Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 40 (2016) 449 – 454

www.elsevier.com/locate/procedia

13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

A measurement scale to evaluate sustainable innovation performance in manufacturing organizations

E. Calik [a,*], F. Bardudeen [b]

[a]Yalova University, Department of Industrial Engineering, Central Campus,Yalova 77200, Turkey
[b]University of Kentucky, Institute for Sustainable Manufacturing, 414L CRMS Building, Lexington KY 40506, USA

* Corresponding author. Tel.: +9-0226-815-5355 ; fax: +9-0226-815-5401; *E-mail address:* ecalik@yalova.edu.tr

Abstract

Sustainable innovation in manufacturing involves developing of new products, processes, services and technologies that enable economic development and well-being of stakeholders and institutions while respecting the worlds' natural resources and regenerative capacity. Defining and measuring even conventional innovation in manufacturing organizations, let alone sustainable innovation, is difficult. This study will present an initial effort at developing a scale for measuring sustainable innovation. For this, first, literature is thoroughly reviewed to identify sustainable innovation measurement related studies. The measurement model is developed from literature and is based on evaluation of decision points. The measurement scale is obtained by evaluating each item for their relevance considering a number of criteria. This study presents the first known scale to measure sustainable innovation performance and can be used by manufacturing companies to evaluate sustainable product or process innovativeness.

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing

Keywords: Mesurement, Model, Performance, Scale, Sustainable innovation

1. Introduction

Sustainable development or sustainability is defined as meeting the needs of the present generation without compromising the ability of future generations to meet their needs [1]. In manufacturing systems, sustainable product and process innovations, as well as system innovation play an important role to meet the responsibilities to the environment and society. It is hard to define and measure even conventional innovation in manufacturing organizations, let alone sustainable innovation. There are some different terminologies and definitions for sustainable innovation in literature, such as 'sustainability oriented innovation' [2] and 'sustainability related innovation' [3]. We prefer the term 'sustainable innovation' in this study. Sustainable innovation can reasonably be defined as "the development of new products, processes, services and technologies that contribute to the development and well-being of human needs and institutions while respecting the worlds' natural resources and regenerative capacity" [4]. Bos-Brouwers [5] defines sustainable innovation as "innovations in which the renewal or improvement of products, services, technological or organizational processes not only delivers an improved economic performance, but also an enhanced environmental and social performance, both in the short and long term have the capacity to generate positive social and environmental impacts." Another definition is "a process where sustainability considerations (environmental, social, and financial) are integrated into company systems from idea generation through to research and development (R&D) and commercialization". This applies to products, services and technologies, as well as to new business and organizational models [6]. We define sustainable innovation as "any new or significant improvement of products, services, technological or organizational processes, commercialized or internally implemented, that not only provide economic benefits but also generate positive social and environmental impacts."

The remaining sections of this paper are organized as follows. Section 2 presents literature review. Section 3 presents model development. In Section 4, item generation

Peer-review under responsibility of the International Scientific Committee of the 13th Global Conference on Sustainable Manufacturing
doi:10.1016/j.procir.2016.01.091

and scale development are discussed. Conclusion and further research are presented in Section 5.

2. Literature Review

In this part of the study, the literature was reviewed thoroughly to identify sustainable innovation measurement related studies. 155 measurement related articles and 5 index studies were obtained to evaluate their basic approaches. These articles consist of not only sustainable innovation but also environmental (or green or eco) innovation because sustainable innovation covers environmental innovation and incorporates societal dimensions alongside and environmental aspects as can be seen in Fig.1.

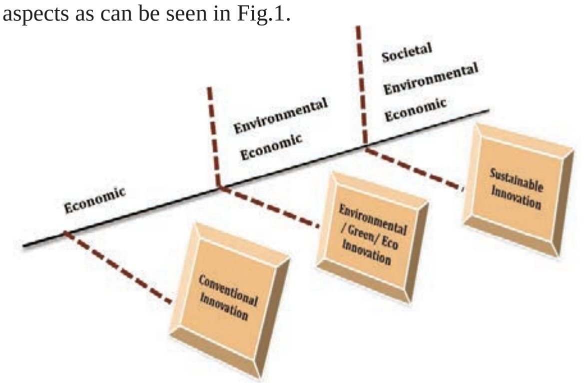

Fig. 1. Evolution of sustainable innovation

There are some prominent studies about green innovation measurement. Chen et al. [7] divide ‘‘green innovation performance’’ into ‘‘green product innovation performance’’ and ‘‘green process innovation performance.’’ They use 4 items for each green innovation type. Chen [8] revised these items and used them in another study. Both studies focus on emissions, end of life management, environmental issues, and usage of energy, material and other resources. Many studies {[9]; [10]; [11]; [12]; [13]; [14]; [15]; [16]; [17]; [18]; [19]} refer to these items of Chen et al. [7] or Chen [8]. A few studies {[20]; [21]} use the items from Community Innovation Surveys (CIS) of the European Commission conducted in 2009 that focus on: Pollution, CO_2 emissions, recycling and, the adoption of procedures such as Environmental Management Systems (EMAS), ISO14001, and usage of energy, material and other resources. At the same time, Arundel & Kemp’s [22] study is one the most prominent studies about measuring eco-innovation. They measure eco-innovation using the following four measures: input, intermediate output, direct output, and indirect impact. Many authors have cited their study. The study by Cheng and Shiu [23] is about developing an eco-innovation implementation scale. This instrument is the first known validation study about an eco-innovation measurement instrument in the literature. They divide eco-innovation implementations into 3 groups as: Eco-organization, eco-product and eco-process. They develop 6, 7, and 4 items for each group respectively. Cheng et al. [24] revise and use the same items in their study about the link between eco-innovation and business performance. In order to measure sustainable innovation, some studies use the number of patents and citations. Aguilera-Caracuel and Ortiz-de-Mandojana [25] use the number of green patents to measure green innovation intensity. Markatou [26] measures sustainable innovation with patent based analysis that focus on newly patented technological product innovations that can be described by sustainability related fields. In contrast, Petruzzelli et al. [27] measure the value of green innovations by the total number of citations the specific patent received within 5 years of the filing date, excluding self-citations belonging to the focal company. Similarly, Berrone et al. [28] use the total number of citations received by the patents granted each year to a focal firm to measure environmental innovation. In another study, Wagner [3] developed a proxy to measure ‘innovation with high social benefits’ using three useful variables of the Kinder Lydenburg Domini (KLD) social rating database and Padgett and Moura-Leite [29] use the same variables as well. Three different outcomes to measure sustainable innovation used by Ketata et al. [30] are: reduction in resource/energy consumption, reduction of environmental stress, and improvement of health and safety.

At the same time, some index studies were reviewed. Shuaib et al. [31] develop a product sustainability index that is one of the most important studies in the literature. They consider economic, environmental, and societal aspects of sustainability. This study has 13 clusters and 45 sub-clusters to evaluate product sustainability. The other prominent evaluation schema, Global Report Initiative [32] is a guide that has different items in sub-indexes to evaluate the sustainability aspect of an innovation. Apart from these studies, measurement scales to evaluate sustainable innovation are lacking in literature. The study presented in this paper is an initial effort at developing such a scale to fill this gap. For this purpose, we propose a model and develop an initial measurement scale based on the literature review as presented in the following sections.

3. Model Development

In the model development phase, studies in literature were reviewed thoroughly to propose a measurement model. We had some critical points to ask the question, what would be the boundaries of the model? Fig.2 shows that there are different decision and alternative points that could be used to propose a model. The color boxes indicate our selections. According to the points that we chose, the measurement model should be result and output oriented because we aim to develop a scale to measure sustainable innovation performance. Also, performance measurement is more related to output and result-oriented processes while capability measurement is more related to the input and process. At the same time, we focused on product and process level innovation. These two levels are more observable to evaluate sustainable innovation than the system level. This study is an initial work and the system level could be taken into consideration in future studies. On the other hand, the measurement model should have economic, environmental and societal aspects of sustainability in accordance with sustainable innovation definition. The question type was also selected as perceptual because it is an easy way to collect data from industry with this type in order to validate the measurement scale. Companies are usually prone to reject requests to give numerical data about themselves. Hence, perceptual questions were preferred to increase response rate. Even though questions are perceptual, they can be converted to numerical ones easily in order to measure a firm's own sustainable innovation performance.

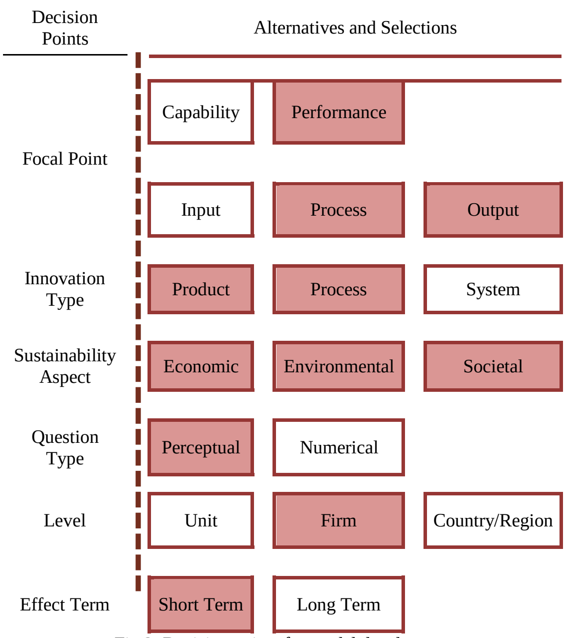

Fig.2. Decision points for model development

Also, the firm level is more suitable for this study because an innovation is the result of an interaction of several units in a company; hence we don't target the region or country level innovation measurement in this study. Moreover, short term effects of innovation were taken into consideration because the long term effects of innovation are related not only to innovation performance but also to financial and marketing performance of a company. Thus, we focus on short term effects of sustainable innovation to avoid interference other components of firm performance. Based on these reasoning, a measurement model was developed by reviewing the literature and based on decision points mentioned above. Key elements were selected from literature by using an overarching investigation about them and each element was evaluated in order to propose the model. All references for each element of the model can be seen in Table 1. Three main sustainability aspects are considered as clusters, aspects to be evaluated for each of them are classified as sub clusters in Table 1.

We focused on some prominent studies that were mentioned by others frequently. At the same time, a few valuable contributions were made to societal aspect in order to increase the understandability of societal aspect of sustainable innovations. In the model, we suggest that three elements should be used to evaluate the economic aspect of each product and process innovation; innovation expenditure, number of new sustainable products or processes, sustainable patents and citations. Innovation expenditure covers total expenditure for innovation, such as R&D activities, training and commercialization, which is needed to manage basic processes of an innovation. Number of new commercialized sustainable products or number of new processes that change resource efficiency and productivity are the common robust output indicators of innovation performance. In a similar vein, number of sustainable patents and patent's citations of a sustainable product or process is another prominent criterion to measure the short term effect of sustainable innovation.

Table 1. Sub clusters and their references.

Aspect	Sub cluster	Innovation Type	References
Economic	Innovation Expenditure	Product/ Process	[22], [33]
	New Sustainable Products	Product	[22], [3], [33]
	Sustainable Patent & Citation	Product/ Process	[22], [27], [26], [33], [34], [28]
	New Sustainable Processes	Process	[22]
Environmental	Material Usage	Product/ Process	[8], [35], [36], [37], [30], [38], [31]
	Energy Usage	Product/ Process	[8], [39], [35], [36] [30], [38], [31]
	Other Resource Usage	Product / Process	[8], [39], [35], [36], [30], [38], [31], [37]
	Waste & Emission & Pollution	Product/ Process	[8], [35], [39], [37], [24], [31]
	End-of-Life Management	Product/ Process	[8], [39], [35], [31]
	Certification & Eco-Label	Product/ Process	[8], [21], [37], [38], [31]
Societal	Health and Safety	Product/ Process	[36], [32], [30], [31]
	Quality and Durability	Product	[31]
	End-of-Life Management	Product	[8], [35], [24], [38], [31]
	Certification	Process	[24]
	Ergonomic	Product/ Process	Added by authors

For the environmental aspect, six elements are proposed for each sustainable product and process innovation: material usage, energy usage, other resource usage, life management, certification & eco-labels, and waste, emission and pollution. Less usage of material, energy and other resources during product usage for product innovation and during production for process innovation are critical points in terms of environmental issues. At the same time, quantity of waste, emission and pollution should be considered during production and product usage in order to respect the environment. Sustainable processes should have capability to reuse and remanufacture components and to recycle materials. Similarly, sustainable products should be designed and improved for reuse, recycling and recovery of materials or component parts. Finally, the production process should adopt environmental procedures like EMAS and ISO 14001 [21]. It is important point for sustainable products to be designed and improved to meet environmental criteria or directives and specific labels, such as Energy Star, Blue Angel, etc., should be attached to products.

For the societal aspects of a sustainable product, four elements are considered: health and safety, durability and quality, end of life management, and ergonomics. Health and safety is one of the most important issues for a product during the usage by a consumer, so it was identified as a criterion to measure the performance of a sustainable product innovation. Also, durability, quality and ergonomics should be taken into consideration to evaluate the societal aspect of a product for consumers. At the same time, products should be easy to disassemble, remanufacture, recycle, disposal, etc. at their end of life in order to be able to evaluate the product as a sustainable innovation. Similarly, for the societal aspects of a sustainable process, three clusters are proposed: health and safety, certification, and ergonomics. Health and safety, and the ergonomic conditions are critical points for employees during production. Also, sustainable processes should be designed and improved continuously to reduce rates of injury, occupational diseases, and work-related fatalities and to provide more ergonomic conditions (noise, resistance, illumination, ease of equipment usage, etc.). At the same time, manufacturing processes should adopt health and safety procedures like OHSAS 18001 or ISO 26000. The sustainable innovation measurement model, considering all the above clusters and sub-clusters is shown in Figure 3. In light of the explanations above and the proposed model, items were gathered from literature to obtain a measurement item pool.

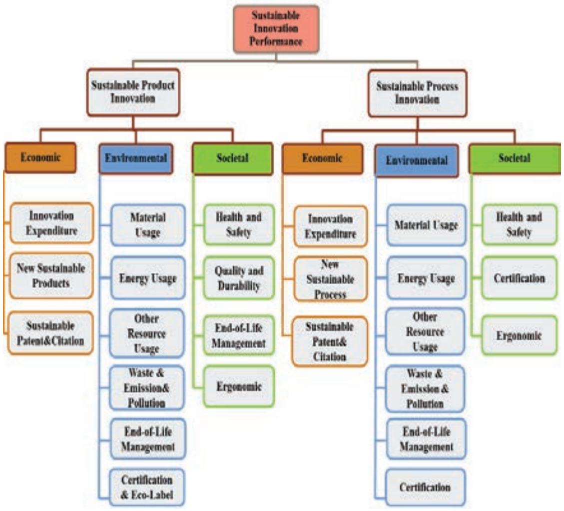

Fig.3. Measurement model

4. Item generation and scale development

Forty seven articles and two index studies were selected to gather measurement items. These studies were classified in terms of sustainability aspect, scale, question type, and other focal points that were mentioned in the model development phase in order to obtain an item pool. This pool had 133 measurement items initially and these items were classified according to the proposed model. The items that had similar meaning and purpose were put together. After that, the initial measurement scale was developed by evaluating each item for their relevance considering: ability to assess economic, environmental and societal aspects of innovation; ability to evaluate innovation at product and process levels; as well as contribution in terms of results or process performance. After this evaluation an initial measurement scale was obtained with 34 questions. The distribution of questions can be seen in Table 2.

Table 2. The distribution of measurement questions.

Type/Aspect	Economic	Environmental	Societal	Total
Sustainable Product Innovation	3	11	5	19
Sustainable Process Innovation	3	9	3	15
Sustainable Innovation	6	20	8	34

Following this, a survey was developed based on this initial scale. Some examples of questions used in the survey are shown in Table.3. A five point Likert scale will be used to evaluate the questions by participants. This part of our study is a work in progress and that data collection and analysis has not been completed. After collecting survey data and conducting statistical analyses, the model will be validated and the final measurement scale will be obtained.

5. Conclusion and future research

In this study, we aim to develop an initial scale to evaluate sustainable innovation performance. For this purpose, the literature was thoroughly reviewed to identify sustainable innovation measurement related studies in order to develop a measurement model and scale. The measurement scale was obtained by evaluating each item in terms of components of our model. This study presents the first known scale to measure sustainable innovation performance and can be used by companies to evaluate sustainable product or process innovativeness.

For future research, this scale needs data from manufacturing companies in order to validate it. Therefore, a survey will be conducted to gather data from industry participants. After collecting survey data, statistical analyses will be conducted to evaluate the data and validate the model presented.

Table 3. Examples of measurement questions.

Aspect	Items	Innovation Type	Questions
Economic	Innovation Expenditure	Process	Over the past few years, our company has consistently increased expenditure for process innovations which provide environmental and social benefits.
	New Sustainable Products	Product	Over the past few years, our company has consistently developed and commercialized new products which provide environmental and social benefits.
Environmental	Material Usage	Process	Over the past few years, our company has improved the manufacturing processes effectively to reduce the use of raw materials.
	Energy Usage	Product	Our new products consume less energy during product usage than those of our competitors.*
	Waste & Emission & Pollution	Process	Our manufacturing processes effectively reduce the emission of hazardous substances or waste more than those of our competitors*
	End-of-Life Management	Process	Over the past few years, our company has actively improved manufacturing process capability to reuse and remanufacture components.
	Certification & Eco-Label	Product	Over the past few years, our company has redesigned and improved our products to meet new environmental criteria or directives (such as WEEE Directive, RoHS Directive etc.).*
Societal	Health and Safety	Process	Over the past few years, our company has actively designed and improved our production process to reduce rates of injury, occupational diseases, and work related fatalities.
	Quality and Durability	Product	Over the past few years, return and recall rate of our products have decreased consistently.
	Ergonomic	Product	Our new products are perceived by consumers as more ergonomic than those of our competitors.

*Questions were adapted from Chen [8]

Acknowledgements

This study is supported by TUBITAK (The Scientific and Technological Research Council of Turkey)-2214/A.

References

[1] World Commission on Environment and Development, 1987. Our Common Future, Oxford University, Oxford.

[2] Klewitz J., Hansen E. G., 2014. Sustainability-oriented innovation of SMEs: a systematic review, Journal of Cleaner Production, 65, p. 57-75.

[3] Wagner M., 2010. Corporate Social Performance and Innovation with High Social Benefits: A Quantitative Analysis, Journal of Business Ethics, 94, p. 581–594

[4] Tello S. F., Yoon E., 2008. Examining Drivers of Sustainable Innovation, International Journal of Business Strategy, 8, 3, p. 164-169.

[5] Bos-Brouwers H. E. J., 2010. Corporate Sustainability and Innovation in SMEs: Evidence of Themes and Activities in Practice, Business Strategy and the Environment, 19, p. 417–435.

[6] Boons F., Lüdeke-Freund F., 2013. Business models for sustainable innovation: state-of-the-art and steps towards a research agenda, Journal of Cleaner Production, 45, p. 9-19.

[7] Chen, Y.-S., Lai S. B., Wen C.T., 2006. The Influence of Green Innovation Performance on Corporate Advantage in Taiwan, Journal of Business Ethics, 67, p. 331–339.

[8] Chen, Y.-S., 2008. The driver of green innovation and green image-green core competence, Journal of Business Ethics, p. 81, 531–543.

[9] Huang, Y.-C., Wu, Y. C.-J., 2010. The effects of organizational factors on green new product success: Evidence from high-tech industries in Taiwan, Management Decision, 48, p. 1539-1567.

[10] Chang, C.-H., 2011. The Influence of Corporate Environmental Ethics on Competitive Advantage: The Mediation Role of Green Innovation, Journal of Business Ethics, p. 104, 361–370.

[11] Chiou, T. Y., Chan, H. K., Lettice, F., Chung, S. H., 2011. The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan, Transportation Research Part E, 47, p. 822–836.

[12] Ar, I. M., 2012. The impact of green product innovation on firm performance and competitive capability: the moderating role of managerial environmental concern, Procedia - Social and Behavioral Sciences, 62, p. 854-864.

[13] Tseng, M. L., Chiub, A. S., 2012. Grey-entropy analytical network process for green innovation practices, Procedia - Social and Behavioral Sciences, p. 57, 10 – 21.

[14] Wong, S. K. S., 2012. The influence of green product competitiveness on the success of green product innovation Empirical evidence from the Chinese electrical and electronics industry, European Journal of Innovation Management, 15, 4, p. 468-490.

[15] Chang, C.-H., Chen, Y.-S., 2013. Green organizational identity and green innovation, Management Decision, 51, 5, p. 1056-1070.

[16] Chen, Y.-S., Chang, K.-C., 2013. The nonlinear effect of green innovation on the corporate competitive advantage, Quality & Quantity Journal, 47, p. 271–286.

[17] Tseng, M. L., Wang, R., Chiub, A. S., Geng, Y., Lin, Y. H., 2013. Improving performance of green innovation practices under uncertainty, Journal of Cleaner Production, p. 40, 71-82.

[18] Wong, S. K. S., 2013. Environmental Requirements, Knowledge Sharing and Green Innovation: Empirical Evidence from the Electronics Industry in China, Business Strategy and the Environment, 22, p. 321–338.

[19] Wu, G.-C., 2013. The influence of green supply chain integration and environmental uncertainty on green innovation in Taiwan's IT industry, Supply Chain Management: An International Journal, 18, 5, p. 539–552.

[20] Horbach, J., Rammer, C., Rennings, K., 2012. Determinants of eco-innovations by type of environmental impact-The role of regulatory push/pull, technology push and market pull, Ecological Economics, 78, p. 112–122.

[21] Antonioli, D., Mancinelli, S., Mazzanti, M., 2013. Is environmental innovation embedded within high-performance organisational changes? The role of human resource management and complementarity in green business strategies, Research Policy, 42, p. 975– 988.

[22] Arundel, A., Kemp R., 2009. Measuring eco-innovation, UNI-MERIT Research Memorandum, Maastricht, The Netherlands.

[23] Cheng, C. C., Shiu, E. C., 2012. Validation of a proposed instrument for measuring eco-innovation: An implementation perspective, Technovation, p. 32, 329–344.

[24] Cheng, C. C., Yang, C.-I., Sheu, C., 2014. The link between eco-innovation and business performance: a Taiwanese industry context, Journal of Cleaner Production, 64, p. 81-90.

[25] Aguilera-Caracuel, J., Ortiz-de-Mandojana, N., 2013. Green Innovation and Financial Performance: An Institutional Approach, Organization & Environment, 26, 4, p. 365–385.
[26] Markatou, M., 2012. Measuring 'Sustainable' Innovation in Greece: A Patent Based Analysis, Journal of Innovation & Business Best Practices, p. 1-10,
[27] Petruzelli, A. M., Dangelico, R. M., Rotolo D., Albino, V., 2010. Organizational factors and technological features in the development of green innovations: Evidence from patent analysis,» Innovation: Management, policy & practice, p. 13, 291–310.
[28] Berrone, P., Fosfuri, A., Gelabert, L., Gomez-Mejia, L. R., 2013. Necessity as the mother of 'green' inventions Institutional pressures and environmental innovations, Strategic Management Journal, 34, p. 891–909.
[29] Padgett, R. C., Moura-Leite, R. C., 2012. Innovation with High Social Benefits and Corporate Financial Performance, Journal of Technology Management & Innovation, 7, 4, p. 59-69.
[30] Ketata, I., Sofka, W., Grimpe, C., 2015. The role of internal capabilities and firms' environment for sustainable innovation: evidence for Germany, R&D Management, 45, 1, p. 1-16.
[31] Shuaib, M., Seevers, D., Zhang, X., Badurdeen, F., Rouch, K. E., Jawahir, I. S., 2014. Product Sustainability Index (ProdSI)-A Metrics-based Framework to Evaluate the Total Life-cycle Sustainability of Manufactured Products,Journal of Industrial Ecology, 18, 4, p. 491-507.
[32] GRI, 2014. Sustainability Reporting Guidelines, Global Reporting Initiatives.
[33] Basso, L. F. C., Braga, A. C. S., Santos, D. F. L., Lopes, F., 2013. Eco-Innovation in Brazil. The Creation of an Index, The Business & Management Review, 4,1, p. 2-17.
[34] Caracuel, J. A., Mandojana, N. O., 2013. Green Innovation and Financial Performance: An Institutional Approach, Organization & Environment, 26,4, p.365– 385.
[35] CIS, 2009. The Community Innovation Survey, European Commission.
[36] De Marchi, V., 2012. Environmental innovation and R&D cooperation: Empirical evidence from Spanish manufacturing firms, Research Policy, 41, p. 614– 623,
[37] Dong, Y., Wang, X., Jin, J., Qiao Y., Shi, L., 2014. Research on effects of eco-innovation types and regulations on firms' ecological performance: Empirical evidence from China,» Journal of Engineering and Technology Management, 34, p. 78–98.
[38] Li, Y., 2014. Environmental innovation practices and performance: moderating effect of resource commitment, Journal of Cleaner Production, 66, p. 450-458.
[39] Lin C. Y., Ho, Y.-H., 2008. An Empirical Study on Logistics Service Providers' Intention To Adopt Green Innovations, Journal of Technology Management & Innovation, 3, 1, p. 17-26.