship amongst firms have focused exclusively on either economic, social, or environmental rather than all three [8,9]. However, researchers have argued that true sustainability manifests equitably in economic, social, and environmental performances [21]. As a result, this study first examines the direct effect of eco-innovation on a firm's sustainability.

Consequently, the inconsistent findings imply that when examining sustainable business performance and eco-innovations nexus, it is worth considering market turbulence moderation potential, as this may resolve the discrepancies between the primary constructs. Contemporary literature has long recognized a firm's resources as crucial in converting eco-innovation efforts into enhanced environmental, social, and financial performance [1]. As a result, this research has taken a resource-based view (RBV) approach and contingency theory (CT) to examine the potential moderation of turbulent market conditions on a firm's eco-innovation activities. We have concentrated on the resource-based view theory since it informs consumers and other stakeholders about a firm's eco-innovation activities and incorporated contingency theory, which is anticipated to amplify eco-innovation effect on the sustainability of business performances.

Ghana's manufacturing sector represents an ever-growing investment attraction compared to other industries. The country's infrastructure and innovation system represent the most important factors in sustaining and expanding the manufacturing industry. Sanni [13] asserted that manufacturing-related activities have a greater impact on the environment in developing nations (such as Ghana) than developed nations, hence the study's focus on sustainability indicators. According to Mady et al. [11], environmental targets have lagged substantially behind other SDGs in terms of progress. But Ghana has initiated study progress towards this initiative as The World Economic Forum and the Ghanaian government have joined forces to create Africa's first Country Financing Roadmap (CFR) for SDGs [107]. The roadmap is a country-led initiative to increase financing, especially from the corporate sector, to accomplish the SDGs by 2030. Funding for long-term, cost-effective infrastructure has been one of CFR's main priorities. The CFR was originally made available in Ghana as a model for other African countries.

Therefore, we expand limited eco-innovation literature based on the example of Ghanaian manufacturing industries by demonstrating the tentative relationship between the two fundamental constructs of eco-innovation and sustainable business performance under turbulent

market conditions. The researchers apply a stepwise Partial Least Squares-Structural Equation Modelling (PLS-SEM) and Artificial Neural Network Analysis (ANN) based on deep learning to produce extra detailed results than a single-step PLS-SEM approach and to address three research questions:

- RQ<sub>1</sub>: What effect do the dimensions of eco-innovation exert in sustaining business performance?
- RQ<sub>2</sub>: Do turbulent market conditions stimulate the eco-innovation nexus with sustainable business performance?
- RQ<sub>3</sub>: Does implementing a dual-layered (hidden) deep learning neural network improves the precision of non-linear relations in the research model?

The study espouses a threefold contribution to eco-innovation literature. First, this study adds to the body of knowledge by integrating market turbulence's moderating stimulus on eco-innovation and sustainable business performance relationship. Our study represents the first research in Ghana and Africa to analyze the impact of eco-innovation and sustainable business performance moderated by market turbulence, which is critical for providing information and feedback to managers and key decision-makers. Thus, this study addresses a theoretical and empirical gap, enabling company managers to understand better the effect of the various moderating factors of market turbulence (environmental turbulence and technology turbulence) to capitalize on and achieve improved sustainable business performance.

Second, the study contributes by emphasizing the significant role of moderators in response to recent sustainability scholars who have urged researchers to investigate the extent to which potential moderators influence the relationship between eco-innovation and the sustainable business performance of firms [22–24]. Tariq et al. [15] argued that some studies examined the combined moderation effect of turbulence (market turbulence and technological turbulence) on sustainability. However, their findings did not account for the autonomous effect of these factors, which are not always combined in a real corporate environment. Additionally, Ch'ng et al. [1] recently asserted that market turbulence does modify the association between eco-innovation and sustainable business performance. While these studies have advanced our knowledge of the subject, there are inconsistent findings and systematic deficient interest in the autonomous moderating role of market turbulence (technology & environment turbulence), a critical stimulator of sustainable business performance and eco-innovation measurement.

Third, in contrast to prior research on eco-innovation and sustainability that employed PLS-SEM in a single-phase analysis, our study extends the mode of computation by employing a stepwise PLS-SEM and ANN technique based on deep learning. Implementing a two-fold PLS-SEM and ANN technique based on deep learning is a novel approach for discovering combined relationships (linear and non-linear) between constructs. Likewise, it is recognized as a statistically superior strategy compared to classic SEM or PLS-SEM single-phase analysis. Additionally, the sensitivity analysis offers normalized significance using a multi-layer perceptron and an algorithm based on forward-back-feed propagation.

This study is predicated on the premise that turbulent market conditions in emerging African economies are catalysts for stimulating eco-innovation. As the excess of contemporary research focuses on western firms and industrialized economies, it is incumbent to propagate the agenda of emerging economies as they too are noteworthy contributors to the sustainability agenda as highlighted by the SDG goals [25]. Crucially, research findings from developed economies offer valuable contributions, but they must be validated in the context of emerging economies.

## 2. Literature review

### 2.1. The concept of sustainable business performance (SBP)

The triumvirate components of economic-environmental-social performance form the sustainability model termed Triple Bottom Line (TBL) [20,26]. Firms selected for this study had to consider all three dimensions because, without these important operational parameters essential for each firm's sustainability, they would be unable to establish genuinely sustainable innovations to stimulate market demand.

Securing the longevity and survival of a firm and its linked economic, social, and environmental components is a considerable concern for the present and future prospects [26]. It's a conundrum for several firms to shift their focus from an obtuse monetary gains (economic) model and be inclusive of environmental and social sustainability. As a result of business sustainability, three performance criteria must be examined. Firstly, economic sustainability pertains to a firm's ability to meet its needs and expectations in a financially sound manner. Secondly, social sustainability includes developing and realizing household demands and needs, including maintaining long-lasting social relationships. Thirdly, environmental sustainability alludes to preserving and renewing the ecosystem for current and future generations [27]. According to some scholars, all three are equally crucial for a firm's sustainability and improve general human well-being as they comply with the SDG's [28].

### 2.2. The concept of eco-innovation (EI)

Eco-innovations are expounded as the creation, integration, or appropriation of novel products, processes, services, organizational strategy for the firm (developer or adopter), resulting in a decrease of excess pollution, a risk to the environment, and adverse effects over its lifecycle [29]. The concept was developed by Fussler and James [30], defined as better use of resources to reduce negative ecological impacts while creating newer products and processes that benefit households and firms [31]. By implementing new ideas, habits, novel products, and procedures, eco-innovation advances environmental stewardship and sustainability goals [32]. According to Ghana's competitiveness and economic growth plan, eco-innovation is critical to accomplishing the stated goal. The notion, which was popularized primarily vis-à-vis Environmental Technology Action Plan (ETAP), seeks to incorporate novelty into products, manufacturing processes, business procedures, and services over a life cycle that precludes or significantly lessen the environmental risk, pollution, and other factors adverse effects of resource usage. Eco-innovations can improve the conditions of the environment without limiting economic growth when supported through a variety of public-private partnership programs and tax exemptions [33].

Several countries support achieving sustainable development goals throughout Africa while maintaining industry competitiveness and economic progress. Recent years have seen a surge in interest in eco-innovation as a means for industry and policymakers to accomplish more dramatic and systemic changes in the business environment to attain sustainable performance [11]. Numerous firms have begun to commit to sustainable development through concerted efforts to adopt and apply eco-innovation or similar alternatives [8]. Conversely, as industry and government both indulge in promoting eco-innovation in the interest of environmental and economic sustainability, the concept's scope and application often diverge. It encompasses not just process, products, organizational and marketing eco-innovations, but also social and institutional components that are novel [34]. Eco-innovation and its environmental benefits extend beyond the innovator's conventional organizational boundaries through changes in social norms, cultural values, and institutional structures [35].

### 2.3. Market turbulence (MKT)

Market turbulence is a significant component since it increases ambiguity and risk in business procedures and the causal relationship between business approach and performance. From a threefold theoretical viewpoint, market turbulence plausibly moderates the effect of eco-innovations on sustainable business performance [55]. First, the law of required variety implies that endowed firms would adapt to evolving market conditions to appropriately respond to environmental sustainability [36]. Household demand and market consumption need constantly shift, necessitating consistent innovations to acclimate a firm's operational responses to the needs [15]. Uncertainties and difficulty in foreseeing occurrences characterize turbulent markets [37]. A firm's strategy and business model are affected by environmental issues since they create both opportunities and threats. Hence, it is conceivable that innovative firms will adopt novel methods to leverage changing market demands swiftly and seize new product opportunities and new market niches [37]. When the market is in a state of turbulence, innovation is especially crucial to meet changes in household demand and needs [38].

Second, the innovative capability of firm's affords them the ability to merge, re-structure tangible and intangible asset portfolios uniquely, enabling them to establish the dynamic capabilities they need to counter threats or risks and seize opportunities within turbulent markets [39]. Thus, innovativeness is expected to be the modus via which a firm efficiently responds to market changes. When turbulent markets are prevalent regarding environmental development, firms may need to eco-innovate to attain sustainable business performance [40].

Thirdly, prior research has examined the role of turbulent market conditions in moderating the relationship between a firm's strategic competencies and competitive performance [41]. Recent studies state that eco-innovation can increase performance in market environments that are turbulent [39]. Though Chu et al. [39] explored eco-innovations link with the performance vis-à-vis market turbulence, the resulting independent measures for the role of turbulent market conditions as a moderator in the eco-innovation and sustainable business performance relationship literature requires additional examination. To that end, Maletic et al. [42] and Gyedu et al. [43] examined the effects of uncertain market conditions on organizational performance. Likewise, a few empirical studies have examined the moderating influence of turbulent market conditions on the different dimensions of eco-innovation and sustainable business performance, particularly from an emerging economy perspective.

## 3. Theoretical-conceptual framework & hypothesis

Based on RBV and Contingency theoretical integration, this study posits that turbulent market conditions stimulate eco-innovations effect on the sustainability of a business's performance. The research framework is depicted in Fig. 1, which summarizes the study's hypotheses.

### 3.1. Eco-innovation and resource-based view (RBV) theory

Neo-classical microeconomics is concerned with the way market forces influence the quantity, quality, and cost of a product and services supplied in a market. Neo-classical microeconomics is concerned with the way product cost, quality, quantity, and supply of services are influenced by market forces. When applied to economic agents (households or firms), RBV assumes that they are rationally bound maximizers of utility since marketplaces differ in their competitiveness and information is dispersed differently among markets [44]. According to Wernerfelt's [45] RBV theory, a firm's competencies are a unique blend of resources, capabilities, and knowledge.

Correspondingly, in the resource-based view, a firm's market power is maintained by its 'valuable', 'rare', 'inimitable', and 'non-substitutable' (VRIN) diverse resources [46]. RBV establishes sound theoretical

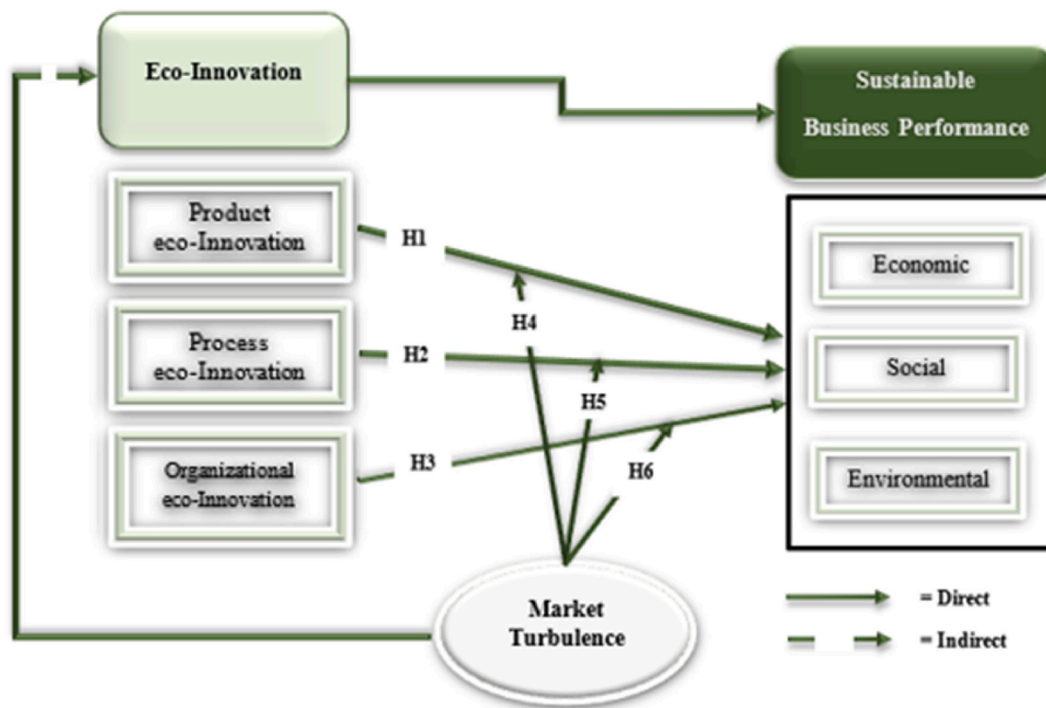


Fig. 1. Conceptual framework.

foundations for investigating the relationship between resources, capabilities, and performance. Most importantly, the RBV theory offers a comprehensive understanding of the eco-innovation concept [9]. Firm capabilities are an indispensable necessity, contingent on the environmental conditions under which the firm operates [47]. As firms are confronted with internal and external demands to adopt and implement environmentally responsible firm practices, it is increasingly incumbent for firms to develop eco-innovation capabilities [48]. Firms acknowledge that environmentally responsible business behaviour has become critical as they face challenges from government legislation, environmental pressure groups, and stakeholders [49]. Hamdoun [103] draws on the primary antecedents and effects of environmental management in the literature using the resource-based perspective (RBV). The authors employ a comprehensive evaluation of peer-reviewed journals included and excluded from the Scopus database up till 2018 to review and synthesize. A systematic literature review uncovered environmental management's primary antecedents and outcomes. Resources and capabilities, institutional and stakeholder pressures, business size, and the role of managers are the primary antecedents. Competitive advantage, company performance, particularly financial, economic, and environmental performance, and resources and capabilities are the primary outcomes of this research. Reviewing the resource-based view theory (RBV), Zhang et al. [47] were able to identify research gaps and uncover previously unexplored avenues for future environmental management studies, revealing the current state of the art in sustainability theory and practice.

In the long run, eco-innovation aids a business to build and strengthen its economic, environmental, and social sustainability and competitive edge. Hence, the viability of eco-innovation as a crucial strategic tool for achieving sustainable business performance is widely recognized among researchers because it satisfies RBV requirements [1, 50].

### 3.2. Market turbulence & contingency theory

The study purports to determine eco-innovations effect on the sustainable performance of businesses under turbulent market conditions.

Firms, as organizations, are susceptible to the pressures of their business milieu. More precisely, the contingency theory emphasizes the need to determine if and under what conditions contingency parameters contribute to a firm's sustainable performance [51]. As a result, firms must acquire and enhance their resources and strengthen their capacity to deal with turbulence in their markets. Firms that evaluate their business environment and establish strategies suited for each type and level of market turbulence are contingency-based firms that gain comparative advantages over their competitors [52]. Resource allocation needs to be calibrated to account for market turbulence's payoffs under uncertainty. For this to become feasible, it requires a firm's exchanges with the business environment to be fully integrated with an existing correlation between its dynamic capabilities and market turbulence [53]. As a result, contingency theory identifies the behaviour of firms that is necessary for their continued existence in turbulent and volatile markets [54].

When the firm's environment is stable, standard and routine operations and centralized decision-making procedures can boost efficiency. However, when the firm's environment is turbulent, the organizational structure becomes less efficient [54]. As part of a contingency model, companies gain knowledge by examining their business environment and establishing strategies suited for each type and level of market turbulence [55].

### 3.3. Constructs mapping

There are three eco-innovation types applied in the study categorized in the context of proactive and preventive solutions that meet environmental standards. They are product (e-Prod), process (e-Proc) and organizational (e-Org) eco-innovation.

#### 3.3.1. Hypothesis and conceptual framework

A process of considerably upgrading new or existing products to lessen their environmental impact is known as product eco-innovation (e-Prod). This innovation is implemented to reduce the ecological effects, satisfy market expectations, and enhance resource efficiency throughout the product's life cycle.

Product eco-innovation enables firms to earn a high return on investment (ROI) by inventing eco-products and capitalizing on market differentiation benefits [56]. Product eco-innovation enables steps that might cut the cost of production and offer the firm a comparative cost advantage [57]. Additionally, firms might acquire a first-mover advantage for novel eco-products through market establishment [11]. According to Yurdakul & Kazan [35], product eco-innovation may positively impact a firm's competitiveness and market share than process and organizational eco-innovation. Correspondingly, Ch'ng et al. [1] assert that, e-Prod can boost economic and environmental sustainability (performance), but its effects on social sustainability may be indirect. Additionally, the authors propose that the consequences of social sustainability may differ depending on the type of eco-product and the regulatory framework. In lieu, the study posits that:

**Hypothesis 1.** Product eco-innovation relates positively with the sustainability of a business's performance.

H1<sub>a</sub>: Product eco-innovation relates positively with the economic performance of a firm.

H1<sub>b</sub>: Product eco-innovation relates positively with the social performance of a firm.

H1<sub>c</sub>: Product eco-innovation relates positively with the environmental performance of a firm.

Process eco-Innovation (e-Proc) emphasizes technological and process modifications that increase manufacturing efficiency and distribution proficiency, resulting in cost reductions [58]. However, in other situations, investment in eco-innovation can result in financial losses when pursuing improved environmental performance. Hence, this is especially true for EOP solutions, as the substantial capital investment required to implement pollution control, cleaner production, and eco-efficiency, for example, may impede enterprises from increasing their market competitiveness [59]. The following hypothesis is proposed:

**Hypothesis 2.** Process eco-innovation relates positively with the sustainability of a business's performance.

H2<sub>a</sub>: Process eco-innovation relates positively with the economic performance of a firm.

H2<sub>b</sub>: Process eco-innovation relates positively with the social performance of a firm.

H2<sub>c</sub>: Process eco-innovation relates positively with the environmental performance of a firm.

Organizational eco-innovation (e-Org) refers to business model and practices, processes, re-design, roles, and responsibilities within the organization that aim to minimize adverse environmental impacts [60]. This innovation advances a firm's development and strengthens the technological eco-innovation components. Organizational eco-innovation (e-Org) strives to sustain and improve firms' environmental performance and resource efficiency and increase their social responsibility [1]. The objective is thus to improve a firm's overall ecological performance per the firm's ecological vision. Extant studies have been conducted to determine the association between e-Org and sustainability, emphasizing environmental performance. The findings suggest organizational eco-innovation is a crucial component that, when paired with the intrinsic characteristics of environmental influence, can considerably impact a firm's sustainable business performance [35].

Due to the application of organizational eco-innovation, firms gain technological and knowledge-based skills, and their economic performance conceivably increases [3]. According to Arranz et al. [40], firms gain a competitive edge through a mix of economies of scale, accumulated experience advantages, organizational eco-competences, and complementary assets. The study proposes the following:

**Hypothesis 3.** Organizational eco-innovation relates positively with the sustainability of a business's performance.

H3<sub>a</sub>: Organizational eco-innovation relates positively with the

economic performance of a firm.

H3<sub>b</sub>: Organizational eco-innovation relates positively with the social performance of a firm.

H3<sub>c</sub>: Organizational eco-innovation relates positively with the environmental performance of a firm.

Evolving household demand and fierce market competition, and the unpredictability in the timing of technology advancements fuel turbulent conditions within markets. Technological innovations and product development are congruent with short cycles, thus propelling technology capabilities to higher levels of desirability for firms' investment to stay competitive and maintain their market power in turbulent markets [61,62]. Among the significant contingencies highlighted are those concerned with the environment, technology, firm age, and firm size [63]. Thus, contingency theory holds that under turbulent market conditions, the capability of firms to respond to their business milieu affects their sustainable business performance [42]. In the manufacturing sector, market turbulence equilibrium and industry dynamics are driven by the synergy of emerging and established technologies, diversified, distinct, connected market needs, and innovation pressure [1]. Under turbulent market conditions, it is envisaged that eco-innovations amongst firms increases to navigate both opportunities and threats. In lieu, the study posits the following hypothesis:

**Hypothesis 4.** Turbulent market conditions enhance Product eco-innovation's positive relationship with the sustainability of a business's performance.

H4<sub>a</sub>: Turbulent market conditions enhance Product eco-innovation's positive relationship with the economic performance of a firm.

H4<sub>b</sub>: Turbulent market conditions enhance Product eco-innovation's positive relationship with the social performance of a firm.

H4<sub>c</sub>: Turbulent market conditions enhances Product eco-innovation's positive relationship with the environmental performance of a firm.

**Hypothesis 5.** Turbulent market conditions enhance Process eco-innovation's positive relationship with the sustainability of a business's performance.

H5<sub>a</sub>: Turbulent market conditions enhance Process eco-innovation's positive relationship with the economic performance of a firm.

H5<sub>b</sub>: Turbulent market conditions enhance Process eco-innovation's positive relationship with the social performance of a firm.

H5<sub>c</sub>: Turbulent market conditions enhance Process eco-innovation's positive relationship with the environmental performance of a firm.

**Hypothesis 6.** Turbulent market conditions enhance Organizational eco-innovation's positive relationship with the sustainability of a business's performance.

H6<sub>a</sub>: Turbulent market conditions enhance Organizational eco-innovation's positive relationship with the economic performance of a firm.

H6<sub>b</sub>: Turbulent market conditions enhance Organizational eco-innovation's positive relationship with the social performance of a firm.

H6<sub>c</sub>: Turbulent market conditions enhance Organizational eco-innovation's positive relationship with the environmental performance of a firm.

## 4. Methodology

### 4.1. Ethical approval

The study did not require ethical approval, and no official permission from a review board or Ethics Committee in Ghana was needed. The study was fully observational, and respondents participated entirely voluntarily in the survey. No compensation was offered to participating firms. All the respondents were above the age of 18. A cover letter introduced the researchers, explained the survey's objective, and

assured all participants confidentiality. Consent was obtained from each of the participating firms. The survey was conducted in accordance with Ghanaian law.

#### 4.2. Constructs and measurement items

The questionnaire was designed based on the Community Innovation Survey (CIS) and the World Bank's Enterprise Innovation Survey (EIS). The measurement items of the eco-innovation questionnaire were adapted from Ch'ng [1] and Fernando et al. [2]. Eco-innovation is assessed by the three dimensions of product eco-innovation (e-prod), process-eco-innovation (e-proc) and organizational eco-innovation (e-org). Four measurement items evaluate E-Prod, E-Proc is evaluated by three measurement items, and E-Org is evaluated by four measurement items. Three contingent measurement items are used to evaluate market turbulence. Sustainable Business performance is assessed by the economic, social, and environmental dimensions. Four measurement items evaluate the Economic construct, the social construct is evaluated by four measurement items and the environmental construct is evaluated by four measurement items. All the measurement items were evaluated on a 5-point Likert scale to operationalize the constructs where (1) signifies "strongly disagree" and (5) signifies "strongly agree" (see Appendix 1 for questionnaire containing research constructs and items).

#### 4.3. Data collection

To accomplish the study's objectives, the researchers applied a quantitative method and engaged manufacturing firms specializing in diverse fields in Ghana as the unit of analysis. Thus, an empirical study was required to compile the most up-to-date directory of manufacturing firms in Ghana. As a result, a non-probability purposive sample of businesses registered with the Association of Ghana Industries (AGI) and the National Board for Small Scale Industries (NBSSI) was collated. Firms were selected from the database as the dataset contains comprehensive information about the firms' eco-innovation activities over five years, from 2015 to 2020 — the database total sample frame comprised 2084 firms. The database of firms excluded firms that had not implemented any consistent form of eco-innovation during the period. We observed that the process of developing and adopting eco-innovations is not static but rather transcends time.

The sampling procedure consisted of three steps. The first step was to create a sampling frame from the listed databases (AGI, NBSSI). Firms selected from the database were allocated second identification numbers. The identification numbers issued to the firms were used to generate and select a randomized sample of respondents in MS Excel. The databases utilized for participant selection provided information about the firms that were used to contact the owners/managers. The sample size of 867 firms was selected using the sample size determination formula developed by Bartlett et al. [106].

The data included in the study came from primary sources, and a questionnaire was the primary data collection tool. The questionnaire was validated by industry and academic and industry experts in the eco-innovation domain. The questionnaire was pilot-tested on a limited sample at the request of the experts. The test survey was piloted to verify the design and construction adequacy of the questionnaire in gathering the data required to satisfy the research objectives. A random sample comprising sixty firms from Greater Accra were drawn and with enumerators surveying four firms each. The survey results for the pilot-test were satisfactory, the construct's reliability was 0.70 and above.

Fifteen enumerators were chosen from a pool of university teaching assistants familiar with data collection for research-related projects. They were trained purposely to gather the data for this study. Following the expert's approval and the pilot-test survey, the enumerators were dispatched to collect the necessary data. The questionnaires were delivered to the manufacturing firms that were sampled. Each

organization received questionnaires addressed to a senior management representative. The respondents included general managers, top-to-middle managers, and other senior to high-level assistants.

The questionnaire's section A included a cover letter summarizing the study's aim. The respondents' demographic information was presented in Section B, whereas the measuring items for each construct employed in the study were included in Section C of the survey.

The research objectives were summarized in the cover letter that accompanied the questionnaire. It is recommended that the general manager respond to inquiries directly or choose a qualified senior manager or high-level assistant on their behalf. Before the survey, the respondent firms were approached to increase response rates using the researchers' network. Data gathering was conducted in 2021, with enumerators paying visits to managers (experts) in four regions of Ghana (Greater Accra, Central, Eastern, and Ashanti) to fulfil their tasks. Each week completed questionnaires were coded and assessed for consistency using data analysis tools. In a few instances, the enumerators returned to the firms to verify the data's reliability—most cases included missing or faulty data entry. Thus, suitable criteria were decided upon before commencing to code the data. When the results of these procedures were compared, a concordance level of 96% was obtained. Where there were contradictions, a further researcher reviewed them, with ambiguous components analyzed in group discussions. These methods are comparable to meta-analyses used previously [64,65]. Consequently, 683 valid responses were obtained out of 867 questionnaires that were sent to the firms.

The data collection is limited to manufacturing firms in Ghana, and the sampled firms are a combination of various manufacturing categories in the AGI and NBSSI databases.

## 5. Results & discussion

### 5.1. Data analysis

The study utilizes PLS-SEM & A-N-N approach based on dual-stage deep learning to validate the hypothesized research models relationships [17,66]. This approach is divided into two stages. First, PLS-SEM usage identified significant predictors impact. Second, a deep learning A-N-N technique is used to determine the hierarchy of components vis-a-vis sensitivity analysis.

#### 5.1.1. A partial least squares structural equation modelling (PLS-SEM)

A PLS-SEM approach is applied to test the conceptual framework based on its ability to test complicated models for valuable insight [67], manage limited, aberrant, and irregular data [68]. PLS-SEM has been proven to be primarily effective for assessing the moderating impact among variables of constructs [69], is considered superior to covariance-based SEM [68,70]. There are two components to the PLS-SEM analysis: assessment of a measurement model and a structural model [66]. The inner model assesses the associational strength amongst variables, whereas the outer model evaluates the reliability and validation [68,71].

#### 5.1.2. The Artificial Neural Network (A-N-N) analysis

After validating both PLS-SEM components, an artificial neural network (A-N-N) is used to appraise, augment, and certify the PLS-SEM results. In predictive research analysis, the use of ANN is favourable as ANN alludes to a processor that can accumulate and apply knowledge. It is a computational approach that mimics how information is transferred in human brains [17]. Additionally, it is considered a functional approximation tool when the relationship between the input(s) and output(s) is non-linear and dynamic. Artificial Neural Network (ANN) comprises three primary mechanisms: network design or architecture, transfer function, and learning rule [72].

The three mechanisms have sub-components classified as feed-forward network, recurrent network, and radian bias [73]. The most

extensively used neural-network is the feed-forward multi-layer perceptron (MLP), which comprises numerous input-output layers. Both input-output layers are coupled through concealed nodes. A weight characterizes each concealed node. Essentially, the input layer comprises many neurons (independent variables) that acquire unprocessed data and transmit it to concealed layers via synaptic weights. Each concealed layer's output(s) is dependent on the activation function chosen; in most cases, sigmoidal function is frequently employed [74, 75]. Additionally, multi-layered neural network models are extremely complex and powerful, capable of resolving complexities in relatively higher-order models. Hence this study tests and trains the conceptual framework using multi-layer perceptron neural networks.

## 5.2. Results

### 5.2.1. Profile of respondents

As exhibited in Table 1, most of the participating firms are over ten years old (84.5%) and are long-established. Firms established over 20 years are 61.1% of the population, followed by those in operation for 11–19 years (23.4%), followed by 5–10 years (11.3%) and less than five years (4.2%). The definitive guide to firm size adheres to Hasan and Jandoc's [76] guidelines. The majority of participating firms are large (53.7%), and 34.8% & 11.5% are medium and small firms, respectively. The specializations of the top three firms are Construction and Electricals (24.6%), Food & Beverages (21.5%) and Wood-Paper-Plastics (11.8%). The composition of the respondent's backgrounds are Males (77.3%) and Females (22.7%), 43.6% are aged 18–35, 50.3% are aged 35–55, and 6.1% are 55 and above. The prevalent qualifications amongst the respondents are a bachelor degree (40.6%), a masters degree (24.6%) and professional qualifications (30.7%). The respondents of the questionnaires are at managerial levels of general manager (26.5%), top-to-middle-manager (58.3%) and senior-to-high level assistants (15.2%).

**Table 1**  
Respondents profile.

(a) Firm Background			
Demographics	Characteristics	Percent (%)	
Industry	Food & Beverages	21.5	
	Textiles, Leather & Garments	8.7	
	Wood, Furniture, Paper, Plastics & rubber	11.8	
	Construction & Electricals	24.6	
	Pharmaceuticals & Chemicals	9.2	
	Refined petroleum product	6.2	
	Recycling	4.3	
	Other	13.7	
	Firm Age	>20 years	61.1
		11–19 years	23.4
5–10 years		11.3	
<5 years		4.2	
Firm Size	Large	53.7	
	Medium	34.8	
	Small	11.5	
(b) Personal Background			
Demographics	Characteristics	Percent (%)	
Gender	Male	77.3	
	Female	22.7	
Age	18–35	43.6	
	36–55	50.3	
	56 >	6.1	
	Education	Diploma	1.8
Education	Bachelors Degree	40.6	
	Masters Degree	24.6	
	Professional Qualification	30.7	
	PhD	2.3	
	Managerial Level	General Manager	26.5
		Top-to-middle managers	58.3
Senior to high-level assistants		15.2	

### 5.2.2. Common method bias (CMB)

Podsakoff et al. [77] guidelines were adopted for rigorous statistical and procedural solutions to account for common method bias. The researcher purposefully used a multi-scale analysis to account for common method variance for procedural measurements [77]. In terms of statistical remedies, this study employed a variety of techniques to ensure robust testing. At the outset, Harman's single factor test is utilized. The results of the total variance are explained by a single factor of 34%, which is less than 50% [77].

Furthermore, despite the widespread use of Harman's single-component analysis, academics have argued that it is inappropriate to be indulged in common method variance [78]. As a result, the study employed a correlation matrix for further validation, as per Bagozzi et al.'s [79] suggestion. The correlation matrix results indicate that none of the constructs' values was 0.90 or more, confirming that common method bias (CMB) was not considered a substantial issue.

### 5.2.3. Linearity test

Additionally, the study used SPSS to examine the researched constructs linearity using the p-value linearity deviation with an ANOVA test. Table 2 demonstrates unequivocally that the analyzed model contains linear and non-linear relationships between the research constructs and predictor variables. For additional confirmation, the researchers used the Ordinary Least Squares test (OLS), and the results confirm the existence of linear correlations using p-values (Table 3).

### 5.2.4. Outer model assessment

At the initial phase of PLS analysis, 'composite (construct) reliability' (CR), 'convergent validity (factor loadings)', 'average variance extracted' (AVE), and 'discriminant validity (heterotrait-monotrait ratio-HTMT)' can be assessed [80]. The factor loadings, 'CR' and 'AVE' in Table 4 are more than the required values of 0.5, 0.7, and 0.707, respectively [80]. Along with construct reliability and convergent validity, the study assessed discriminant validity using HTMT ratios to benchmark Kline's [81] guideline. As indicated in Table 5, none of the HTMT construct values is above the 0.85 thresholds [67], hence no severe doubts about discriminant validity were revealed. As a result, the measurement model can be considered validated.

### 5.2.5. Multi-collinearity assessment

Additionally, the study examined lateral collinearity. While the study fulfilled discriminant validity during the outer model assessment in the previous step, lateral collinearity challenges occasionally lead the researcher astray thus, it was examined [82]. A variance inflated factor (VIF) value of 5 or greater indicates possible collinearity, as Hair et al.

**Table 2**  
Linearity deviation.

		Sum of Sq.	df	Mean Sq.	F	Sig	Linear
SBP*MKT	Linearity	36.471	11	2.264	1.317	0.183	Yes
	Deviation						
SBP*e-Prod	Linearity	18.411	15	1.143	0.582	0.952	Yes
	Deviation						
SBP*e-Proc	Linearity	21.732	11	2.334	2.493	0.005	No
	Deviation						
SBP*e-Org	Linearity	11.259	11	0.614	1.015	0.834	Yes
	Deviation						
MKT*e-Prod	Linearity	7.845	15	1.391	1.368	0.139	Yes
	Deviation						
MKT*e-Proc	Linearity	15.683	10	0.381	0.326	0.144	Yes
	Deviation						
MKT*e-Org	Linearity	13.116	15	1.409	2.105	0.013	No
	Deviation						

Note: SBP = 'Sustainable Business Performance', MKT = 'Market Turbulence', e-Prod = 'Product eco-innovation', e-Proc = 'Process eco-innovation', e-Org = 'Organizational eco-innovation'.

**Table 3**  
Ordinary least squares (OLS) test.

Model	Sum of Squares	Df	Mean Square	F	Sig
Regression	384.604	1	384.604	230.468	0.000 <sup>b</sup>
Residual	630.205	408	1.662		
a. Dependent variable: SBP					
b. Predictors: (Constant), EI					
Regression	384.604	1	384.604	509.475	0.000 <sup>b</sup>
Residual	312.512	408	0.918		
a. Dependent variable: SBP					
b. Predictors: (Constant), MKT					

**Table 4**  
Construct and measurement items.

Construct	Reference	Measure	Loadings	CR	AVE
<b>e-Prod</b>	[97]	Green Product Packaging	0.896	<b>0.943</b>	<b>0.897</b>
	[17]	Recyclable, Reusable & recoverable products	0.868		
	[35]	Design eco-products that reduce hazards in the product manufacturing	0.911		
	[102]	Eco-labelling of products	0.836		
<b>e-Proc</b>	[7]	Eco-process that protects against contamination	0.885	<b>0.922</b>	<b>0.884</b>
	[100]	Energy-saving manufacturing process	0.893		
	[23]	Operating process that meets environmental standards	0.795		
<b>e-Org</b>	[100]	R&D investment in eco-innovation	0.864	<b>0.955</b>	<b>0.911</b>
	[97]	Novel green management practices to support eco-innovation	0.901		
	[97]	Staff sensitization on eco-innovation	0.859		
<b>MKT</b>	[17]	Supplier eco-evaluation	0.863	<b>0.861</b>	<b>0.782</b>
	[55]	Technology Turbulence	0.906		
	[1,42]	Competition intensity	0.922		
	[36,42]	Household change in taste and greener demands	0.849		
<b>ECO</b>	[3]	Revenue	0.963	<b>0.918</b>	<b>0.868</b>
	[40]	Market Share	0.942		
	[12]	Sustainable Product Cost Reduction	0.958		
	[12]	Sustainable value to the consumer	0.921		
<b>SOC</b>	[8,25]	Enhanced Social Image	0.815	<b>0.911</b>	<b>0.859</b>
	[92]	Employee Training	0.746		
	[100]	Information Disclosure	0.794		
	[5]	Health & safety at work	0.848		
<b>ENV</b>	[32]	Pollution Control	0.857	<b>0.886</b>	<b>0.795</b>
	[27]	Cleaner Production	0.881		
	[10]	Eco-efficiency	0.787		
	[61]	Green Competencies	0.894		

Note: SBP = ‘Sustainable Business Performance’, MKT = ‘Market Turbulence’, e-Prod = ‘Product eco-innovation’, e-Proc = ‘Process eco-innovation’, e-Org = ‘Organizational eco-innovation’, ECO = ‘Economic’, SOC = ‘Social’, ENV = ‘Environmental’.

CR= Composite Reliability, AV = Average Variance Extracted.

**Table 5**  
Heterotrait-monotrait (HTMT) ratio values.

	e-Prod	e-Proc	e-Org	MKT	ECO	SOC	ENV
e-Prod							
e-Proc	0.783						
e-Org	0.724	0.794					
MKT	0.611	0.646	0.452				
ECO	0.503	0.633	0.682	0.558			
SOC	0.723	0.513	0.712	0.437	0.518		
ENV	0.684	0.501	0.610	0.572	0.644	0.512	

Note: SBP = ‘Sustainable Business Performance’, MKT = ‘Market Turbulence’, e-Prod = ‘Product eco-innovation’, e-Proc = ‘Process eco-innovation’, e-Org = ‘Organizational eco-innovation’, ECO = ‘Economic’, SOC = ‘Social’, ENV = ‘Environmental’.

[80] noted. Conversely, as shown in Table 6, no multi-collinearity evidence is observed as values less than 5 are obtained for VIF.

5.2.6. Inner model assessment

After analyzing the measurement model, we proceed to the structural model to measure the hypothesized relationship of the research model (conceptual framework). A bootstrapping approach with 5000 iterations was used to validate the proposed hypotheses, as Hair et al. [80] recommended. The outcomes of the hypotheses are summarized in Table 6. Additionally, the existing study factors explained 56.32% of the variance in sustainable business performance (SBP), i.e., economic (62.30%), social (49.21%), and environmental (57.44%), respectively. Effect sizes ( $f^2$ ) were also computed using the Cohen [83] recommendations, as shown in Table 6. Apart from calculating the coefficient of determination ( $R^2$ ) and the effect magnitude ( $f^2$ ), the study estimated predictive power ( $Q^2$ ). The values for  $Q^2$  (endogenous) were above zero SPB: 0.517, and MKT: 0.263 [84]. Additionally, as Shmueli et al. [85] indicated, this study used the PLS-SEM-predict procedure to confirm the predictive power for the study. High predictive power for the model is demonstrated in Table 7.

5.2.7. Structural model evaluation

The path coefficients and hypothesis of the structural model in Table 6 reveals that H1<sub>c</sub> ( $\beta = 0.318$ ,  $\rho.v. = 0.001$ ), H2<sub>c</sub> ( $\beta = 0.035$ ,  $\rho.v. = 0.018$ ), H3<sub>b</sub> ( $\beta = 0.212$ ,  $\rho.v. = 0.021$ ) & H3<sub>c</sub> ( $\beta = 0.224$ ,  $\rho.v. = 0.019$ ) are supported and positively relate to a dimension of SBP. Contrariwise, the remaining H1<sub>a</sub> ( $\beta = 0.237$ ,  $\rho.v. = 0.503$ ), H1<sub>b</sub> ( $\beta = 0.119$ ,  $\rho.v. = 0.813$ ), H2<sub>a</sub> ( $\beta = 0.216$ ,  $\rho.v. = 0.632$ ), H2<sub>b</sub> ( $\beta = 0.049$ ,  $\rho.v. = 0.726$ ), and H3<sub>a</sub> ( $\beta = 0.040$ ,  $\rho.v. = 0.622$ ) are not supported in the model.

5.2.8. Market turbulence (MKT) moderation

The study opted for an orthogonalizing procedure for the interaction effect of MKT on the EI and SBP nexus to analyze the stimulus enhancement provided by the moderation effect of market turbulence [74]. The results indicated that MKT positively moderates the hypothesized relationships of H4<sub>a</sub> ( $\beta = 0.412$ ,  $\rho.v. = 0.001$ ), H4<sub>c</sub> ( $\beta = 0.216$ ,  $\rho.v. = 0.032$ ), H6<sub>a</sub> ( $\beta = 0.211$ ,  $\rho.v. = 0.016$ ), H6<sub>b</sub> ( $\beta = 0.386$ ,  $\rho.v. = 0.003$ ) & H6<sub>c</sub> ( $\beta = 0.226$ ,  $\rho.v. = 0.025$ ). Conversely, H4<sub>b</sub> ( $\beta = 0.204$ ,  $\rho.v. = 0.613$ ) H5<sub>a</sub> ( $\beta = 0.098$ ,  $\rho.v. = 0.511$ ), H5<sub>b</sub> ( $\beta = 0.064$ ,  $\rho.v. = 0.615$ ) and H5<sub>c</sub> ( $\beta = -0.108$ ,  $\rho.v. = 0.747$ ) are not supported.

5.2.9. Artificial neural network (A-N-N) analysis

The Artificial Neural Network (A-N-N) evaluates, complements, and validates the results of the PLS-SEM analyses. Most importantly, A-N-N utilizes double hidden layers to identify non-linear relationships to boost the model’s ability to learn and improve its accuracy. In this study, the research model’s complex decision-making process cannot be predicted solely by using SEM analysis, which reveals linear relationships between the model’s constructs. Hence the authors attempt to alleviate this restriction by introducing the Artificial Neural Network (A-N-N) as the second step of data analysis, a procedure used in some studies [86,104,

**Table 6**  
Summary of hypothesis and coefficients (paths).

Hypothesis	Relationship	Std $\beta$		T-Value	P-Value	Decision	f <sup>2</sup>	VIF
H1 <sub>a</sub>	e-Prod → ECO	0.237	0.225	0.687	0.503	Not Supported	.013	1.733
H1 <sub>b</sub>	e-Prod → SOC	0.119		0.853	0.813	Not Supported	.056	1.526
H1 <sub>c</sub>	e-Prod → ENV	0.318		2.352	0.001***	Supported	.017	2.088
H2 <sub>a</sub>	e-Proc → ECO	0.216	0.077	0.146	0.632	Not Supported	.044	2.147
H2 <sub>b</sub>	e-Proc → SOC	0.049		0.058	0.726	Not Supported	.006	1.668
H2 <sub>c</sub>	e-Proc → ENV	0.035		0.443	0.018**	Supported	.016	3.442
H3 <sub>a</sub>	e-Org → ECO	0.040	0.159	0.113	0.622	Not Supported	.058	1.718
H3 <sub>b</sub>	e-Org → SOC	0.212		2.531	0.021**	Supported	.019	1.006
H3 <sub>c</sub>	e-Org → ENV	0.224		2.618	0.019**	Supported	.071	1.559
Moderating effect of Market Turbulence								
H4 <sub>a</sub>	MT*e-Prod → ECO	0.412	0.277	5.149	0.001***	Supported	.033	
H4 <sub>b</sub>	MT*e-Prod → SOC	0.204		1.112	0.613	Not Supported	.017	
H4 <sub>c</sub>	MT*e-Prod → ENV	0.216		2.513	0.032**	Supported	.008	
H5 <sub>a</sub>	MT*e-Proc → ECO	0.098	0.018	0.344	0.511	Not Supported	.014	
H5 <sub>b</sub>	MT*e-Proc → SOC	0.064		0.814	0.615	Not Supported	.027	
H5 <sub>c</sub>	MT*e-Proc → ENV	-0.108		1.001	0.747	Not Supported	.031	
H6 <sub>a</sub>	MT*e-Org → ECO	0.211	0.274	2.183	0.016**	Supported	.015	
H6 <sub>b</sub>	MT*e-Org → SOC	0.386		3.053	0.003***	Supported	.023	
H6 <sub>c</sub>	MT*e-Org → ENV	0.226		2.118	0.025**	Supported	.031	

Note: SBP = ‘Sustainable Business Performance’, MKT = ‘Market Turbulence’, e-Prod = ‘Product eco-nnovation’, e-Proc = ‘Process eco-nnovation’, e-Org = Organizational eco-nnovation, ECO = ‘Economic’, SOC = ‘Social’, ENV = ‘Environmental’.

\*\*p < .01.  
\*\*\*p < .001.

**Table 7**  
PLS-SEM predict.

Items	LM	PLS	LM-PLS	Q <sup>2</sup> Predict
	RMSE	RMSE		
ECO	0.112	1.141	0.112	0.549
SOC	0.113	0.914	0.113	0.478
ENV	0.112	0.113	0.112	0.524
SBP	-	0.607	-	0.517

Note: LM = Linear Model, RMSE = Root Mean Square Errors.

105]. As PLS-SEM determines significant variables, A-N-N is further used to rank the relative importance of predictions from PLS-SEM.

Next, SPSS was used to perform deep learning artificial neural network (A-N-N) analysis. A-N-N takes into account all significant predictors identified in the PLS-SEM findings. Due to the presence of numerous endogenous constructs, we concentrate exclusively on variables with the most significant predictors; thus, a sole deep A-N-N model is developed (Fig. 2). The A-N-N model consists of multiple input neurons representing indicators that are significant and one output neuron representing the dependent variable. Instead of using a single hidden layer model, a dual one is applied to allow deeper learning for each output neuron node [86].

The sigmoid function used activates both output and hidden neurons in this investigation. Additionally, the normalized range {‘0’, ‘1’} of

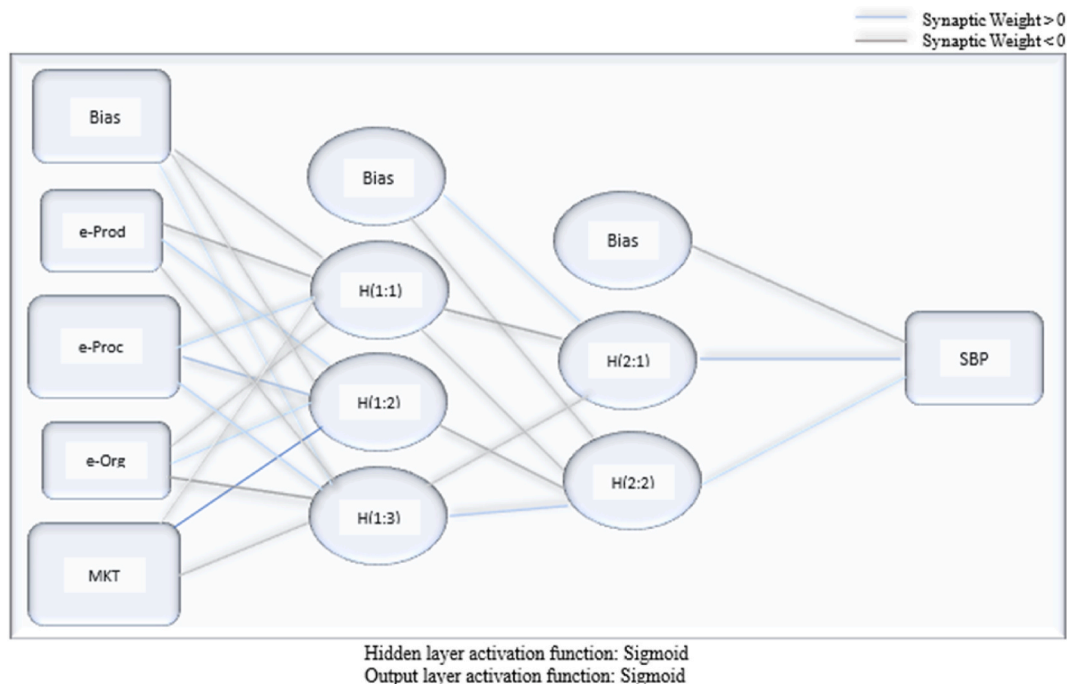


Fig. 2. Deep learning artificial neural network.

input-output neurons improves the performance of the current model [87]. Furthermore, to prevent A-N-N models from overfitting, a tenfold cross-validation process of 10:90 ratio was operationalized for training and testing data. 'Root Mean Square Error' (RMSE) is advocated in terms of neural network model correctness. The RMSE of the A-N-N model used in the study ranges between 0.074 and 0.113 for training and 0.069 to 0.085 for testing data (Table 8). Due to the training and testing data minutiae variations in the RMSE and standard deviation, it's inferred that the model obtains more accuracy using A-N-N.

Moreover, the predictor mean is compared to the maximum mean value given as a percentage to estimate the relative normalized importance. Table 9 summarizes the normalized and the mean important means for the predictors utilized in A-N-N modelling. All sensitivity analysis results (Table 9) indicate organizational eco-innovation (e-Org) has a 100% normalized relative importance and is the most important predictor of sustainable business performance (SBP) amongst manufacturing firms, followed by product eco-innovation (e-Prod) and process eco-innovation (e-Proc) with 89% & 41% respectively. Additionally, process eco-innovation (e-Proc) was the least predictive of sustainable business performance among Ghanaian manufacturing firms, which is also confirmed by the SEM results in Table 6. SEM and A-N-N are ranked according to their Path Coefficient and Normalized Relative Importance strength, respectively (Table 10). The results are quite intriguing, as organizational eco-innovation (e-Org) is placed first in A-N-N but is second in SEM in terms of effect strength, which contradicts the results of SEM. This is explained by A-N-Ns capability of capturing both linear and non-linear relations between variables [88]. That is, after the non-linear relationship between e-Org innovation and sustainable business performance is accounted for, e-Org becomes more significant than e-Prod and e-Proc. This fact would be obscured if only one step of the analysis was employed (i.e., PLS-SEM), demonstrating the value of the dual-stage analysis approach of PLS-SEM. & A-N-N in this study.

Additionally, to validate the A-N-N models performance, Leong et al. [89] suggested calculating goodness of fit, equivalent to R<sup>2</sup> from the SEM results. The proposed conclusions infer the proposed research model's predictive power is stronger than the R<sup>2</sup> results from SEM, satisfying one of the study's aims (Table 8). The difference in results can be explained by the higher prediction accuracy achieved when deep learning A-N-N and a dual-hybrid is used. Additionally, these findings indicate that A-N-N analysis is more effective in explaining studied endogenous variables than SEM analysis. Simultaneously, the authors assert that the study's outcome owes its superiority to deep learning's ability to capture non-linear relationships.

### 5.3. Discussion

This study examines the relationship between EI and SBP, with the moderating effect of MKT introduced to assess the stimulating impact on Ghanaian manufacturing firms. This research has theoretical and

**Table 8**  
RMSE values.

	RMSE (Training) SBP	RMSE (Testing) SBP	R <sup>2</sup> PLS-SEM	R <sup>2</sup> A-N-N
	0.074	0.072	56.32%	71.08%
	0.113	0.083		
	0.081	0.078		
	0.082	0.080		
	0.076	0.081		
	0.089	0.081		
	0.092	0.077		
	0.084	0.069		
	0.082	0.075		
	0.081	0.079		
SD	<b>0.005</b>	<b>0.007</b>		
Mean	<b>0.085</b>	<b>0.076</b>		

Note SBP = 'Sustainable Business Performance', SD = 'Standard Deviation'.

**Table 9**  
Sensitivity analysis.

	e-Prod	e-Proc	e-Org	MKT
A-N-N:1	0.223	0.116	0.267	-
A-N-N:2	0.151	0.051	0.316	-
A-N-N:3	0.184	0.153	0.225	-
A-N-N:4	0.263	0.103	0.294	-
A-N-N:5	0.224	0.114	0.331	-
A-N-N:6	0.186	0.032	0.268	-
A-N-N:7	0.282	0.111	0.337	-
A-N-N:8	0.126	0.126	0.285	-
A-N-N:9	0.201	0.121	0.186	-
A-N-N:10	0.259	0.159	0.341	-
Mean Relative Importance	<b>0.210</b>	<b>0.109</b>	<b>0.285</b>	N/A
SD	<b>0.031</b>	<b>0.203</b>	<b>0.042</b>	N/A
Normalized Relative Importance (%)	<b>89%</b>	<b>41%</b>	<b>100%</b>	N/A
Ranking	<b>2</b>	<b>3</b>	<b>1</b>	N/A

Note: e-Prod = 'Product eco-innovation', e-Proc = 'Process eco-innovation', e-Org = 'Organizational eco-innovation', MKT = 'Market Turbulence', SD = 'Standard Deviation'.

practical implications for sustainability, offering novel evidence in an emerging economy context.

The results from the study indicate that the triumvirate of e-Prod, e-Process and e-Org innovation has no direct effect on economic performance. This intriguing finding conforms with similar studies by Liao [63] and Ch'ng et al. [1]. The Ghanaian government recognizing the need for eco-friendly organizations, has initiated the e-Transform Ghana Project with several possible beneficial outcomes. Under the e-transform project, the country has been proliferated with numerous innovation hubs focusing on increasing start-ups within the green space, accelerating existing firms to become sustainable and providing incubators to harness novel business ideas. These initiatives enable manufacturing and other sectors to include eco-models in their business and organizational strategies, thus creating economic value for households, firms, and government while the environment benefits.

Usually synonymous with an emerging economy context, e-Prod and e-Proc do not associate positively or directly with economic performance, as this study uncovers. In contrast to developed countries whose maturity levels in eco-innovating and investment in R&D are not comparable to a country like Ghana, this finding is not remarkable. Earlier works have also highlighted the considerable capital investment needed to initiate and implement e-Proc and e-Prod. Results from the research works of Tumelero et al. [90] and Cai & Li [91] indicates that EI (e-Prod & e-Proc) are yet to bloom due to the significant cost involved.

Moreover, congruent to extant literature [1,92,93], the study provides more evidence that product and process eco-innovation do not relate directly with social performance. This finding can be associated with the variables measured under the social dimension in Ghana. The development required under employee training, information disclosure, health & safety at work, and enhanced social image within firms has yet to be improved to the level where eco-innovation can directly impact. However, studies allude to the contributions of socially responsible activities helping firms create new resources and competencies, with evidence that generous corporate social responsibility can help organizations improve their reputation and image, enhancing their social performance [94]. Organizational eco-innovation in this study has a direct and positive relationship with social performance, conforming with the notion of corporate social responsibility relationship with social performance among firms in manufacturing. Conversely, though it may take longer to build a social image in an emerging economy context, achieving recognizable performances under the social dimension of sustainability may be incremental.

Eco-innovations (EI) direct relationship with environmental performance is positive with e-Prod, e-Proc and e-Org. The Climate and Clean Air Coalition (CCAC) enlist Ghana as a founding member and the first country to include short-lived climate pollutants (SLCPs) and other air

**Table 10**  
PLS-SEM and A-N-N results comparison.

	Path Coefficient	Sign	Ranking PLS-SEM	Path Coefficient	Rank A-N-N: Normalized Relative Importance	A-N-N Result Normalized Relative Importance	Decision
e-Prod	0.225	Positive	1		2	89%	
e-Proc	-0.077	Negative	3		3	33%	Matched
e-Org	0.159	Positive	2		1	100%	
MKT	N/A	N/A	N/A		N/A		

pollutants in the United Nations Framework Convention on Climate Change’s fourth official National Greenhouse Gas Inventory (UNFCCC) [95]. Ghana made an unconditional commitment to reduce greenhouse-gas discharges by 15% by 2030. Thus, voluntarily committing to an additional 30% reduction if the government secures external funds to cover the overall cost of mitigation initiatives [48]. Firms are thus compelled to integrate e-Proc and e-Prod that assures pollution control, cleaner production and eco-efficiency—the work of Tariq et al. [59] found direct positive relationships between e-Prod, e-Proc and environmental performance.

From the standpoint of RBV, a firm’s resources serve as the foundation for potential innovation [96]. When a business adopts an e-Org strategy, it increases the available resources for e-Prod and e-Proc, thus improving its sustainable business performance. Wang’s [97] study validated eco-organizational culture as one of the essential elements affecting green competencies in firms. Fernando & Wah [60] argues that e-Org culture has a beneficial effect on environmental performance. This is bolstered by Geng et al. [4], where the authors assert that e-Org serves as the foundation for e-Prod and e-Proc innovation. Thus, the author’s analysis highlights e-Org’s positive effect on the environmental dimension of the sustainability relationship.

Intriguingly, the effect of e-Org on all the dimensions of SBP is enhanced or become positive under market turbulence (MKT). The stimulation of technology and environmental (household demand and competition) turbulence enhances the e-Org’s positive relationship with the triumvirate of economic, social and environmental performance among Ghanaian manufacturing firms. The findings regarding the moderation of market turbulence between e-Org and environmental performance are consistent with Borsatto and Amui [98], who asserts that precise environmental turbulence will almost certainly foster e-Org innovation. Accordingly, a competent e-Org strategy reduces the firm’s exposure under any form of market turbulence (technology, consumer & competitor pressure) as they are better suited to respond to sudden changes in market conditions. The economic performance of firms under turbulent markets when a business prioritizes e-Org enables it to expand the resources available to increase revenue, attain sustainable cost and create sustainable value for customers, hence improving its performance [35]. Furthermore, e-Org can influence employees to accept eco-innovation as a firm’s core value and feel more connected to environmental and social challenges. According to Amara [12], an eco-organizational culture encourages employees to participate in environmental activities while also harnessing the development of novel, creative ideas and behaviours that foster collaborations to mitigate the undesirable environmental implications of the manufacturing firms. Thus, firms that are receptive to eco-innovation may be better prepared and successful in implementing changes in several areas to reduce ecological shortcomings under turbulent conditions [43]. As a result, organizational eco-Innovation (e-Org) contributes significantly to environmental sustainability transition in Ghanaian manufacturing firms.

Product eco-Innovations (e-Prod) relationship with economic performance becomes positive under market turbulence, and the relationship with environmental performance is also further enhanced. Conversely, the relationship with social performance remains negative even when stimulated by market turbulence. Thus under turbulent market conditions, a firms response to e-Prod investment and new

product development paths (R&D) does not only benefit them in mitigating the social and financial costs associated with technological changes, household demand, and intensifying market competition but also in developing opportunities in new markets to enhance the competitive advantage of the firm [96]. The Porter and Linde [99] hypothesis postulate that volatile market conditions can stimulate a firms’ eco-innovation efforts and ultimately cause organizations to transition from an obsolete and backward technical paradigm to a green creative one. Porter and Linde [99] hypothesize that unpredictable market conditions might promote a firm’s eco-innovation activities, ultimately leading to an organization’s transformation from an outmoded and backward technological mindset to a green-innovative one.

Considerably, the discussion reveals how e-Prod under turbulent markets may empower manufacturing firms to be proactive by encouraging fresh ideas, stimulating innovative sustainable business performance in the long run [100]. Lastly, a key point of note; the study uncovers that market turbulence does not enhance nor stimulate eco-innovations (e-Proc) relationship with any of the SBP dimensions. The positive direct effect means turbulent market conditions do not necessarily stimulate process eco-innovations impact on sustainable business performance beyond the existing contributing factors when the market turbulence is considered. Correspondingly, it can be asserted that there exists an inverted u-shape between e-Proc and SBP when moderated by MKT. When further resources are added to enhance process eco-innovation effect on sustainable business performance beyond its optimum, it will negatively affect the relationship. The study reveals the optimum is attainable when the relationship is direct without moderation.

## 6. Conclusion

The findings of this study reveal that each of the three types of EI, e-Proc, e-Prod, and e-Org, exerts a direct effect on the distinct dimensions of SBP. The empirical research findings confirm the beneficial effects of e-Prod, e-Proc and e-Org on environmental performance and the positive impact of e-Org on social performance absent the moderation of market turbulence (MKT) in Ghanaian manufacturing firms. The inference from these findings posits that regardless of the impact of turbulent market conditions in the manufacturing sector, management of these firms should strive to uphold a continual state of e-Prod, e-Proc, and e-Org to achieve improved environmental and economic performance. When highly turbulent conditions are proliferate in the market, manufacturing firms management should continue to deploy e-Org to enhance economic, social and environmental performance and e-Prod innovation to enhance economic and environmental performance.

### 6.1. Theoretical implication

Currently, eco-Innovation (EI) literature is not replete in Africa, hence the study attempts to extend coverage via significant evidence that reinforces the resource-based view theory and contingency theory underpinning for sustainable business performance (SBP). Thus, utilizing a contingency theory framework, this research discovered that market turbulence positively alters the independent role of e-Prod on economic performance and significantly enhances the existing positive relationship between e-Prod and environmental performance.

Furthermore, market turbulence greatly altered the positive link between e-Org and all the dimensions of SBP (economic, social, and environmental). In a nutshell, market turbulence has a greater impact on the association between economic-environmental performance and e-Prod, e-Org than on social performance. A possible explanation is that manufacturing firms in Ghana who implement eco-innovations can differentiate themselves and are better suited to address issues associated with the need for greener products, evolving household demands or preferences, advancements in new technologies, intensive competition while effectively responding to changing environmental and important stakeholder demands. Thus, eco-innovation firms thrive in turbulent markets (technology and environment). These findings bolster earlier assertions that a turbulent market stimulates the uncertain relationship between EI and SBP [15]. This is consistent with several scholars' contingency theory-based claims that turbulent market conditions influence performance outcomes of firms, contingent on pertinent sustainability dimensions.

Moreover, this research has been guided by the resource-based view, which holds the view that a firm can significantly advance its EI attempt with committed market resources. Owing to dedicated market resources, eco-innovation firms can establish and maintain a favourable green image and differentiation advantage [15]. Precisely, this study identified the configurational market turbulence factors that amplify EI's influence on a firm's SBP.

Additionally, the researchers bridged the current research gap by utilizing a dual-stage deep-learning SEM & A-N-N analysis to uncover linear and non-linear offsetting relationships. By applying A-N-N with artificial intelligence (AI) plus machine learning techniques, considered robust against dataset noise and adept at learning from data, the study obtained more accurate predictions and identified non-linear relationships overlooked in the existing literature. Hence the proposed research model is more robust owing to its novelty and valuable approach. The two-stage deep learning method is critical because linear relationships may not fully explain EIs relationship with SBP due to the complexity of human decision-making; hence, employing linear and compensatory relationships could overgeneralize the human decision-making process [101]. As a result, it can be concluded that by combining artificial intelligence (AI) and an expert system based neural network, the study expounds more accurate predictions and obtain more accurate findings. The discovery of non-linear relationships represents significant advancement in EI literature, particularly in an emerging economy like Ghana and may catalyze researchers to pursue the subject further in the future.

## 6.2. Practical implication

In terms of managerial implications, this study contributes to dispelling any misgivings about implementing eco-Innovation (EI) methods into their firm's investment strategies. The data reveals that despite the incipient nature of each eco-innovation in Ghanaian manufacturing firms, it has a differing impact on each sustainable business performance dimension. Hence management can distinguish between the EI types to implement for specific sustainable results. If a firm wishes to attain environmental performance, e-Prod, e-Proc, and e-Org must be implemented. If a firm aspires for social performance, then e-Org is necessary to build upon and sustain. Furthermore, for firms operating in turbulent markets, economic performance (financial) can be improved by establishing e-Prod and e-Org. Finally, embracing more e-Org under turbulent markets conditions enable firms to accrue all the benefits of SBP dimension.

The findings contribute to the conceptual framework by establishing a relationship between EI and SBP for operational strategy experts. The

study discovered some direct-positive effects and significant moderation influence of market turbulence in linking specific dimensions of EI and SBP. Market turbulence has been shown to act as a buffer for enhancing the effects of EI on SBP, a conclusion that is consistent with earlier research. The stimulus of market turbulence as moderation for optimal resource utilization amongst manufacturing firms in Ghana, we believe, is consistent with eco-innovation approaches and studies. Eco-innovation (EI) establishes sustainability (SBP) based on information derived from ecologically-friendly manufacturing processes. EIs implemented in manufacturing firms driven by green principles strengthens technical capabilities, affords product differentiation, expand market opportunities resulting in cheaper costs, prompt, and flexible responses to turbulent market conditions.

## 6.3. Limitations

A key limitation to this study relates to the subjectivity of the survey data, as the variables analyzed were measured using a variety of intuitive indicators. As a result, future research should operationalize the variables of e-Prod, e-Proc, and e-Org by incorporating objective data from manufacturing firms. This would aid in determining whether the results obtained are inconsistent with those obtained in this empirical study. Future studies can evaluate the selection criteria for eco-Innovation (EI) based on a sustainable mechanism.

Secondly, different manufacturing industries were surveyed as part of this study. The distinctive peculiarities of each sector may be obscured by collective analysis of the industry as a whole. Future research should concentrate on a single industry to ascertain more nuanced managerial implications.

Lastly, the study prioritized manufacturing firms in Ghana neglecting the key contributions of firms in the service industry towards eco-innovation and sustainability. To attain more generalized results, future studies should consider the service sector in their empirical setting or make a comparative assessment of eco-innovation between the service and manufacturing industries to better understand the each sectors contribution to environmentally beneficial initiatives in the Ghanaian economy.

## Author statement

All authors certify that they have participated sufficiently in the work, including participation in the concept, design, analysis, writing, and revision of the manuscript.

## Author contribution

HX was involved in planning, supervised the project and the findings of this work. OLS worked on the data, statistical analysis and discussion. AOA & EO conceived the idea, developed the theory, and worked on the research design, including collecting survey data. OLS worked on the research design, including collating survey data. BEF & SAF participated in the design of the study and the draft of the final manuscript. All authors read and approved the final manuscript.

## Ethical considerations

None to report.

## Declaration of competing interest

The authors declare that they have no competing interests.

## Appendix A. Construct Questions

<b>Product eco-innovation</b>	The firm designs and uses green product packaging. The firm produces products that are recyclable, reusable & recoverable. The firm designs eco-products that reduce hazards in the manufacturing of products. The firm provides eco-labelling information on all its products.
<b>Process eco-innovation</b>	The firm uses innovation processes that protect against contamination The firm uses innovative technologies that enhance energy-saving in manufacturing processes. The firm engages in operating processes that meet environmental standards.
<b>Organizational eco-innovation</b>	The firm prioritizes high R&D investment in eco-innovation. The firm promotes novel green management practices to support eco-innovation. The firm engages staff in sensitization on eco-innovation.
<b>Market Turbulence</b>	The firm subject's suppliers to eco-evaluation before the selection process Technology within the industry is changing rapidly, providing new opportunities in the sector. Competition within the industry is highly unpredictable. Household taste and greener demands are changing rapidly and unpredictably.
<b>Sustainable Business Performance Economic</b>	The firm's is experiencing increased market share. The firm's net revenue has increased. The firm has experienced sustainable product cost reduction. The firm provides sustainable value to the consumer.
<b>Social</b>	The social image of the firm has been enhanced. The firm has increased employee training in eco-innovation and sustainability. The firm is more forthcoming with information disclosure to the public. The firm ensures health & safety at work.
<b>Environmental</b>	The firm's environmental sustainability measures improve pollution control. The firm prioritizes cleaner production. The firm strives for eco-efficiency to aid environmental performance. The firm develops green competencies to manage its environmental impact.

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