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A PROPOSED FRAMEWORK FOR CONSTRUCTING AN ENVIRONMENTAL LEAN INDEX BY USING ANALYTICAL HIERARCHY PROCESS TO MEASURE ENTERPRISE'S ENVIRONMENTAL PERFORMANCE

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Abstract: This study creates a single AHP environmental lean index to assess the effects of lean adoption on environmental performance and its information systems from a scholarly perspective. Additionally, the suggested Prior research has mostly neglected how leanness has affected environmental management accounting systems and has instead concentrated on quantifying leanness levels. Therefore, the purpose of this article is to establish a unified environmental lean index utilizing the analytical hierarchy process (AHP) in order to assess the effect of an organization's lean implementation on the environmental performance of its value chain. To show sustainable performance measurement for a lean company and the creation of a lean index, a descriptive analytical technique is utilized to analyze the body of literature. Additionally, a framework for creating an integrated AHP-environmental lean index based on publicly published financial and non-financial environmental accounting information is proposed using a constructive approach. To implement the proposed index, a case study methodology was used at a facility that makes washing machines. The findings demonstrate that while previous performance accounting information systems had their shortcomings, modern performance measurement methods have overcome them, but none of them are suitable for measuring lean performance. As

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a result, an integrated AHP-environmental lean index is created. With an 80.5% current AHP-environmental lean, the factory has met 80.5% of its long-term environmental objectives. Significantly favorable effects on the factory's environmental performance and its environmental management index gives managers a way to gauge performance gaps and pinpoint areas where integrated corporate reporting systems need strengthening. Through the creation of a single AHP environmental lean index and integrated business reporting tool, this study is the first to assess the effects of lean adoption on the environmental performance of an enterprise's value chain.

Keywords: Lean Index, Environmental Management Accounting Systems, Integrated Business Reporting Systems, Environmental Accounting Information, Environmental Performance Index, Environmental Performance, Performance Measurement, Analytical Hierarchy Process

1. INTRODUCTION

Bresciani *et al.* (2023) stated that environmental management accounting (EMA) supports managers in making better decisions by informing them about the environmental impacts of an organization beyond its boundaries and about environmental issues that influence the organization. This includes economic drivers and the consequences of environmental issues. EMA can help identify environmental problems caused, environmental improvements made, and how they relate to the economic performance of the organization. Recently, the World Economic Forum released the Environmental Performance Index (EPI) 2022, which is a global rating system to rank 180 countries using 40 performance indicators in terms of climate change performance, environmental health, and ecosystem vitality. This index is a useful tool to support the achievement of sustainable development goals (SDGs). Also, this index can help decision-makers identify all the factors that can contribute to enhanced environmental performance and integrated business reporting systems.

In 1992, the United States Environmental Protection Agency (USEPA) initiated a voluntary program for EMA development conducted by the Environmental Management Accounting Research and Information Center (EMARIC). This program aims to build a unified framework for identifying and defining environmental costs, establishing principles, and integrating environmental information in the decision making process. Since 2000, EMA has become more popular in research and practice. EMA has been viewed as an extension of management accounting for solving environmental problems. Management accountants are trained to improve the quality of environment-related information and apply it in decision-making for investment appraisal, capital budgets, and strategic management because management accountants play an important role in verifying the honesty and reliability of information, from tracking, collecting, and disclosing information to more strategic roles in policy and planning (Tam Le *et al.*, 2019).

Although the environment is becoming an increasing issue in many countries, traditional management accounting practices have many limitations related to environmental performance. A traditional accounting system does not provide a specific view of environmental impacts but instead focuses on financial performance. Nowadays, the important role of environmental management accounting (EMA) in environmental management has become more obvious (Deb *et al.*, 2022).

Consequently, environmental sustainability has received increasing attention because of external regulations that result in imposed responses to environmental practices and their impact on environmental management accounting systems. It also results in increasing organizational commitment toward the environmental dimension of sustainability across the entire enterprise (Closs *et al.*, 2011). As a result, the increasing interest in performance measurement is considered a reflection of increasing pressure on enterprises to improve their sustainable performance, especially environmental performance, and its impact on environmental management accounting systems.

Although performance measurement is considered a challenging task, it represents a risk to an enterprise if inappropriate or irrelevant measures are used. So, an enterprise should first understand its goals, which can be achieved through performance measurement, and then select appropriate performance measures (El-Khalil, 2020).

On the other hand, many enterprises failed to become lean due to the difficulty of managing and controlling lean transformation without an appropriate performance measurement system. It was indicated that many enterprises all over the world started their lean journey, but only 10% or less of these enterprises had succeeded in their transformation of business information systems. That is due to an unclear understanding of lean performance and how to measure it. In addition, most enterprises have been confused between the measurement of leanness level and the measurement of leanness impact, which results in the selection of inappropriate measures in the assessment process (Mirdad & Eseonu, 2014; Alaskari *et al.*, 2016).

Although the impacts of lean implementation on an enterprise's sustainable performance and its environmental management accounting systems have been mentioned in the literature, there is still a scarcity of literature about the measurement of these impacts. It was found that many studies had focused on measuring an enterprise's leanness level and ignored the measurement of lean implementation's impact on the enterprise's sustainable performance in its environmental management accounting systems. Wichramasinghe and Wichramasinghe (2017) and Wong *et al.* (2014) stated that the term leanness is used to determine the extent of adopting lean to fulfil the prerequisites of a successful and sustainable lean enterprise transition. Measurement of leanness level, which is also called practice-based assessment. Narayanamurthy and Gurumurthy (2016) stated that practice-based assessment was performed to monitor an enterprise's progress toward its lean journey by determining the extent to which prerequisites of lean transition are fulfilled. Measurement of leanness impact, which is also called performance-based assessment. Narayanamurthy and Gurumurthy (2016) stated that performance-based assessment should be performed after practice-based assessment to assess the benefits attained from lean transition. In other words, the purpose of measuring the impact of leanness is to measure the impact of lean implementation on the sustainable performance of a firm's value chain.

In addition, no attempts have been found in the literature to measure lean implementation's impacts on an enterprise's environmental performance and its environmental management accounting systems through constructing a unified measure that combines both quantitative and qualitative lean and environmental measures across an enterprise's value chain activities.

To fill this gap, the main contribution of this paper is to propose a framework to construct a unified environmental lean index based on financial and non-financial disclosed environmental accounting information by using the analytical hierarchy process (AHP) to measure the impact of lean implementation on the environmental performance of an enterprise's value chain as one sustainability dimension. Consequently, the following question can also be answered: how can the proposed AHP-environmental lean index be constructed to measure the environmental performance of an enterprise's value chain?

The proposed AHP-environmental lean index, based on financial and non-financial disclosed environmental accounting information, can be used by managers to measure the environmental performance of their enterprises' value chain as a whole and identify the performance gap of its lean implementation. The proposed index involves both quantitative and qualitative lean and environmental measures across the value chain's activities. In addition, AHP is used in constructing the proposed index to rank or select the appropriate performance measures according to their relative importance.

To achieve these goals, Section 2 presents a literature review and theoretical background; Section 3 presents the methodology; Section 4 presents the proposed framework; Section 5 presents a case study and the implementation of the proposed index; Section 6 presents results and discussion; and Section 7 presents conclusions and recommendations for future research.

2. LITERATURE REVIEW AND THEORETICAL BACKGROUND

This section involves studies related to sustainable performance measurement in a lean enterprise and the construction of a lean index for measuring the environmental performance of an enterprise's value chain. So that literature review can be divided as follows:

2.1. Sustainable performance measurement of a lean enterprise

Performance measurement is defined by Neely *et al.* (1995) as a process of quantifying an enterprise's actions through the use of performance measures. Performance measurement systems are considered a set of balancing multiple financial and nonfinancial measures across the entire enterprise that are used to quantify the efficiency and effectiveness of the enterprise's actions. Any performance measurement system could demonstrate if an enterprise is going in the right direction or not and monitor its movements continuously.

Arif-Uz-Zamman and Ahsan (2014) and Kumar *et al.* (2017) stated that performance measurement supports monitoring and recording actual performance, identifying, and bridging the gap between expected and actual performance, identifying performance improvement opportunities, providing relevant information to make decisions, and encouraging continuous improvement.

It was found that performance measurement has gained significant interest as a popular research topic in the last 15 years. During this period, many attempts have been made to design new performance measurement systems due to the limitations of traditional performance measurement systems. These limitations, which were highlighted in the literature (Bhasin, 2015; Eaidgah & Maki, 2016; Pickering & Byrnes, 2016), can be summarized as follows:

- Traditional performance measures are not relevant for strategic decisions.
- Traditional performance measures are focused only on financial measures. On the other hand, non-financial measures like quality, flexibility, and productivity have been ignored.

- There are too many measures, which may increase the risk of information overload and inconsistency among performance measures.
- Traditional performance measures are backward-looking. It means that traditional measures are historically oriented, which can't provide an indication of future performance.
- Lack of strategic focus. It means that traditional financial measures are not linked to the enterprise's strategy.
- Traditional performance measures are short-term focused, which means that they focus only on the results of an organization's activities.
- Traditional performance measures are internally focused. It means that traditional measures are focused only on internal stakeholders of the enterprise and ignore external stakeholders like customers or suppliers.
- Traditional performance measures are irrelevant and harmful to a lean enterprise because they motivate non-lean behaviours.

2.2. Analyzing current performance measurement systems from a sustainable lean enterprise perspective

Susilawati *et al.* (2013) presented an overview of current performance measurement systems like strategic measurement analysis and reporting technique (SMART), performance measurement questionnaire (PMQ), balanced scorecard (BSC), performance prism, integrated performance measurement system (IPMS), and dynamic multi-dimensional performance (DMP) framework. Also, a performance measurement and improvement system (PMIS) for a lean manufacturing system was proposed in the study to overcome the limitations of current systems. The proposed framework considered hierarchical levels of organization and multiple criteria for lean manufacturing performance measures.

Sangwa and Sangwan (2017) presented an integrated performance measurement framework to measure the impact of lean implementation on some organizational functions. The study identified these functions in terms of seven categories, which were divided into twenty-six performance dimensions. These categories are manufacturing, new product development, human resource management, finance, administration, customer, and supplier management. Also, key performance indicators for each performance dimension had been determined and classified into quantitative and qualitative measures.

Swarnakar *et al.* (2022) proposed an approach to develop and prioritize lean performance measures to assist managers in measuring the sustainable performance of their firms. Sarker *et al*. (2021) and Trisyulianti *et al*. (2022) presented a sustainability performance measurement model by integrating a balanced scorecard (BSC) with a fuzzy multiple criteria decision-making approach. This model integrates the firm's profit motives with environmental and social aspects. It means that additional perspectives are added to the four BSC perspectives to involve sustainable measures within the BSC template. The proposed model can be used by managers looking to measure the sustainability level of their firms.

Although current performance measurement systems have overcome the limitations of traditional systems, the strengths and weaknesses of these systems from a sustainable lean enterprise perspective are demonstrated in table 1.

Table 1: Strengths and weaknesses of current performance measurement systems

Performance Measurement System	*Strengths*	*Weaknesses*
SMART	It involves both financial and nonfinancial measures. It integrates an enterprise's strategy with operational measures.	It excludes the continuous improvement concept. It focuses only on customers and ignores other stakeholders like suppliers and employees.
BSC	It involves financial and nonfinancial measures. It is widely accepted and used. It provides a strategy map to reflect interrelationships among measures.	It focuses on internal factors with less attention to external factors. It consumes a great amount of time and resources to be implemented and updated. Not all measures proposed in the template are appropriate at any time. It is considered as a monitoring and controlling tool rather than an improvement tool.
Performance Prism	It identifies stakeholders and their needs first then selects the appropriate strategy. Appropriate measures are selected in the light of chosen strategy.	It focuses only on external organizational view.
IPMS	It considers continuous improvement concept. It provides a comprehensive performance measurement system.	It does not specify objectives and timelines for development and implementation.

Performance Measurement System	*Strengths*	*Weaknesses*
PMQ	It determines improvement areas of enterprise as a whole and their associated performance measures. It evaluates the ability of existing performance systems used in supporting such improvements.	It is complicated. It excludes the continuous improvement concept. It does not consider human resource dimensions. It does not align strategy with performance measurement system. So, it does not reflect changes occurred in enterprise's strategy
DMP Framework	It can reflect an organization's sustainable performance in multiple time horizons. It considers human resource dimensions. It is more flexible because, it can be used by different organizations in different industries.	It is criticized by Susilawati *et al.*, (2013) because DMP cannot provide a clear way of measuring performance at enterprise's levels and does not consider external environment within which an enterprise operates.

It can be noted from table 1 that none of these current performance measurement systems is relevant for a sustainable lean enterprise because of the following reasons:

- None of these systems involves both lean and sustainable measures together across the whole enterprise.
- None of these systems considers the relative importance of performance measures as a criterion for their selection.
- None of these systems involves sustainable measures except BSC. Figge *et al.* (2002) provided three alternatives to incorporating sustainability into BSC. For example, integrating social and environmental measures within BSC's perspectives, developing a separate but linked social or environmentally sustainable scorecard, or adding non-market elements (social or environmental) to the scorecard as a fifth perspective.

It was stated that a lean enterprise requires new kinds of performance measurements derived from the enterprise's strategy. These measures should reflect lean principles, drive the value stream's improvement, monitor commitment to standards in lean cells, and link cells and the value stream to the enterprise's strategies and goals. These measures are called the "starter set of performance measures at three levels: cell, value stream, and enterprise-level performance measurements (Baggaley, 2006).

Also, conventional VSM and box scores were provided to measure and assess only the economic performance in terms of financial and operational lean improvements. In other words, traditional VSM does not consider environmental and social sustainability performance. On the other hand, various studies have focused on proposing sustainable value stream mapping (Sus-VSM), which is considered an extension of traditional VSM to involve environmental and social measures besides economic measures, or "lean measures" (Faulkner & Badurdeen, 2014; Yin Lee *et al.*, 2021).

It can be noted that although many studies have focused on proposing Sus-VSM to capture lean measures with sustainability measures, the emphasis is still limited to only environmental performance in conventional VSM, except for the study of Faulkner and Badurdeen (2014). This study focused on measuring the performance of manufacturing activities only in terms of three dimensions of sustainability.

Also, it was stated that without unified lean measures to be used across the enterprise, demotivation, dissatisfaction, and a drop in performance can be achieved. So, the desired lean outcomes cannot be attained. Therefore, it is recommended that multiple lean measures be integrated into a unified index through which all enterprises' aspects can be aligned and employees have been willing to work together to achieve lean enterprises' goals. It can be discussed in the following section.

2.3. Construction of a lean index for measuring the environmental performance of an enterprise's value chain

Environmental issues such as changing climates, carbon emissions, waste disposal, landfill usage, land and water contamination, resource consumption, and material recycling have enhanced managers' awareness. Additionally, "increased regulatory demands and public concern are forcing firms to consider environmental and social considerations in all aspects of their operations," as stated by Baah *et al.* (2021). Environmental issues are becoming increasingly important to many stakeholders, including shareholders, consumers, workers, suppliers, and governments (Baah *et al.*, 2021; Deb *et al.*, 2022). Because of this, many firms are motivated to improve environmental measures and report on the ecological impacts to fulfill their customers' and shareholders' requirements (Iredele *et al.*, 2020). As a result of these expectations, enterprises have been required to experiment with various environmental management practices, bringing environmental sustainability into the realm of strategic management. Thus, this paper establishes a holistic link between the impact of lean implementation on an enterprise's environmental performance and its environmental management accounting systems.

Garza-Reyes (2015) stated that a lean enterprise is faced with environmental challenges like climate change, environmental degradation, and natural resource scarcity. So, it is not enough for the lean enterprise to achieve operational and financial benefits; it also should rethink how its processes and products become more environmentally sustainable. There is a general agreement in the literature that lean implementation can improve the environmental performance of enterprises. Chiarini (2014) stated that the relationship between lean and environmental performance was investigated in the 1990s for the first time. But the nature of this relationship had not been explored yet. At the beginning of the 2000s, the nature of this relationship started to be explored.

Some authors argued that lean implementation results in significant environmental benefits inadvertently, even though there is no direct intention to reduce environmental impacts or adopt green practices (Hajmohammed *et al.*, 2013; Pampanelli *et al.*, 2013; Moreira *et al.*, 2010). It is known as a direct relationship between lean and green.

On the other hand, an enterprise's ability to adopt green practices tends to be greater when the enterprise becomes lean (Jabbour *et al.*, 2013). It is argued that lean implementation can act as a catalyst for the adoption of green practices to realize more environmental improvements, which is known as indirect relationships. Also, Dues *et al.* (2013) stated that when lean and green practices are simultaneously implemented, greater benefits can be attained than when they are separately implemented.

Environmental performance of a lean enterprise can be measured in terms of energy, water, and resource usage, emissions (pollution), and waste management, which are considered aspects of environmentally sustainable performance and will be discussed as follows:

Energy usage: Environmental performance is focused on utilizing clean energy resources efficiently to reduce energy consumption, which results in cost reduction. It is stated that energy consumption has a direct impact on environmental performance because of the utilization of non-renewable resources and the reduction of GHG emissions. Consequently, efficient use of energy in a lean enterprise leads to resource efficiency and economic savings. Improving lighting systems, green building designs, and the utilization of renewable energy solutions are considered examples of energy-efficient technologies (Caldera *et al.*, 2017; Oryncz *et al.*, 2020; Salah & Mustafa, 2021).

Water usage: Water is a scarce resource and should be carefully utilized to satisfy current and future needs. Water usage is an important aspect because it assesses the amount of water consumed during the product's life cycle (Viles *et al.*, 2021). Also, Caldera *et al.* (2017) stated that increasing water capacity for reuse, reducing wasted water, and reducing pollution are considered better ways for water management.

Resource (material) usage: Materials' usage, especially non-renewable resources, influences the availability of the resources, which may harm the environment. So, environmental impacts and the rate of natural resource depletion can be reduced by reducing material usage and increasing the ability to recycle scrap materials. Also, the usage of toxic (chemical) substances should be reduced because they pose threats to human health and the environment (Sangwan *et al.*, 2017; Garcia-Alcaraz *et al.*, 2021). So, it can be concluded that recycling scrapped materials and efficient utilization of non-hazards and/or renewable resources are considered important aspects of improving environmental performance.

Emissions management: Emissions management is an important strategy to reduce carbon dioxide and other emissions that have negative impacts on the environment, like global warming, air pollution, and changes in weather patterns. So, carbon footprint analysis, renewable energy usage, and emissions trading are critical strategies for emissions management (Caldera *et al.*, 2017).

Waste management: Manufacturing companies should focus on techniques of waste reduction in their production processes to enhance their environmental performance and reduce negative impacts on the environment. It can be done by promoting reusing, recycling, and remanufacturing practices to extend the life of materials and products, which in turn attains circular economy (CE) goals (Vrchota *et al.*, 2020). Solid or liquid wastes are examples of wastes that can be discharged into the environment. Improperly discarding waste would have negative impacts on human health and the environment. Therefore, waste management practices like reduce, reuse, and recycle should be adopted (Caldera *et al.*, 2017; Purushothaman *et al.*, 2020; Sari Hartanti *et al.*, 2022).

There were many attempts in the literature to provide a lean index, which was defined as the summation of weighted scores of multiple lean measures, representing the performance of many lean aspects. Searcy (2009) proposed a unified AHP-lean production score involving both quantitative and qualitative measures to only measure the leanness level of manufacturing activities to determine the extent of adopting lean tools to fulfil the prerequisites of a successful and sustainable lean enterprise transition. Wong *et al.* (2014) proposed a quantified lean index to measure an organization's degree of leanness to sustain a lean transition. Analytical network process (ANP) was used as a type of multi-criteria decision-making tool to consider interrelationships among different measures.

Pakdil and Leonard (2014) provided qualitative and quantitative lean indices based on fuzzy logic to only measure the leanness level of manufacturing activities. Oleghe and Salonitis (2015) proposed a single composite lean index that involves quantitative and qualitative measures to monitor the firms' progress in lean implementation. Multiple lean metrics reflect the performance of various lean aspects. Also, it was stated by Hwang *et al.* (2020) that lean enterprises face another challenging issue, which is the lack of awareness about which and how performance measures can be selected. Some organizations give their performance measures equal weight for simplicity, but this is illogical behaviour because lean and sustainable measures are diversified, and their relative importance is not equal. Salvado *et al.* (2015) stated that the relative importance of performance measures has become an important issue to be considered when decision-makers are interested in many different measures.

Therefore, the findings of the literature review revealed that:

- None of the current performance measurement systems is relevant for measuring the impact of lean implementation on the environmental performance of an enterprise's value chain and its environmental management accounting systems.
- There were no studies focused on measuring lean implementation's impacts on the sustainable performance of an enterprise's value chain and its environmental management accounting systems.
- There were no previous attempts to propose a unified environmental lean index that combines both quantitative and qualitative lean and environmental measures.

3. METHODOLOGY

3.1. Research method

The research methodology of this paper involves a critical review of the literature to demonstrate current performance measurement systems, their strengths and weaknesses from a sustainable lean enterprise perspective, and current lean indices used to measure the sustainable performance of a lean enterprise. In addition, a deductive approach is used to deduce appropriate quantitative and qualitative lean and environmental measures as components of the proposed index. Also, a constructive approach is used to propose a framework for constructing a unified environmental lean index based on financial and non-financial disclosed environmental accounting information by using AHP to measure both the impact of lean implementation on the environmental performance of an enterprise's value chain and the performance gap of its lean implementation.

AHP is considered a multi-criteria decision-making (MCDM) tool that can be used as a methodology to rank the proposed lean and sustainable measures through the enterprise's value chain according to their relative importance in constructing the proposed index. MCDM began in the 1970s and can be used to find the most suitable options or rank them based on how they can satisfy the goals (Abdullah *et al.*, 2023). MCDM analysis permits the ability to analyze different forms of data that have high uncertainty (Pour *et al.*, 2023). MCDM involves several techniques, like AHP, the best- worst method (BWM), and the technique for order preference by similarity to an ideal solution (TOPSIS).

Ranking or selecting the appropriate lean and sustainable measures can be considered a multiple-criteria decision-making problem. So, in this research, AHP can be used as one of multiple criteria decision-making tools to compute the weights of lean and sustainable measures in a mathematical way. So, the researcher would try to measure the impact of lean implementation on the sustainable performance of the enterprise's value chain by constructing a unified AHP-sustainable lean index.

3.2. The proposed framework for constructing the AHP-environmental Lean Index

The proposed index is important because it involves both quantitative and qualitative lean and environmental measures across the enterprise's value chain. The weights of these measures are computed by using AHP to be selected or ranked according to their relative importance. Also, it is a useful measure of both the environmental performance of a lean enterprise's value chain and the performance gap of lean implementation. The proposed AHP-environmental lean index can be constructed by following some phases provided by Searcy (2009) with some modifications, which can be demonstrated in Figure 1. These phases can be discussed as follows:

Phase one is calculating weights and priorities for each component of the proposed AHP-environmental lean index

To calculate weights and priorities for each component of the proposed environmental lean index, two steps should be followed as follows:

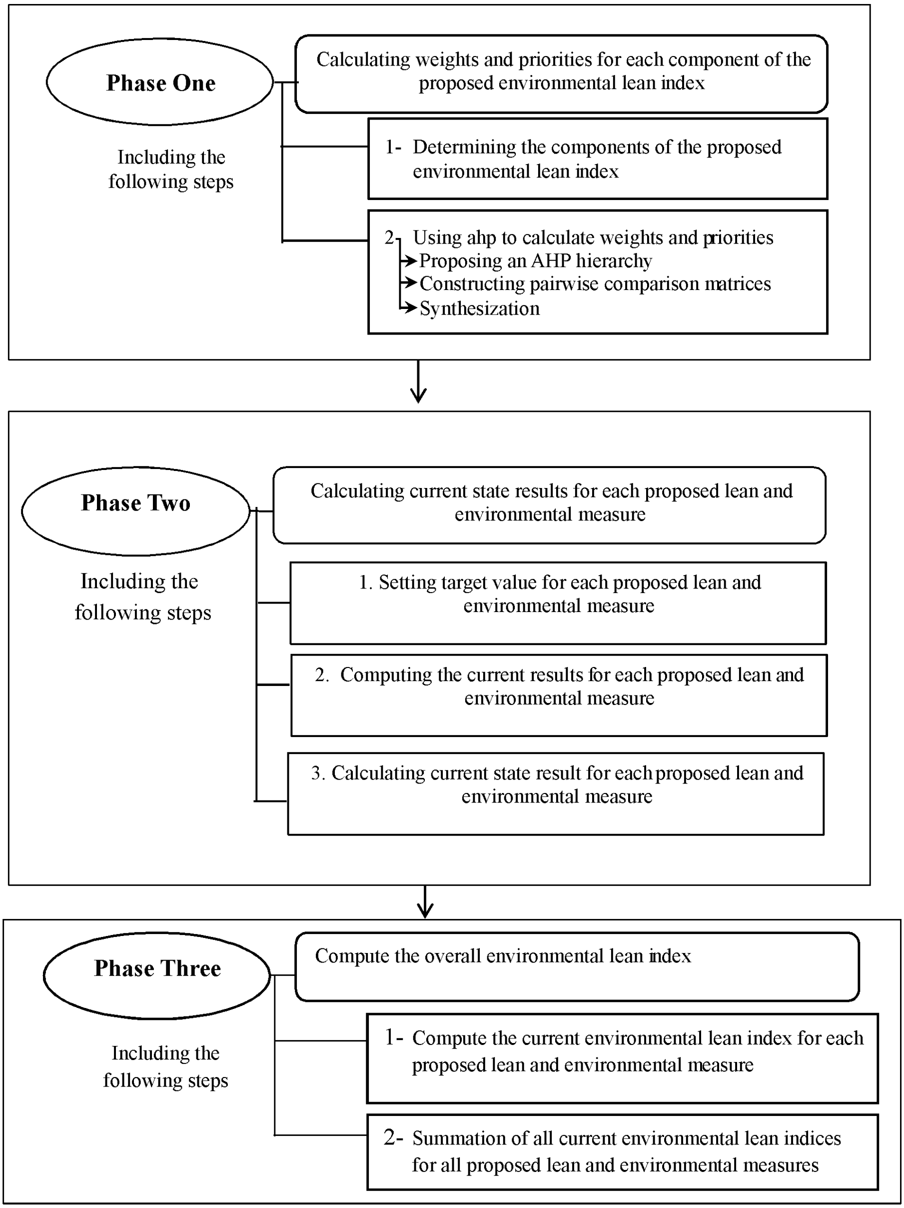

Figure 1: A Proposed Framework for Constructing Environmental Lean Index (Prepared by Researcher)

Step one is determining the components of the proposed sustainable lean index

Environmental performance aspects and proposed lean and environmental measures for each performance aspect represent the components of the proposed environmental lean index. Environmental performance of a lean enterprise can be measured in terms of energy, water, and resource usage, emissions (pollution), waste management, environmental standards, and management systems, which are considered aspects of environmentally sustainable performance.

Also, proposed lean and environmental measures for each environmental performance aspect that were highlighted in the literature can be summarized in Table 2.

Table 2: Proposed lean and environmental measures for each environmental performance aspect

Performance Aspect	*Measures*	*Code*	*Literature*
Resource Usage	Total amount of material used	ER_{e1}	Ocampo (2015); Winroth *et al.*, (2016)
	% of recycled materials used	ER_{e2}	Winroth *et al.*, (2016); Sangwan *et al.*, (2017)
	% of products from recyclable materials	ER_{e3}	
	% of renewable resources used	ER_{e4}	Winroth *et al.*, (2016); Helleno *et al.*, (2017); Sangwan *et al.*, (2017)
	% of green resources used	ER_{e5}	
	Land use	ER_{e6}	
	% of recycled or remanufactured products at end-of-life cycle	ER_{e7}	
	% of products designed for recycle or reuse	ER_{e8}	
	% of hazardous materials substitution during design stage	ER_{e9}	Johansson and Sundin (2014)
	% of green products developed	ER_{e10}	
Water Usage	Total amount of water consumed	EW_{at1}	Ocampo (2015); Winroth *et al.*, (2016); Sangwan *et al.*, (2017)
	% of recycled water used	EW_{at2}	
Energy Usage	Total amount of energy consumed	EE_{n1}	Ocampo (2015); Winroth *et al.*, (2016)
	% of renewable energy consumed	EE_{n2}	
	% of energy efficient vehicles used for transportation	EE_{n3}	Sangwan *et al.*, (2017)
	% of idle energy loss	EE_{n4}	Winroth *et al.*, (2016)
	% of energy consumed for material recycling	EE_{n5}	Sangwan *et al.*, (2017)
	Amount of energy saved due to continuous improvements	EE_{n6}	Winroth *et al.*, (2016)
Emissions	Total amount of GHG emissions released to air	EE_{m1}	Winroth *et al.*, (2016); Sangwan *et al.*, (2017)
	% of emissions released from IT tools	EE_{m2}	
	% of emissions from ozone depleting substances	EE_{m3}	

Performance Aspect	*Measures*	*Code*	*Literature*
Waste	Space for landfill area required for waste treatment	EW_{as1}	Ocampo (2015); Sangwan *et al.*, (2017)
	Waste per unit produced	EW_{as2}	
	% of recycling waste	EW_{as3}	Garbie (2014)
	% of disposing waste	EW_{as4}	
	% of hazardous solid / or liquid waste	EW_{as5}	Winroth *et al.*, (2016); Sangwan *et al.*, (2017);
	% of disposing defected materials/or products after usage	EW_{as6}	
Environmental standards and management system	The extent to which a LE adopts an environmental management system	EES_1	Garbie (2014); Sangwan *et al.*, (2017)
	The extent to which a LE adopts a complete green manufacturing plan	EES_2	
	The extent to which a LE adopts green IT procurement policy	EES_3	Winroth *et al.*, (2016);
	Number of sustainable environmental reports	EES_4	
	Number of environmental awards	EES_5	Garbie (2014); Winroth *et al.*, (2016)
	Number of environmental complaints received per year	EES_6	

*Code
ER_e : refers to resource usage as an environmental performance aspect
EW_{at} : refers to water usage as an environmental performance aspect
EE_n : refers to energy usage as an environmental performance aspect
EE_m : refers to emissions as an environmental performance aspect
EW_{as} : refers to waste as an environmental performance aspect
EES : refers to environmental standards as an environmental performance aspect
1,2,…,n (number of measures under each performance aspect)

Step two is using AHP to calculate weights and priorities

AHP is one of the multi-criteria decision-making (MCDM) tools developed by Saaty in 1980. It can be used to solve problems that require making a decision that satisfies a specified objective by ranking many alternatives in terms of a group of criteria and sub criteria.

To use AHP, the decision-maker can decompose the complex problems into a multilevel hierarchical structure: the overall goal at the top level, criteria and sub-criteria at the middle level, and decision alternatives at the lower level. At each level, all elements are relatively compared with respect to the upper level. The results of the comparisons are used to obtain a relative priority for each element of the hierarchy. Also, a consistency ratio is computed for each pairwise comparison matrix (Oliveira *et al.*, 2022; Hwang *et al.*, 2020).

Saaty (1980) and Salvado *et al.* (2015) stated that AHP is based on decomposition, comparative judgment, and synthetization. Also, AHP involves qualitative considerations of human perception and provides a fundamental ratio measurement scale to convert the verbal preferences of experts or decision-makers into numerical values to determine the relative importance of an alternative or criterion compared with another alternative or criterion in achieving the overall goal. Table 3 presents Saaty's 1-9 scale as follows:

Table 3: Saaty's fundamental ratio measurement scale

Intensity of Importance	*Definition*	*Explanation*
1	Equally important	Two elements contribute equally to the goal
3	Moderately important	Experience and judgment slightly favor one element over another
5	Strongly important	Experience and judgment strongly favor one element over another
7	Very strongly important	An element is strongly favored, and its dominance is demonstrated in practice
9	Extremely important	The importance of one element over another is affirmed on the highest possible order
2,4,6,8	Intermediate values	It is used when compromise is needed

A proposed AHP hierarchy has been constituted from some levels, which can be presented in Figure 2. It can be noted that a proposed AHP hierarchy comprises the following levels:

- Level one represents the overall goal, which is to construct a unified AHP environmental lean index for measuring the impact of lean implementation on the environmental performance of an enterprise's value chain.
- Level two represents criteria that are considered performance aspects of the environmental sustainability dimension, like environmental standards and management systems, resource usage, energy usage, emissions, and waste management.
- Level three represents decision alternatives, which present the proposed lean and environmental measures of each performance aspect.

Pairwise comparison matrices should be established at levels two (criteria) and three (alternatives). A pairwise comparison matrix is established at level two (criteria level) to make a comparison among performance aspects of the environmental performance of a lean enterprise's value chain to determine the relative importance of each performance aspect in constructing the proposed index. Six pairwise comparison matrices are established at level three (alternatives) with respect to level two (criteria) to make a comparison among proposed lean and environmental measures in terms of their corresponding performance aspects. This comparison determines the weight of each proposed measure toward achieving its related performance aspect. Therefore, the proposed lean and environmental measures can be ranked according to their relative importance toward satisfying their related criteria.

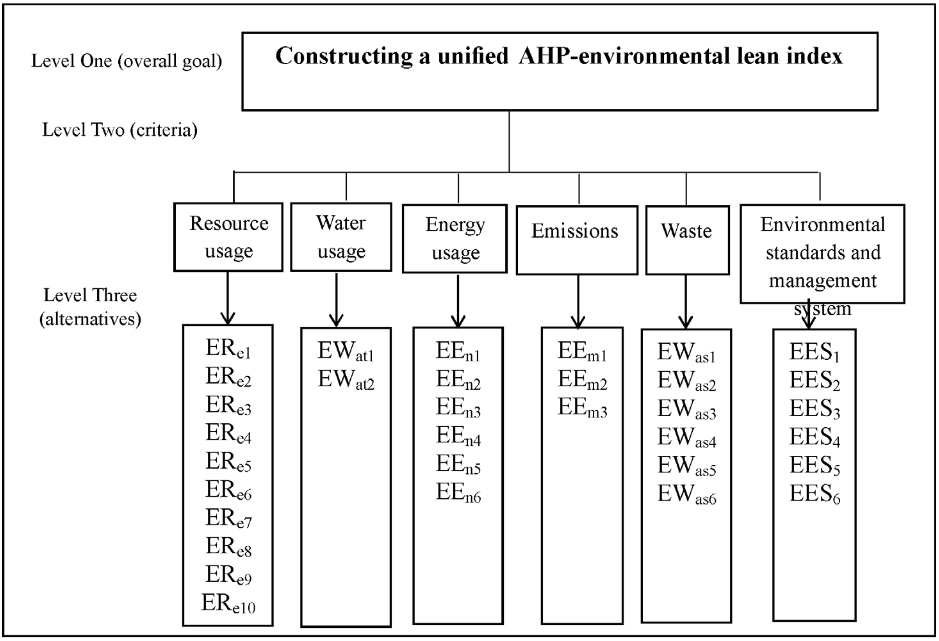

Figure 2: A Proposed AHP Hierarchy (Prepared by Researcher)

Finally, the synthesizing step should be made to obtain the global weights of each decision alternative. The global weight of each proposed lean and environmental measure can be computed by multiplying its local weight by the importance of its related performance aspect. Therefore, the overall priorities of the proposed lean and environmental measures can be calculated to rank these measures according to their relative importance to construct the proposed environmental lean index.

Phase two is calculating the current state results for each proposed lean and environmental measure

There are three steps that should be followed to calculate the current state results for each proposed measure. Step one is setting target values for each proposed lean and environmental measure. Step two is computing the current results for each proposed lean and environmental measure. Current results represent the actual performance of each proposed lean and environmental measure. Step three is calculating the current state results for each proposed lean and environmental measure. Current state results represent the achievement percentage, which can be computed by dividing actual performance by target values.

Phase three is computing the overall AHP-environmental lean index

There are two steps to compute the overall environmental lean index. Step one is computing the current environmental lean index for each proposed lean and environmental measure. The current environmental lean index for each proposed measure can be computed by multiplying the current state result of each measure by its AHP weight. Step two is the summation of all current environmental lean indices for all proposed measures to compute the overall current environmental lean index.

Once the overall current environmental lean index is computed, the performance gap of lean implementation can be measured. The performance gap of lean implementation is computed through the difference between the overall current environmental lean index and the overall future environmental lean index. Overall, the future environmental lean index should be equal to 100%. This gap should be analyzed to determine its drivers, which measures have deteriorated, and to use AHP weights to prioritize improvement efforts.

A Case Study and the Implementation of the Proposed Index

The manufacturing sector, like the home appliance industry, plays a critical role in attaining the SDGs. This sector helps enhance social welfare and minimize the negative environmental impacts of processes and products. Home appliance companies produce refrigerators, washing machines, dishwashers, air conditioners, stoves, and microwave ovens. Nowadays, home appliance companies struggle to provide not only products with high quality and innovative levels but also more environmentally friendly and socially safe products (Sarker *et al.*, 2021).

Unit of analysis: There were no studies in the literature review focused on measuring the impact of lean implementation on the environmental performance of home appliances enterprises" value chain in general and washing machine factories in particular. Also, there has been no prior attempt to propose a unified AHP-environmental lean index based on financial and non-financial disclosed environmental accounting information that can be used to measure the environmental performance of an enterprise's value chain.

So, this study attempts to fill the research gap by proposing a framework for constructing a unified AHP-environmental lean index for measuring the environmental performance of a washing machine factory's value chain and its environmental management accounting systems. So, this factory was selected as a unit of analysis in this study.

Data collection methods: Questionnaires are used as a method of collecting data to attain research objectives. Two questionnaire statements are prepared as follows:

Questionnaire No. 1 is prepared to collect data about target and actual performance for each proposed lean and environmental measure listed under each environmental performance aspect across the factory's value chain. This data will be used in constructing the proposed lean index to measure the impact of a factory's lean implementation on the environmental performance of its value chain. This questionnaire is divided into two parts. The first part involves quantitative learning and environmental measures for each environmental performance aspect. The second part involves qualitative measures for each environmental performance aspect. Only two copies of the first part of the questionnaire were distributed to managers of both the production and planning departments of the washing machine factory, and 10 copies of the second part of the questionnaire were distributed to many people at different management levels.

A questionnaire No. 2 in the form of pairwise comparisons based on a scale range from 1 to 9 is created to be filled with managers of both the production and planning departments of the washing machine factory who have sound knowledge and understanding about lean and sustainability concepts. Decision-makers are required to fill out this statement to provide their judgments about the relative importance of components of the proposed index. This questionnaire is designed based on Saaty's scale, which ranges from 1 to 9. The questions were: which performance aspect is more important to enhance the environmental performance of a washing machine's value chain, and which measure is relatively weighted more with respect to the given aspect? An example of questionnaire No. 2 based on pairwise comparison established at the criteria level to make a comparison among environmental performance aspects is presented in Table 4. Subsequently, comparison matrices were developed.

Table 4: Comparison among environmental performance aspects

what is more important to enhance environmental performance of washing machine's value chain?																		
	9	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	
Resource usage																		Energy usage
Resource usage																		Water usage
Resource usage																		Waste management
Resource usage																		Environmental standards & management system
Energy usage																		Water usage
Energy usage																		Waste management
Energy usage																		Environmental standards & management system
Water usage																		Waste management
Water usage																		Environmental standards & management system
Waste management																		Environmental standards & management system

3.3. Data analysis

The first part of questionnaire No. 1 was received, which involved estimated data about target performance for lean and sustainable measures at the end of 2020 and actual performance for the year 2021 to calculate the achievement percentage for each measure. There are six performance aspects under the environmental sustainability dimension, with 31 quantitative and sustainable measures. According to the estimates collected about target and actual performance for each measure, they can be summarized in table 5 as follows:

Table 5: Environmental performance measures

Lean and Sustainable Measures for Each Environmental Performance Aspect			
Measures	*Actual Performance (1)*	*Target Performance (2)*	*Achievement (%) (1÷2)*
1. Resource usage			
1-1. Total amount of materials used in production	480,000 tons	480,000 tons	100%
1-2. Percentage of total amount of recycled materials used divided by total amount of materials used.	11,520/480,000 = 2.4%	24,000/480,000 = 5%	48%
1-3. Percentage of total number of washing machines produced from recyclable materials divided by total number of washing machines produced	NA	NA	NA
1-4. Percentage of total amount of renewable materials divided by total amount of materials used	2,400/480,000 = 0.5%	4,800/480,000 = 1%	50%
1-5. Percentage of total amount of green materials used divided by total amount of materials used	465,600/480,000 = 97%	470,400/480,000 = 98%	98.9%
1-6. Number of squared meters of land occupied by the factory	12,900 m^2	15,000 m^2	86%
1-7. Percentage of total number of models designed for recycle/reuse divided by total number of models designed (1)	12/20 = 60%	16/20 = 80%	75%
1-8. Percentage of total number of recycled/reused models divided by total number of models sold	NA	NA	NA
1-9. Percentage of total number of green models (designs) developed divided by total number of models (designs)	15/20 = 75%	17/20 = 85%	88.2%
1-10. Percentage of hazards materials substitution during design stage divided by total amount of materials used	NA	NA	NA

Lean and Sustainable Measures for Each Environmental Performance Aspect			
Measures	*Actual Performance (1)*	*Target Performance (2)*	*Achievement (%) (1÷2)*
2. Water usage			
2-1. Total amount of water used in production (2)	5,520 m^3/year	4,800 m^3/year	1.15
2-2. Percentage of total amount of recycled water used divided by total amount of water consumed	3,864/5,520 = 70%	4,080/4,800 = 85%	82%
3. Energy usage			
3-1. Total amount of energy consumed in production (3)	222,600 Kw/year	204,000 Kw/year	1.09
3-2. Percentage of total amount of renewable energy divided by total amount of energy consumed	2,226/222,600 = 1%	4080/204,000 = 2%	50%
3-3. Percentage of total amount of unused energy divided by total capacity of energy	NA	NA	NA
3-4. Percentage of total number of efficient vehicles used divided by total number of vehicles used	NA	NA	NA
3-5. Percentage of total amount of energy consumed for material recycling divided by total amount of energy consumed	22,260/222,600 = 10%	51,000/204,000 = 25%	40%
3-6. Amount of energy saved due to continuous improvements (4)	18,600 Kw/year (1,550/month)	18,600 Kw/year (1,550/month)	100%
4. Emissions			
4-1. Total amount of GHG emissions released to air	NA	NA	NA
4-2. Percentage of total amount of GHG emissions released to air divided by acceptable level of GHG emissions	NA	NA	NA
4-3. Percentage of total amount of GHG emissions from Information technology (IT) tools divided by total amount of emissions released to air	NA	NA	NA
4-4. Percentage of total amount of emissions from ozone depleting substances divided by total amount of emissions released to air	NA	NA	NA
5. Waste			
5-1. Space for landfill area required for waste treatment	NA	NA	NA
5-2. Percentage of waste (liquid/or solid) generated during production divided by total number of washing machines produced (5)	1,310/131,040 = 1% (per unit)	2,620/131,040 = 2% (per unit)	50%
5-3. Percentage of amount of recycling waste divided by total amount of waste generated	982.5/1,310 = 75%	1,834/2,620 = 70%	1.07

Lean and Sustainable Measures for Each Environmental Performance Aspect			
Measures	*Actual Performance (1)*	*Target Performance (2)*	*Achievement (%) (1÷2)*
5-4. Percentage of amount of waste disposed divided by total amount of waste generated	327.5/1,310 = 25%	786/2,620 = 30%	83.33%
5-5. Percentage of amount of hazardous waste divided by total amount of waste generated	13.1/1,310 = 1%	78.6/2,620 = 3%	33.3%
5-6. Percentage of total amount of defected materials/or units disposed divided by total amount of materials used/or units produced	NA	NA	NA
6. Environmental Standards and Management System			
6-1. Number of sustainable environmental reports	5	7	71.4%
6-2. Number of environmental awards	5	8	62.5%
6-3. Number of environmental complaints received per year	Zero	Zero	Zero

Hint:
There are 20 models of washing machines are produced by the factory.
Actual amount of water consumed by all processes is 460 m^3 monthly (5,520 m^3 /year). Also, needed (target) amount of water for all processes is 400 m^3 monthly (4,800 m^3 /year).
Actual amount of energy usage by all processes and transport is 15,550 and 3,000 Kw/month respectively. Also, target amount of energy usage for all processes and transport is 14,500 and 2,500 Kw/ month respectively.
Due to lean improvements, total amount of energy saved is 18,600 Kw/year.
The actual and expected number of units (washing machines) produced is 420/day on average and the total number of working days during the year is 312. So, total number of units produced is 131,040 units/year on average.

The second part of questionnaire No. 1 10 copies of the second part of questionnaire No. 1 were distributed to respondents in different departments like planning, R&D, production, quality, and maintenance. It received 10 valid copies of the second part of questionnaire No. 1, representing a response rate of 100%. Also, Statistical Package Social Science (SPSS) Version 22 is used to analyze data collected from questionnaires. The reliability test was conducted to test the internal reliability or consistency of questionnaire statements (variables) by calculating Cronbach's alpha value, which is presented in Appendix 1. The value of Cronbach's alpha was 84.7 percent, which is greater than the acceptable value of 60%. This part is designed based on a 5-point Likert scale that ranges from 1 to 5 (where 1 represents not important and 5 represents very important). Respondents are asked to rank each qualitative lean and environmental measure under its related performance aspect to indicate the extent to which each measure listed under its related performance aspect is applicable. The descriptive statistics variable "mean," which is presented in Appendix (1), can be used to measure the achievement percentage for each qualitative measure. It can be presented in table 6 as follows:

Table 6: Qualitative lean and environmental measures

Measures	*Achievement (%) (Mean)*
Environmentally Sustainable Performance Dimension	
Environmental Standards and Management System Aspect	
1. The extent to which the factory adopts an environmental management system	88% (4.4)
2. The extent to which the factory adopts a complete green manufacturing plan	84% (4.2)
3. The extent to which the factory adopts green IT procurement policy	96% (4.8)

Application of the proposed AHP-environmental lean index for washing machine factories

In this section, the proposed framework for constructing a unified AHP environmental lean index based on financial and non-financial disclosed environmental accounting information has been applied to measure the environmental performance of a washing machine factory's value chain. The proposed index is important because there is no unified measure that can be used across the factory as a whole, and the factory management gives their performance measures equal weights for simplicity. But it is illogical behaviour because performance measures are diversified, and their relative importance is not equal. So, the proposed index would be constructed by following the phases demonstrated in Figure 1.

During phase one, a proposed AHP hierarchy is applied, as presented in figure 2. Also, pairwise comparison matrices and synthesization would be established. There are six pairwise comparison matrices that will be established as follows: o A pairwise comparison matrix is established at level two to make a comparison among the environmental performance aspects of the washing machine factory's value chain to determine the weights of each performance aspect in constructing the proposed index. Then, a normalized pairwise comparison matrix is established by dividing each element in the original matrix by its column sum. The weights of resource usage (RU), energy usage (EU), water usage (WU), waste (W), and environmental management system (EMS) can be computed in table 7 as follows:

Table 7: Comparison among environmental performance aspects

Pairwise Comparison Matrix						*Normalized Matrix*					*Sum of row*	*Weights (Sum of row/5)*
	RU	*EU*	*WU*	*W*	*EMS*	*RU*	*EU*	*WU*	*W*	*EMS*		
RU	1	1	4	3	0.25	0.152	0.132	0.3	0.187	0.135	0.91	0.181
EU	1	1	3	4	0.2	0.152	0.132	0.225	0.25	0.108	0.87	0.173
WU	0.25	0.333	1	3	0.2	0.038	0.044	0.075	0.187	0.108	0.45	0.09
W	0.333	0.25	0.333	1	0.2	0.051	0.033	0.025	0.062	0.108	0.28	0.056
EMS	4	5	5	5	1	0.61	0.66	0.375	0.312	0.54	2.5	0.5
Column Sum	6.58	7.58	13.33	16	1.85							1

- Also, the consistency ratio (CR) is calculated in table 8. So, if the CR is 0.1 or less, the consistency of the pairwise comparisons is considered reasonable. But if the CR is greater than 0.1, it shows inconsistency in pairwise judgments.
- It can be computed through the following steps: (1) Multiply each value in the first column of the pairwise comparison matrix by the priority of the first item. This process should be continued for all columns of the pairwise matrix. Then, (1) sum the value across the rows to obtain the weighted sum; (2) divide the elements of the weighted sum vector by the corresponding priority; and (3) calculate the average of the values obtained. This average is denoted as λ.

Table 8: Consistency ratio for table 7

	RU	*EU*	*WU*	*W*	*EMS*	*Weighted Sum Vector (sum of row)*	*Consistency Vector*	λ
RU	0.181	0.173	0.36	0168	0.125	1.007	5.56	26.91 ÷ 5 = 5.382
EU	0.181	0.173	0.27	0.224	0l.1	0.948	5.47	
WU	0.045	0.057	0.09	0.168	0.1	0.46	5.11	
W	0.06	0.043	0.029	0.056	0.1	0.288	5.14	
EMS	0.724	0.865	0.45	0.28	0.5	2.819	5.63	
Consistency index (CI) = [5.382 – 5] /4 = 0.0955; CR = CI/RI; Random Ratio (RI) is 1.12; where n is equal 5 so, CR= 0.0955/1.12 = 0.08 (acceptable)								

Five pairwise comparison matrices are established at level three with respect to level two to make a comparison among proposed lean and environmental measures in terms of their corresponding performance aspects. It was noted that the pairwise comparison matrix under the emission aspect was excluded. Because the manufacturing of washing machines does not release any emissions into the air. This comparison determines the weight of each proposed measure toward achieving its related performance aspect. For example, the weights of proposed measures under the energy usage aspect and consistency ratio are computed in table 9. Total amount of energy consumed (EE_{n1}), % of renewable energy consumed (EE_{n2}), % of energy consumed for material recycling (EEn5), and % of energy savings (EE_{n6}) are the proposed measures under the energy usage aspect.

Table 9: Comparison between proposed lean and environmental measures under energy usage aspect and consistency ratio

Pairwise Comparison Matrix					*Normalized Matrix*				*Sum of row*	*Weights (Sum of row/4)*	*CR*
	EE_{n1}	EE_{n2}	EE_{n5}	EE_{n6}	EE_{n1}	$\boldsymbol{EE_{n2}}$	$\boldsymbol{EE_{n5}}$	$\boldsymbol{EE_{n6}}$			
EE_{n1}	1	0.333	5	7	0.23	0.199	0.434	0.411	1.274	0.319	0.06
EE_{n2}	3	1	5	7	0.69	0.597	0.434	0.411	2.132	0.533	
EE_{n5}	0.2	0.2	1	2	0.046	0.119	0.086	0.117	0.368	0.093	
EE_{n6}	0.143	0.143	0.5	1	0.033	0.085	0.043	0.058	0.219	0.055	
Column Sum	4.343	1.676	11.5	17						1	

By following the same previous steps, the weights of proposed measures under each other are determined by the environmental performance aspect. These weights can be summarized in table 10.

Table 10: Weights of proposed measures

Proposed measures	*Weights*	*Proposed measures*	*Weights*
ER_{e1}	0.062	EE_{n6}	0.055
ER_{e2}	0.16	EW_{as2}	0.17
ER_{e4}	0.07	EW_{as3}	0.383
ER_{e5}	0.19	EW_{as4}	0.064
ER_{e6}	0.023	EW_{as5}	0.383
ER_{e7}	0.19	EES_1	0.47
ER_{e8}	0.305	EES_2	0.192
EW_{at1}	0.5	EES_3	0.192
EW_{at2}	0.5	EES_4	0.052
EE_{n1}	0.319	EES_5	0.047
EE_{n2}	0.533	EES_6	0.047
EE_{n5}	0.093		

According to the synthesization, the global weight of each proposed lean and environmental measure can be computed by multiplying its local weight by the importance of its related performance aspect. Therefore, the global weights of the proposed measures can be calculated to rank these measures according to their relative importance in constructing the proposed index. It can be summarized in table 11.

Table 11: Synthesized AHP table for washing machines factory

Criteria Performance Aspects (1)	*Importance (2)*	*Decision Alternatives*		
		Proposed Lean and environmental Measure (3)	*Local Weights (LW)* (4)*	*Global Weights (GW)** (5)*
Environmental Standards and Management System	50%	EES_1	47%	23.5%
		EES_2	19.2%	9.6%
		EES_3	19.2%	9.6%
		EES_4	5.2%	2.6%
		EES_5	4.7%	2.35%
		EES_6	4.7%	2.35%
Resource Usage	18.1%	ER_{e1}	6.2%	1.122%
		ER_{e2}	16%	2.89%
		ER_{e4}	7%	1.267%
		ER_{e5}	19%	3.44%
		ER_{e6}	2.3%	0.416%
		ER_{e7}	19%	3.44%
		ER_{e8}	30.5%	5.52%
Water Usage	9%	EW_{at1}	50%	4.5%
		EW_{at2}	50%	4.5%
Energy Usage	17.3%	EE_{n1}	31.9%	5.51%
		EE_{n2}	53.3%	9.22%
		EE_{n5}	9.3%	1.6%
		EE_{n6}	5.5%	0.9515%
Waste Management	5.6%	EW_{as2}	17%	0.952%
		EW_{as3}	38.3%	2.144%
		EW_{as4}	6.4%	0.3584%
		EW_{as5}	38.3%	2.144%
	$\sum$			100%

Hint:
*Local weights of decision alternatives column (4) are derived from pairwise comparison matrics.
** Global weight of each alternative (column 5) is derived by multiplying local weight of each alternative (column 4) by the importance of high-level criteria (column 2) which it relates to.

Then, phase two is conducted to compute the current state results, which are demonstrated in tables 5 and 6. Finally, the overall AHP-environmental lean index for washing machine factories can be computed in table 12.

Table 12: Calculation of overall AHP-environmental lean index for washing machines factory

Dimension	*Proposed Lean and Environmental Measures*	*AHP Weights*	*Current State*		*Future State Index (Global Weights)*
			Results (Achievement %)	*Index*	
Environmental Performance	EES_1	23.5%	88%	20.68%	23.5%
	EES_2	9.6%	84%	8.064%	9.6%
	EES_3	9.6%	96%	9.216%	9.6%
	EES_4	2.6%	71.4%	1.856%	2.6%
	EES_5	2.35%	62.5%	1.4687%	2.35%
	EES_6	2.35%	Zero	Zero	2.35%
	ER_{e1}	1.122%	100%	1.122%	1.122%
	ER_{e2}	2.89%	48%	1.3872%	2.89%
	ER_{e4}	1.267%	50%	0.6335%	1.267%
	ER_{e5}	3.44%	98.9%	3.4021%	3.44%
	ER_{e6}	0.416%	86%	0.3577%	0.416%
	ER_{e7}	3.44%	75%	2.58%	3.44%
	ER_{e8}	5.52%	88.2%	4.868%	5.52%
	EW_{at1}	4.5%	1.15	5.175%	4.5%
	EW_{at2}	4.5%	82%	3.69%	4.5%
	EE_{n1}	5.51%	1.09	6.0059%	5.51%
	EE_{n2}	9.22%	50%	4.61%	9.22%
	EE_{n5}	1.6%	40%	0.64%	1.6%
	EE_{n6}	0.9515%	100%	0.9515%	0.9515%
	EW_{as2}	0.952%	50%	0.476%	0.952%
	EW_{as3}	2.144%	1.07	2.294%	2.144%
	EW_{as4}	0.3584%	83.3%	0.2985%	0.3584%
	EW_{as5}	2.144%	33.3%	0.7139%	2.144%
Overall Environmental Lean Index				80.5%	100%

4. RESULTS AND DISCUSSION

The results of applying the proposed index can be summarized as follows:

- ER_{e8} is given the highest importance with a weight of 30.5%, followed by ER_{e5} and ERe7, which have the same weight of 19%. It means that washing machine factories adopt green practices during the design and manufacturing stages to provide more environmentally and socially safe washing machines. On the other hand, ER_{e6} is given the lowest importance, with a weight of 2.3%.
- EE_{n2} is given the highest importance with a weight of 53.3%, followed by EE_{n1} with a weight of 31.9%. It means that the factory focuses on renewable energy sources to reduce air pollution and improve public health.
- EW_{as3} and EW_{as5} are equally important, with a weight of 38.3%. It means that the factory focuses on these measures because they have significant impacts on environmental performance. As a result, EW_{as4} is given the lowest importance with a weight of 6.4% because the factory focuses on recycling waste generated.
- EES_1 is given the highest importance, with a weight of 47%. It means that the factory adopts an effective environmental management system to enhance its environmental performance. Also, EES2 and EES3 are equally important, with weights of 19.2%, which means that the factory adopts green practices across different value chain activities. On the other hand, the number of environmental complaints received (EES_6) is given the lowest importance with a weight of 4.7%, which means that the factory complies with environmental standards.
- The current AHP-environmental lean index is 80.5%, which indicates that the factory's lean implementation has significant impacts on its environmental performance.
- Through computing the overall AHP-environmental lean index, the performance gap can be measured. The performance gap is 19.5%. This gap is related to some measures that need to be improved, like ER_{e2}, ER_{e4}, EW_{at1}, and EE_{n1}.

5. CONCLUSION, IMPLICATIONS, LIMITATIONS, AND FUTURE RESEARCH

5.1. Conclusion

In recent years, enterprises in developing and developed countries have been more likely to face many challenges in terms of managing their processes to achieve sustainable development. It results in putting tremendous pressure on enterprises to adopt advanced manufacturing practices to achieve a sustainable competitive advantage. In addition, there is significant pressure on enterprises to manage their operations responsibly in light of their environmental, social, and economic impacts. Therefore, enterprises have been motivated to identify ways to respond to customers' needs through sustainable operations.

Environmental management accounting (EMA) is considered a significant area of discussion because it assists management in recognizing and exploiting the needed information for environmental performance. The EMA is deemed an essential part of modern business as it allows the business to identify, evaluate, and assemble different kinds of information. Few of the researchers supported those intangible resources, such as EMA, that are essential for firms' success, as stated by Bresciani *et al.* (2023).

Consequently, environmental sustainability is considered one of the strategic necessities for enterprises, which must be aligned with their traditional priorities of profitability and efficiency, as stated by Brozzi *et al.* (2020). Kluczek *et al.* (2022) and Uriarte-Gallastegi *et al.* (2022) asserted that environmental sustainability has received increasing attention because of external regulations that result in imposed responses to environmental practices. Many companies are required to consider environmental issues in their strategies to enhance manufacturing processes and reduce their environmental impacts. So, manufacturers are motivated to prioritize environmental sustainability in their operations.

To achieve sustainable growth, a radical rethinking of many enterprises' practices is required. It means that continuous improvement is not enough, and a change in environmental performance is required. Rezaee (2016) stated that environmental performance reflects how an enterprise addresses its environmental challenges to leave a better environment for future generations.

Although new performance measurement systems have overcome limitations of traditional performance systems, no one is relevant to measure lean performance. It results in paying more attention to developing a relevant performance measurement tool to measure the sustainable performance of a lean enterprise's value chain and sustain its lean transition. Furthermore, there is a scarcity of literature about measuring the impact of lean implementation on an enterprise's sustainable performance, especially environmental performance and its environmental management accounting systems. Also, no studies in the literature presented a lean index to measure leanness impact.

To answer the research question and achieve the research objectives, this study focused on measuring lean implementation's impacts on an enterprise's environmental performance through the construction of a unified AHP-environmental lean index based on financial and non-financial disclosed environmental accounting information as presented in Figure 1, which involves quantitative and qualitative measures across a lean enterprise. The weights of lean and environmental measures have been calculated using AHP to rank the measures according to their relative importance. A proposed index is used to measure the environmental performance of an enterprise's value chain and the performance gap of lean implementation. The performance gap can be analyzed to determine its drivers and which measures should be improved according to AHP weights to prioritize improvement efforts.

5.2a. Theoretical implications

This study provides significant theoretical implications in terms of the following insights:

- The present study contributes to the existing literature by addressing the importance of measuring the impacts of lean implementation on enterprises' sustainable performance and their environmental management accounting systems to enable enterprises to compete in the global market.
- No studies were found in the literature measuring the impacts of lean implementation on enterprises' environmental sustainability. Consequently, to the best of our knowledge, this study is the first attempt to propose a hierarchical framework by using AHP to rank lean and environmentally sustainable measures according to their relative importance toward measuring environmental sustainability. In this case, researchers can utilize this framework as a basis to assess the importance of other performance measures that do not exist in the framework.
- The proposed framework in this study combined the case study and MCDM tools to enhance the applicability of the proposed framework.
- A useful measure of both the environmental performance of a lean enterprise's value chain and the performance gap of lean implementation can be provided. It means that the proposed environmental lean index can identify the gap between the current state and the future lean state.
- A comprehensive view of strengths and weaknesses in a lean enterprise can be provided. So, improvements' priorities via weights used in constructing the proposed index can be clarified.

5.2b. Practical implications

In this study, the analysis of the literature review and the proposed framework provide practical implications. The proposed hierarchical framework in this study could support managers or decision-makers in their thoughts and analyses about measuring lean implementation impacts on environmental performance in many ways:

First, the proposed framework for constructing an environmental lean index shows how lean implementation can impact each aspect of environmental performance. So, this information is valuable, especially for managers of the most polluting firms.

Second, the proposed framework could help decision-makers prioritize lean and environmentally sustainable measures according to their relative importance toward measuring environmental sustainability.

Third, the proposed framework can be used by different companies in different industries by making modifications to the components of the framework according to the companies' goals, policies, or circumstances.

5.3. Limitations and future research

As with any research, this study has some limitations and offers opportunities for several future studies.

First, this study focused only on measuring the impacts of lean implementation on environmental sustainability. So future research on measuring the impact of lean implementation on economic or social performance and investigating the potential negative impacts of lean implementation on sustainable performance is strongly needed.

Second, interrelationships among lean measures are not demonstrated in this study. So, researchers may extend the present study by applying another MCDM tool like the analytical network process (ANP) to explore the potential impacts of interrelationships among lean measures on sustainable performance.

Third, this study conducted a case study on a manufacturing firm. So, future research can be conducted on service firms.

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Conflict of Interest

There is no conflict of interest involved in the publication of this paper.

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APPENDIX 1: Statistical analysis of questionnaire No. (1)

Reliability Statistics				
Cronbach's Alpha		N of Items		
.847		17		
Descriptive Statistics				
	N	*Minimum*	*Maximum*	*Mean*
En111	10	4	5	4.40
En112	10	4	5	4.20
En113	10	4	5	4.80
Valid N (listwise)	10			