Performance measure of eco-process innovation: insights from a literature review

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Abstract. Eco-process innovation has been recognised as one of the important strategies for mitigating the growing environmental challenges. Its concept has succeeded in drawing the interests of many scholars worldwide. The aim of this paper is to review the literature to clarify how one actually measure eco-process innovation performance. Critical analysis of literature has been performed in this study. Database searches were mainly relied to compile the literature. In relation to eco-process innovation assessment, results revealed that most prior works focused on the economic and environmental performance with the exclusion of social performance and very limited attempts done in analysing real operational data. It was identified that there is a need for empirical investigations on measuring the social performance of eco-process innovation along with the economic and environmental performance, and on development of operational measuring instrument as these study area have not been well explored.

1Introduction

The environmental conservation agenda has emerged as essential concern amongst manufacturers around the globe due to growing unfavourable environmental impacts of their operations. As major consumers of energy and natural resources ([1]), and main potential producers of pollutions ([2], [1]), manufacturing firms are forced by various factors to seek for secret recipes of mitigating the environmental risks. Eco-innovation is one of the strategic green solutions to achieve sustainable development in manufacturing industries in response to the increasing economic, environmental and economic pressure ([3], [4], [5]). It is evident that manufacturers have focused on improving production processes (i.e. eco-process innovation) to ensure the optimal use of resources and minimal generation of waste and pollution in their production processes ([6]). This will change the perspective of seeing the manufacturing activities as causing the negative environmental

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impacts to the one that perceives manufacturers as an entity which fulfilling society's needs and increasing their standard of living, and improving quality of environment.

The evaluation of eco-innovation implementation among manufacturers is essential to see if their performances are at par or corrective actions are required to reach the balance priority of economic, environmental and social targets ([7]). However, the existence of various versions of assessment indicators has limited the value of assessment results to the firm. Literature showed that limited knowledge has been established to create comprehensive performance measures of eco-innovation ([8]). Hence, the development of better instrument of assessing eco-process innovation performance is in need. Considering the highlighted necessity to establish comprehensive assessment indicators, it is important to ask: What are the main dimensions of eco-process innovation assessment in previous published works? How does one actually measure eco-process innovation performance? The purpose of this paper is to review the literature on measuring aspects and approaches which have been the focus of previous researchers.

This study offers some notable contributions to the literature by pointing out the most important gaps in assessing eco-process innovation performance at firm-level. It proposes a future study agenda for measuring eco-process innovation performance. This paper is structured as follows: Section 2 consists of methods applied to compile relevant literatures for analysis. Section 3 summarises the literatures on emergence of sustainable development, sustainable manufacturing and eco-innovation concepts, and definition and nature of eco-innovation. Section 4 discusses the main findings from the literature review and Section 5 concludes with future research agenda on measures of eco-process innovation performance.

2Research methods

A literature review was conducted to explore how eco-process innovation implementation has been measured, which involved the critical analysis of previous published studies. In compiling the literature, database searches were mainly relied whereby the published studies were identified from the Web of Science, Scopus and Google Scholar databases to ensure the analysis is inclusive of all relevant literature and not limited to the top journal publications only such as implemented by [9]. "eco-process innovation" OR "process eco-innovation" OR "green process innovation" OR "environmental process innovation" OR "sustainable process innovation" OR "green process improvement" AND "manufacturing"' were the search strings employed in finding by topic, title, abstract and keyword. The compiled literature was assessed and downsized based on their main focus in applying indicators for measuring eco-process innovation, in the context of manufacturing firms (i.e. micro-level), full text accessibility and included only empirical studies.

3The emerging concepts

3.1 Sustainable development, sustainable manufacturing and eco-innovation

With the global concerns over the worsening environmental degradation associated with the rapid expansion of industrial activities, there is growing consciousness to move gradually towards the concept of sustainable development. They started to realise the importance of establishing a healthy and sustainable business environment where economic wealth creation, environmental preservation and social wellbeing priority are placed on equal footing in deciding their operational actions ([6]). Manufacturers are playing more

significant role to deal with growing environmental challenges by taking more comprehensive and integrated approaches ([1]). The resultant difficulties from economic development such as resource exhaustion (economic), environmental pollution (environment), and social injustice (social) have led to the introduction of sustainable development approach ([10]).

The first use of phrase "sustainable development" could be traced back to the 1980 "World Conservation Strategy", the United Nation Environment Programme (UNEP) and The World Wildlife Fund (WWF) ([10]). The definition then noted in publication of Brundtland Report in 1987 and the subsequent Earth Summits in Rio de Janeiro in 1992 and Johannesburg in 2002, where sustainability and environmental issues gained the participants' attention ([11], [12]). Sustainable development was referred to development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs ([13]). The idea of sustainable development stressed the essential of balancing the Triple Bottom Line (TBL) – economy, environmental and society, in value creation activities in order to pursue the green and sustainable growth ([14]). It is an effort to preserve the earth as a place where human and nature can live together in harmony, while permitting the meeting of current and future generations' needs. In order to ensure the survival of the planet, the economic, ecological and social aspects should be put in a balanced priority. The use of sustainability concept within a more confined context such as production and manufacturing area has promoted the idea of sustainable manufacturing.

Sustainable manufacturing which is also known as environmentally responsible manufacturing or green manufacturing emerged from the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 ([1], [15]). It was defined as manufacturing practices that do not harm the environment during any part of the manufacturing process ([16]). The concept emphasises on designing and delivering products that minimise negative effects on the environment through their production, use, and disposal. The focus of the idea is on the use of processes that do not pollute the environment or harm consumers, employees, or other members of the community. This includes the initiatives of recycling, conservation, waste management, water supply, environmental protection, regulatory compliance, pollution control etcetera. Manufacturers are focusing on integrating these multiple green methods in their attempts to gain extensive benefits of sustainable manufacturing approach including minimisation of resources and energy consumption, reduction of waste and environmental pollution, and less safety and health threats as much as possible ([12]).

Recently, caused by the necessity to achieve sustainability, firms have been compelled to implement innovation to enjoy the privileges of putting a balanced priority to the three pillars of sustainable development ([17], [18], [10]). As such, the concept of eco-innovation was put forward. It received worldwide attention, was perceived as a bridge ([11], [19], [12]), a critical driver and provides promising way of leading manufacturing industry towards sustainable manufacturing ([20]). This require the manufacturers to adopt a holistic and integrative strategy, encompassing the identification of any potential for eco-innovation implementation at any stage of the manufacturing system, either technical or non-technical solutions, and extends beyond the conventional firm's boundaries which entails shifts in current socio-cultural norms and institutional structures. Thus, each change in ecological solutions introduced by the firm for instance from end-of-pipe technique (elimination of pollution at the point of discharge) to cleaner production technology (reducing energy and materials consumption in the production process) is considered as improvement facilitated by eco-innovation practice ([21], [1]). In other words, eco-innovation is the process of improving manufacturing sustainability ([17]). The adoption of

eco-innovation concept plays essential roles in directing the manufacturing sector towards sustainable manufacturing.

The concepts of manufacturing sustainability and eco-innovation are not similar but closely related, and associated with many conceptual overlaps ([21], [1]). Figure 1 illustrates the overlaps that exist between the concepts of sustainable manufacturing and eco-innovation. The evolutionary stages of various sustainable manufacturing approaches are shown by the "waves" spreading towards the right-hand corner of the figure, connected and can only be realised through a combination of the eco-innovation targets on the left and mechanisms at the bottom. As the sustainable manufacturing practices evolve, the eco-innovation processes such as process modification, product design, business model alternatives and the creation of new methods, procedures and arrangements should also advance to induce greater economic, environmental and social gains out of the initiatives. Closed-loop production practice (removal of product disposal stage through wastes treatment and use them as new resources for production), for example, is associated with the application of alternative business model, but when changed to the adoption of industrial ecology approach, will require manufacturer to consider the creation of entirely new production system which also involves the introduction of new organisational and institutional structures.

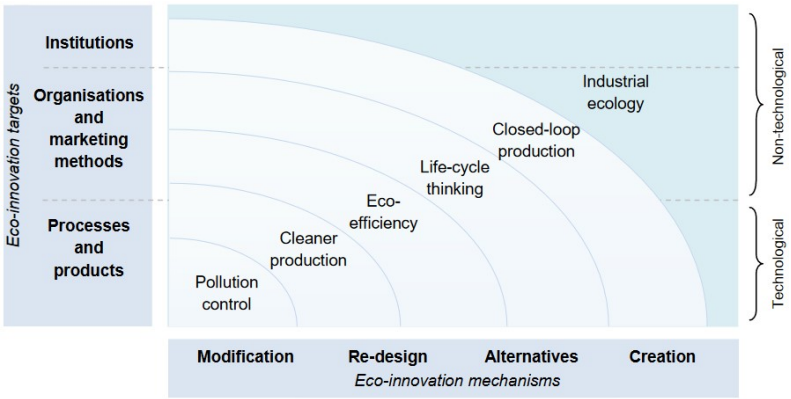

Fig. 1. Conceptual relations between sustainable manufacturing and eco-innovation. Source: [21]

3.2 Definition and nature of eco-innovation

Understanding the meaning which carried by the term 'eco-innovation' is challenging because the definition keeps on changing and evolving since its first appearance in a book titled *Driving Eco-innovation: A Breakthrough Discipline for Innovation and Sustainability* by [22] ([23], [24], [25]). Since then, scholars have defined eco-innovation differently according to various perspectives and contexts the term is used. Economists, ecologists and sociologists, just to name a few disciplines, all have their preferred perspective. For the purpose of this study, eco-innovation refers to strategic implementation of any form of technical (product and process) and non-technical (organisational, marketing, institutional and system) changes that are either new to the world or new to the firm (through adaptation or adoption approach), with the intention of achieving a balanced priority of economic returns, environmental preservation and society well-being resulting in sustainable economic, environmental, social and institutional benefits. The adapted definition

characterises key concerns of recent definitions proposed by scholars such as [26], [27], [28] and [29].

In a broader perspective of the nature of innovations, eco-innovation comprises of activities namely technical eco-innovation and non-technical eco-innovation ([30], [31], [32]). Technical eco-innovations take place in products and processes and involve technologies aimed at improving the environmental performance of products and processes. Non-technical eco-innovations include people-oriented changes which normally occur in marketing (related to implementation of more green product design and packaging, pricing, distribution and promotion activities) ([33]), organizational (shift to a new or improved ecological-oriented managerial arrangement such as Environmental Management System (EMS)) ([34]), institutional (includes improvement of values, norms, culture and behaviour) ([1]) and system (systemic level transformation among networked organizations which involve combination of all other types of eco-innovation – product, process, marketing, organizational and institutional) ([35]). The concern of this study is on the technological eco-innovation which taking place in the production processes. [34] and [12] used the term "eco-process innovation" to describe this type of eco-innovation, and the similar term is also used throughout the discussion of this paper.

Eco-process innovation refers to the changes of existing production methods or addition of new processes to minimise the environmental impacts ([34]). Its practice encompasses activities such as utilising closed looping for solvents, material recycling and consumption of less resource ([36]). Eco-process innovation is directly related to operations activities and concerned with process upgrades or introduction of new techniques and technology into production operations, which improve production efficiency, thereby lead to cost reduction ([34], [8]). In summary, for the purpose of this study, any changes or improvement made on production processes which aimed at or resulted in the reduction of unfavourable environmental impacts is considered as eco-process innovation.

4Results

There have been limited studies of measuring eco-process innovation performance carried out at the firm level. In total, 41 full papers, all empirical were extracted and reviewed to meet the aim of this paper which shown in Table 1. If looking at the measuring aspects, most prior works focuses on the economic and environmental performance without the assessment of social performance. Limited empirical studies have been found evaluating the social aspect of eco-process innovation performance. This is due to the complex nature of evaluating the social performance such as healthcare, safety, workers' satisfaction etcetera, and therefore in need of attention from scholars to develop an appropriate assessment method ([37]). It is noted that only [38], [12] and [39] carried out studies on evaluating the social performance of eco-process innovation practice. In their survey, [38] investigated the relationship between organisations' sustainability performance management practices and sustainability performance (economic, environmental, and social aspect). Whereas [12] study focuses on the influence of green manufacturing and eco-innovation on firm economic, environmental, and social performance. [39], however, performed survey investigation on the effect of eco-product and eco-process innovation on job satisfaction through job intensity (social aspect) with no assessment done on the economic aspect. Apart from these studies, the literature clearly visualise that the investigation on social performance of eco-process innovation implementation has not been well explored by previous researchers.

In terms of measuring approach, all scholars except for [40], [41] and [42], have conducted survey study (i.e. perceptual approach) to validate their proposed eco-process innovation measuring indicators. Results revealed that there were limited attempts to

develop eco-process innovation measuring tool capable of quantifying technical and operational data of real production process (i.e. operational approach). [40] developed and tested a model of linking lean system and eco-innovation implementation in production process of a metal working firm. Their Life Cycle Analysis (LCA) showed a significant improvement of incomes, sustainability and social responsibility performance. [41] employed simulation of manufacturing systems method called Discrete Event Simulation (DES) for assessing lean and eco-process improvements. They developed model of manufacturing system which then verified and validated using the empirical data collected through interview of the expert consultants, shop floor measurement and historical data of an automotive manufacturing firm. Their cost-time profile analysis showed reduction in cost as impact of a tailored combination of lean and eco-process innovation. Using the similar method, [42] evaluated the energy efficiency in a vehicle assembly line. Results of the simulation model indicated improvements for energy saving and cost reduction objectives. Even though [40], [41] and [42] have undertook objective analysis of real operational data, but their assessment have been found to only cover the economic and environmental aspects of eco-process innovation. This demonstrates that the development of instrument which can assess the quantifiable measures of eco-process innovation performance has not been well addressed and therefore deserves a specific attention.

Table 1. Studies on eco-process innovation measure at firm level.

No.	Author	Measure Approach		Measure Aspect			Analysis Method	[Country] Sector
		Perceptual	Operational	Economic	Environmental	Social		
1.	[43]	√			√		Statistical	[Taiwan] Information & electronics
2.	[44]	√			√		Statistical	[Taiwan] Information & electronics
3.	[45]	√		√	√		Statistical	[Netherlands] Petrochemicals production
4.	[46]	√			√		Statistical	[Taiwan] Manufacturing & service
5.	[47]	√			√		Statistical	[Taiwan] Manufacturing
6.	[48]	√		√	√		Statistical	[Russia] Manufacturing
7.	[38]	√		√	√	√	Statistical	[Australia] Manufacturing
8.	[36]	√		√	√		Statistical	[Taiwan] IT, electronics, telecommunication

								& others
9.	[49]	√			√		Statistical	[German] Manufacturing & service
10.	[50]	√			√		Statistical	[Italy] Manufacturing
11.	[51]	√			√		Statistical	[Africa] Manufacturing & service
12.	[52]	√			√		Statistical	[Taiwan] Information & electronics
13.	[53]	√			√		Fuzzy set theory, Analytical Network Process (ANP) & entropy weight	[Taiwan] Electrical & Electronics (E&E)
14.	[54]	√			√		Statistical	[China] Manufacturing
15.	[40]		√	√	√		LCA	[Spain] Metal working
16.	[41]		√	√	√		DES	[USA] Automotive
17.	[12]	√		√	√	√	Statistical	[Turkey] Automotive, chemistry & electronic
18.	[55]	√			√		Statistical	[China] E&E
19.	[56]	√			√		Statistical	[Ireland] Manufacturing & service
20.	[57]	√			√		Statistical	[Ireland] Manufacturing & service
21.	[58]	√			√		Statistical	[German] Manufacturing & service
22.	[59]	√			√		Statistical	[China] Manufacturing
23.	[34]	√		√	√		Statistical	[Taiwan] Information technology, electronics, telecommunication & others

24.	[8]	√		√	√		Statistical	[China] Manufacturing
25.	[60]	√			√		Statistical	[French] Manufacturing
26.	[61]	√		√	√		Statistical	[Taiwan] Information technology, electronics, telecommunication & others
27.	[62]	√		√	√		Statistical	[Malaysia] Manufacturing
28.	[39]	√			√	√	Statistical	[Malaysia] (E&E)
29.	[63]	√		√			Statistical	[Malaysia] Food & beverage, rubber & plastics, chemical, E&E & metal working
30.	[64]	√		√	√		Statistical	[Spain] Manufacturing & service
31.	[65]	√		√	√		Statistical	[Brazil] Textile
32.	[66]	√			√		Statistical	[Europe] Manufacturing
33.	[67]	√			√		Statistical	[China] Manufacturing
34.	[68]	√			√		Statistical	[China] Manufacturing
35.	[69]	√			√		Statistical	[Brazil] (E&E)
36.	[42]		√	√	√		DES	[Malaysia] Automotive
37.	[70]	√		√	√		Statistical	[Slovenia] Manufacturing & service
38.	[71]	√		√	√		Statistical	[China] Manufacturing
39.	[72]	√			√		Statistical	[Slovenia] Manufacturing & service
40.	[73]	√			√		Statistical	[Malaysia] Chemical
41.	[74]	√			√		Statistical	[Malaysia] Green technology

5Conclusions

This study drew propositions for further empirical research on measures of eco-process innovation performance. It is argued that eco-innovation could contribute to the three pillars of sustainability performance. Eco-innovation is the process towards improved sustainability, thus measured with the focus on the resulting impact of the innovation process ([17]). The measurement should entail the three pillars of sustainability, namely economic, environmental and social aspects in accordance with eco-innovation definition ([29], [28], [27]). However, this study provides evidence that most empirical research on eco-process innovation assessment address the economic and environmental impacts with no consideration of social performance.

If looking at the measuring approach adopted in previous studies, most scholars have proposed and tested questionnaire-based survey, which noted as associated with respondents' generic and bias responses. Survey questionnaire only provides general information about eco-innovation practice in which technical and operational information of products and processes, and micro-level eco-efficiency aspects of innovation are not able to be assessed ([75], [76]). Moreover, provided data could be seriously biased since responses are self-declared by respondents and tend to give favourable answers to show socially desirable image of themselves or their firms ([76]). [34] added that studies which involve the analysis of objective data would lead to the actual eco-innovation performance and overcome biases. However, the analysis of real production system (i.e. objective data analysis) in measuring eco-process innovation performance has not been fully addressed in the literature and there is a need of extending its application in other quantifiable impacts.

Hence, it is the intention of our future study to develop an instrument of assessing eco-process innovation practice with the measurement indicators of economic, environmental and social performances. The developed set of performance indicators will be validated using operational data of a selected manufacturer.

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