EVALUATION OF LIFE CYCLE ASSESSMENT IN FURNITURE MANUFACTURING USING THE ANALYTICAL HIERARCHY PROCESS

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ABSTRACT

Environmental issues in the furniture industry are of great importance due to the use of natural materials, such as wood and chemical substances like adhesives and paints. These issues encompass environmental conservation and managing the pollution and waste that is generated. This study adopted an integrated AHP-LCA decision model which helped identify several key factors as higher priorities. These factors include the bio-economic aspects, the production process, wood quality, stable supply of raw materials, technical considerations, and the recycling process. A pairwise comparison of 24 sub-criteria revealed that the quality of wood as a raw material, wood supply management and connections, the punching process, user education and trained workforce, and process design are critical criteria. Prioritizing these factors not only helps in the removal of pollutants, but also enhances the Life Cycle Assessment (LCA) framework in the furniture industry. The Life Cycle Assessment (LCA) results using Sima-Pro software indicated that scenario 1, which involves designing recyclable furniture, has a significant impact on water toxicity and CO_2 emissions. Additionally, replacing birchwood as an imported raw material (scenario 2) can help mitigate ionizing radiation effects. Finally, using recycled wood in the furniture manufacturing processes (scenario 3) significantly affects land use and emissions.

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Keywords: life cycle assessment; furniture; Analytic Hierarchy Process; indicators; alternatives

1. Introduction

Environmental issues in the furniture industry are of great importance due to the use of natural materials such as wood and chemical substances like adhesives and paints. These issues encompass environmental conservation and managing pollution and generated waste. Improper use of wood resources, along with the use of chemicals and their release into the environment, leads to the depletion of natural resources, damage to forests, and the emission of greenhouse gases. Life Cycle Assessment (LCA) is a systematic method used to evaluate the environmental impacts of a product, process, or service during all stages of a life cycle. This method is used to assess the effects of products on the environment, from the extraction of raw materials to waste disposal to recycling. LCA can help improve the environmental performance of products and processes and reduce the consumption of resources and ecological emissions using a detailed analysis of environmental impacts. Therefore, identifying influential indicators by applying the Analytic Hierarchy Process (AHP) and LCA to classic furniture and proposing solutions to reduce environmental impacts becomes crucial. Reducing environmental impacts through LCA is essential for improving the product life cycle in the furniture industry. However, furniture manufacturers face several challenges in implementing LCA, such as substituting materials with sustainable alternatives, adopting eco-friendly manufacturing processes, optimizing energy use, and recycling and reusing waste materials. To address these challenges, it is crucial to identify the criteria and sub-criteria that influence the integration of sustainability into LCA implementation. Moreover, incorporating eco-design into industrial practices and focusing on sustainable product delivery processes can significantly impact the environmental footprint of the furniture industry. In this context, the AHP has emerged as a valuable tool for understanding and addressing these effects. The aim of this study is to conduct the AHP to facilitate a thorough examination of the inherently complex delivery process of the furniture industry in order to highlight the significance of integrating the LCA implementation, which has not yet been investigated.

1.1 Stages of Life Cycle Assessment (LCA)

First, the goal and scope of the evaluation are determined. The objective may include an environmental impact assessment, energy consumption assessment, and economic impact assessment. The domain is also related to the product, process, or service under consideration.

All stages of the product, process, or service life cycle are identified and analyzed during this stage. It also includes the extraction of raw materials, production, transportation, use, disposal, and recycling. During this stage, energy consumption, greenhouse gas emissions, waste production, and other environmental impacts are examined. Next in the interpretation stage, the results obtained from the inventory registration and impact assessment stages concerning the study's objectives are examined and interpreted. Finally, in the evaluation stage, the results of the LCA are evaluated. This includes environmental, energy consumption, and economic impact assessments. The results can be used to inform management decisions, design better products, and optimize processes.

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LCA is used as a strategic decision-making tool in the environment. With the help of a detailed analysis of environmental impacts, this method can help improve the environmental performance of products and processes and reduce resource consumption and environmental emissions. Using the life cycle technique in furniture production is considered a sustainable and responsible solution. The use of this technique in furniture production has many advantages. First, it helps reduce the consumption of natural resources and energy in furniture production. By recycling materials and reusing old pieces of furniture, the need to extract new resources is reduced. Second, using the life cycle technique helps reduce the destruction of natural resources and environmental pollution. Adverse environmental effects are reduced by decreasing waste production and greenhouse gas emissions. Third, using this technique increases the useful life of furniture and reduces the need to replace it, saving costs and resources.

1.2 Life Cycle Assessment (LCA) in the furniture industry

The importance of the LCA in the classic furniture industry is due to the following benefits:

- Reduction of environmental impacts: By using the LCA, the environmental impacts of products are reduced. This includes decreasing the consumption of natural resources, reducing pollutants, and reducing waste generation.

- Resource-saving: By using the LCA, the consumption of natural resources such as wood, water, and energy is reduced. This leads to cost savings and conservation of wood resources.

- Increase in sustainability: By using the LCA, more sustainable products with a longer useful life are produced. This leads to a reduction in the need for remanufacturing and disposal of products. It makes it possible to cover a significant gap in environmental impact assessments within the country by bringing a localized perspective to sustainability evaluations. It sheds light on the specific challenges and opportunities unique to the region, providing valuable insights for more effective and context-specific sustainability practices.

- Increase customer satisfaction: Customers are more interested in products that are manufactured with life cycle techniques. These products have the most negligible environmental impact and contribute to environmental sustainability.

In this research, the life cycle of a piece of furniture was evaluated from the cradle to the grave; in other words, all the stages of the life cycle of a piece of furniture, from the extraction of raw materials to the production process, marketing, recycling, and product disposal were evaluated. This research breaks new ground by selecting key criteria and sub-criteria, prioritizing them, and conducting sensitivity analyses to enhance the implementation of LCA in the furniture industry.

1.3 Effect groups in Life Cycle Assessment (LCA)

Based on the collected data from the case study, the effective parameters of LCA were selected for consideration in the model. In the production process, lumber or wooden pieces and other raw materials such as fabric, foam, and other materials first enter the factory (Figure 1). Then, cutting and grating work is done on the desired wooden pieces

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during the finishing stage. Next, the crotch and tongue connections are made on the wooden parts, and then the parts enter the assembly and coil-making stage. Then, the furniture coil is transferred to the painting unit, then it is transferred to the stamping unit, and after the stamping and packaging unit it is finally transferred to the storage place or warehouse of the factory.

The effective parameters are as follows:

Energy consumption: This group includes energy consumption from fossil fuels (oil, natural gas, and coal) and renewable sources (such as wind and sun). Energy consumption at different stages of the life cycle, from the production of raw materials to the disposal of waste, is examined.

Greenhouse gases: This group includes carbon dioxide, methane, and nitrogen oxide, which are related to greenhouse effects and climate change. These gases are produced in the production, transportation, use, and disposal of manufactured products.

Water: The use of water resources, water pollution, and water-related health impacts throughout the life cycle of products are examined. These include water consumption in production, water treatment, use in processes, and dewatering of products at the end of their life cycle.

Minerals: The extraction and use of minerals such as metals, non-metallic minerals, and other minerals are considered in the production process. These materials create different environmental effects in the products' extraction, production, and disposal of the product.

Gaseous acids and air pollutants: This group includes the production of gaseous acids (such as sulfur and nitrogen oxides) and air pollutants (such as suspended particles, organic contaminants, etc.). These groups have different effects on air and environmental air quality.

Consumption of natural resources: This group includes non-renewable resources such as wood, land, freshwater, and other natural resources. Unbalanced use of these resources during the life cycle of products can lead to the reduction of natural resources and the destruction of the environment.

Radiation: This group includes various radiations, such as electromagnetic radiation (radio frequencies and microwaves, ultraviolet, and radioactive rays). Radiation may be created in production, use of products, and waste disposal and have environmental effects on humans and the environment.

Waste formation: This group includes the consumption of resources to produce waste, soil and water pollution due to waste disposal, and waste's health and environmental effects. These include solid waste, liquid waste, hazardous waste, etc.

Health effects: This group includes the impact caused by the disposal of pollutants, air, water, and soil pollution, as well as human health effects during the life cycle of products. These include diseases, damage to the respiratory system, toxic effects of substances, allergic effects, etc.

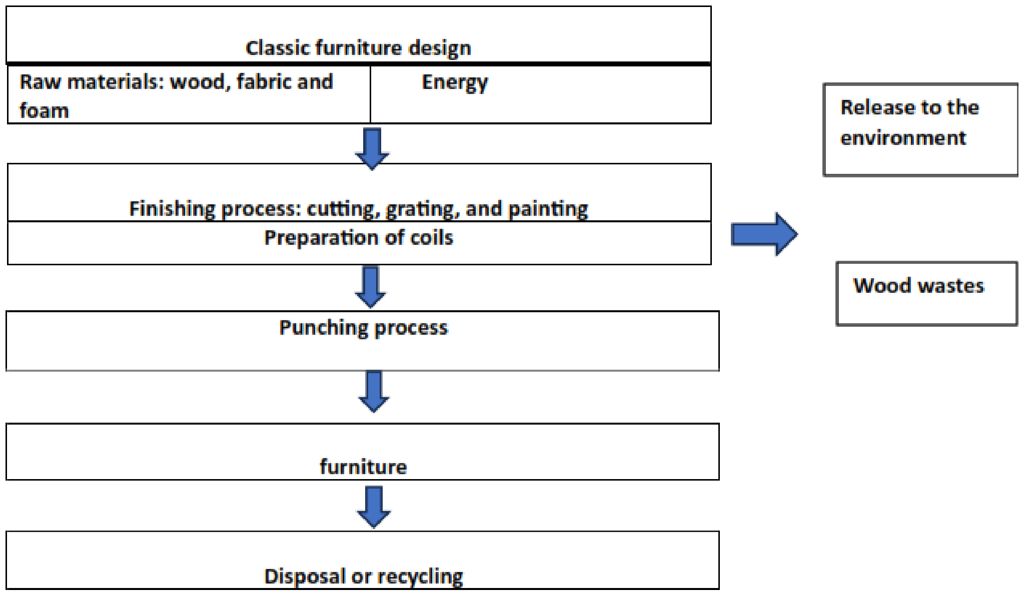

Figure 1 Classic furniture production process system

1.4 Goals

The goal of this study is to identify indicators that influence the life cycle of classic furniture to offer actionable recommendations for the furniture industry based on the study's findings. It is also essential to guide stakeholders in adopting more sustainable practices in the production and distribution of pinewood tables. These recommendations should focus on optimizing material usage, enhancing energy efficiency, minimizing waste, and promoting eco-friendly processes. By prioritizing sustainable sourcing, implementing efficient manufacturing techniques, and encouraging the reuse and recycling of materials, stakeholders can significantly reduce the environmental impact of pinewood table production. Additionally, adopting greener logistics and distribution methods will further contribute to a more sustainable supply chain, ensuring that the environmental benefits extend beyond the manufacturing stage. Finally, solutions should be provided to reduce the environmental effects of classic furniture production and increase the lifespan of classic furniture.

1.5 Hypothesis

The first hypothesis is that the raw material index will be more critical than other indices; raw material recycling is also the most important solution for reducing environmental effects.

The second hypothesis is that the investigation and identification of indicators affecting the life cycle of classic furniture can determine the most critical indicators that affect the life cycle of classic furniture at each stage of the life cycle process.

1.6 Integration of AHP and LCA

Integrating the AHP and life cycle LCA is a useful and efficient method to help consider environmental factors in decisions and help achieve sustainable development goals

(SDGs). This research delivers practical guidance for the furniture industry through an in-depth integration of the AHP method and LCA production and distribution. It highlights sustainable strategies, including the substitution of materials, the adoption of eco-friendly manufacturing processes, and the implementation of responsible end-of-life practices. These findings empower stakeholders to make informed choices that minimize environmental impact and advance sustainability across the entire product life cycle.

1.7 Research background

Abbasi et al. (2015) stated that the amount of pollution spread is directly related to the cutting and assembling stages of furniture coils. Therefore, the longer the cutting and assembling stages take in a production workshop, the more pollution is created. This research also found that the different stages of production of comfortable furniture will cause pollution. In the first stage of furniture production, pollution will have the most significant impact on the ecosystem, human health, and fossil fuel resources. In addition, by using newer systems and modern methods of irrigation and agriculture, the amount of energy consumed and the amount of greenhouse gas emitted can be significantly reduced. Brown and Davis (2018) investigated the experimental use of furniture parts instead of timber in furniture production. The results of their research showed that the use of furniture parts instead of timber can reduce the wastage of resources and energy, increase the durability of products, and reduce production costs. Also, this method can help improve the stability of products and reduce the environmental impacts associated with furniture production. Prakash et al. (2019) studied the challenges and opportunities of sustainable furniture production. They suggested that instead of traditional materials such as hardwood, sustainable and renewable materials such as bamboo or reclaimed wood should be used to make furniture. They also emphasized the importance of using non-toxic materials to reduce air pollution. Bauman and Tillman (2004) stated that LCA is one reliable method for analyzing environmental effects during the life cycle of a product and is part of the decision-making process to move towards environmentally friendly products. Werner et al. (2007) and González García et al. (2009) have showed that it is very important to consider volatile organic compounds and the amount of greenhouse gas production to ensure the reduction of environmental impacts in furniture manufacturing. Medeiros et al. (2017) evaluated the life cycle of office furniture. They found that to reduce the environmental effects due to the release of suspended materials during particle board production and to reduce the energy consumption in office furniture production, it is necessary to recycle and reuse waste to form raw materials or energy recovery from waste and garbage. Also, changing the fuel of the office furniture transportation trucks, reducing the transportation distance to minimize transportation costs, and using ships to transport furniture can reduce the environmental impact. Chen and Huang (2019) concluded during their study on the life cycle of furniture and its environmental impact assessment that considering the environmental effects of the furniture industry, the development of a recycling process seems necessary, as well as the development of the recycling industry for the sustainable use of regional resources, pollution reduction and environmental protection is vital. Modular furniture enables the creation of more bespoke combinations to suit the specific needs of each project, since they allow a higher level of customization and optimization of the space. A timeless aesthetic, adaptability, and ease of assembly are other benefits of this type of furniture. Sathre and González (2014) discussed the design and construction of buildings and infrastructure made of wood, with an emphasis on eco-design processes. They described the system-wide material and energy flows associated with wood-based construction from a life cycle perspective and the climate benefits of using wood material from sustainably managed forests. Han et al. (2009) conducted a review of the furniture industry in China, and found that to improve the status of the furniture industry, the government managers and industrial unions managed the transformation of the leading manufacturers into the foremost designers of furniture and finally created a brand for the products of the Chinese furniture industry. John et al. (2021) evaluated four types of renewable energy (solar, wind, biomass, and mini-hydro energy) using the integrated LCA and AHP approaches to select the best renewable energy source in Tatau, Sarawak, Malaysia. The criteria under consideration in this study included the environment, engineering, and economics. These findings can be used to develop a systematic procedure for determining the best form of renewable energy for rural areas. This approach could be vital for the authorities that are responsible for decision making and breaking down multi-perspective criteria for future decision-making in the transition into renewable energy.

Moosavi et al. (2021) applied the AHP and LCA to evaluate life cycle assessment in paper manufacturing. They generated a comprehensive model to facilitate the life cycle of products and develop a cleaner production strategy in paper manufacturing. In this research, an AHP model was designed to assess the LCA qualification of the paper manufacturing process according to the selected criteria. Results showed circulation of water and solid waste reuse from wastewater treatment plants through dissolved air flotation (DAF) and disk filters provided many advantages including not only pollutant removal but also the enhancement of the LCA framework.

Shen et al. (2010) indicated that the economic, technological, and social criteria should be considered to achieve a successful framework for LCA. Michelsen et al. (2023) stated a Cleaner Production (CP) program for a group of furniture companies in a small community. The goal for another case study running in parallel with the CP project was to define a common set of environmental performance indicators (EPIs) for reporting purposes for both companies and municipalities to reduce waste and improve its treatment according to circular principles. LCA was used for product improvements based on hot spots detected through the analyses and to generate Environmental Performance Declarations (EPDs) for products. The implementation of these new procedures was integrated into the organization's strategic work through a certified Environmental Management System (EMS).

The LCA is adopted to minimize the negative environmental concerns throughout the manufacturing processes. The indicator system of LCA is also an impressive tool to measure clean technology levels. At clean technology levels, the path towards a sustainable process is unclear because of complex interrelated behavior between indicators (Singlitico, Goggins, & Monaghan 2019; Verghese, Horne, & Carre 2010; Vinodh & Rathod 2010). LCA is a survey method that interconnects environmental impacts on the manufacturing process (Jacquemin, Pontalier, and Sablayrolles 2012; Pomponi and Lenzen 2018; Raymond, Slater, and Savelski 2010).

The results of this research can improve environmentally sustainable processes, optimal use of resources, reduction of pollution, and attention to recyclability. Providing the proposed solutions and scenarios can improve the economic factors related to classic furniture. This research will also help manufacturers, consumers, and policymakers in the classic furniture industry to make better decisions about furniture life cycle management

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and move towards sustainability-based systems. Therefore, it seems necessary to conduct research to identify indicators affecting the life cycle.

2. Material and methods

The research algorithm (Figure 2) is as follows:

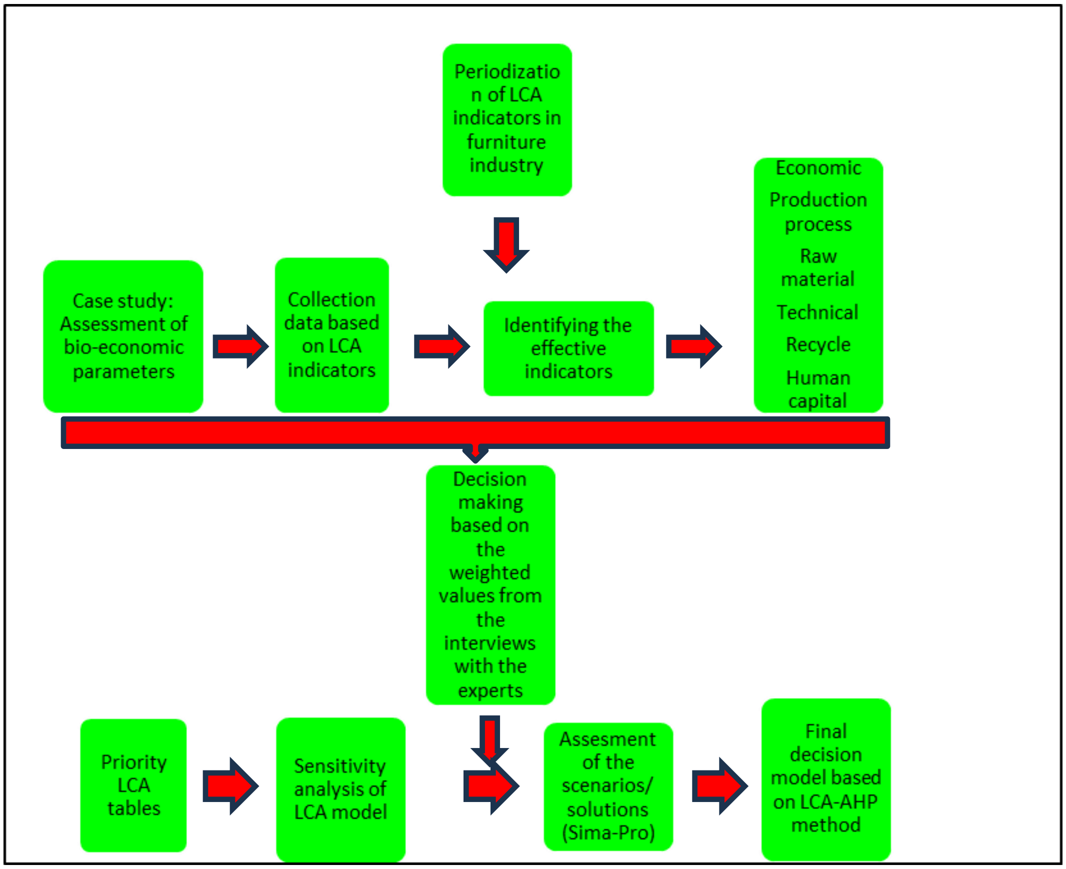

Figure 2 Schematic framework of LCA-AHP indicators prioritization in the Furniture Industry.

2.1 Indicators

In this research, Figure 3 shows the study's six groups of indicators and related sub-indices (Figure 3).

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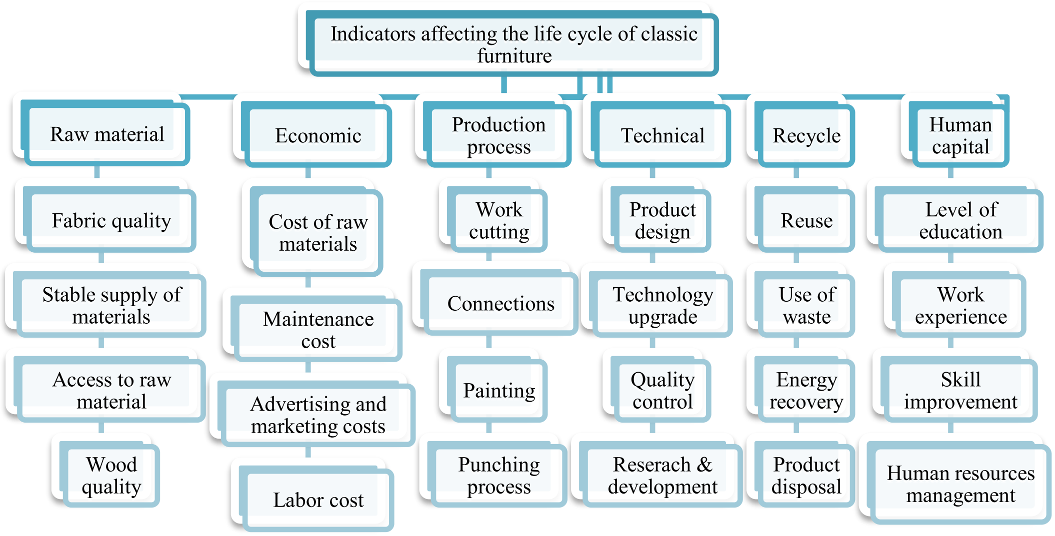

Figure 3 Decision tree to identify the influencing indicators on classic furniture

2.2 Alternatives

The study considered three different scenarios as follows:

Scenario 1: Economic design of classic furniture production using birchwood or other woods. Replacing beechwood with birch or other woods saves about 50-100% of the price of classic furniture due to the high cost of beechwood. Due to the decrease in the supply of beechwood, the price has increased. Since most of the classic furniture is made of beechwood, birchwood could be a suitable alternative to beechwood for making classic furniture.

Scenario 2: Designing furniture production with recycled parts (about 10% for making classic furniture, 50% for comfortable furniture, and 100% for making chipboard)

Scenario 3: Classic furniture design with ready-made parts. Replacing ready-made pieces of furniture with standard dimensions and polished parts will reduce wood waste due to the lack of the need for finishing processes such as cutting, grating, sanding, and other finishing processes. This will result in a maximum use of wood and minimize damage to forest resources. Also, the lack of need for the finishing process uses less machinery as well as labor, which consequently reduces the cost of machinery maintenance and labor cost.

2.3 Questionnaire

Field research was conducted to identify the influencing indicators on the life cycle of classic furniture by compiling two types of questionnaires and distributing them among 12 university professors, industry managers, and furniture industry experts. The first questionnaire was developed to compare the main indicators and sub-indices pairwise, and the second compared the options concerning the sub-indices.

To obtain the degree of confidence in the obtained answers, their degree of inconsistency was determined, which is calculated by using the Expert Choice software. If the

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inconsistency rate is less than 10%, the research is reliable, and if the inconsistency rate is more than 10%, it indicates that the answers and questionnaires need to be reevaluated by the evaluators and experts.

2.4 Analytic Hierarchy Process

The AHP, developed by Saaty (2000), determines the relative importance of a set of activities in a multi-criteria decision problem. The process makes it possible to concurrently incorporate judgments on intangible qualitative criteria with tangible quantitative criteria into an analysis of alternatives. The AHP method is based on three steps as follows: model the structure, perform a comparative judgment of the alternatives and criteria, and synthesize the priorities. In the literature, the AHP has been widely used to solve many complicated decision-making problems (Ishizaka &, Labib, 2011). In the first step, a complex decision problem is structured as a hierarchy. The AHP initially breaks down a complex multi-criteria decision-making problem into a hierarchy of interrelated decision elements (criteria, decision alternatives). The objectives, criteria, and alternatives are then arranged in a hierarchical structure similar to a family tree. This hierarchy has at least three levels, with the overall goal of the problem at the top, multiple criteria that define the solution alternatives in the middle, and decision alternatives at the bottom (Albayrak & Erensal, 2004). The second step is the comparison of the alternatives and criteria. Once the problem has been decomposed and the hierarchy constructed, a prioritization procedure is conducted to determine the relative importance of the criteria within each level. The pairwise judgment starts at the second level and ends with the lowest-level alternatives. At each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria in the higher level. In the AHP, multiple pairwise comparisons are based on a standardized comparison scale of nine levels (Table 1).

Table 1
Standardized nine-level comparison scale used in AHP

Definition	**Importance ranking**
Equally important	1
Moderately more important	3
Strongly more important	5
Very strong more important	7
Extremely more important	9
Intermediate values	2, 4, 6, 8

Let C= {Cj | j=1, 2,…, n} be the set of criteria. The result of the pairwise comparison on n criteria can be summarized in an (n’n) evaluation matrix A in which every element a_{ij} (i,j=1,2,…,n) is the quotient of weights of the criteria, as shown in Equation (1):

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$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} a_{ii} = 1, a_{ij} = 1/a_{ji} \tag{1}$$

where a_{11} represents the comparison between element i and element j.

In the final step, the relative weights for each matrix are normalized and identified. The relative weights are given as the eigenvector (W) corresponding to the largest eigenvalue (λmax), as

$$A.W = \lambda\max W, \tag{2}$$

where λmax = the maximum eigenvalue and W= eigenvector corresponding to λmax.
If the pairwise comparisons are consistent, the matrix A has rank n and λmax = n. In this case, weights can be obtained by normalizing any of the rows or columns of A.

An essential advantage of the AHP over other algorithmic methods is that it takes into account inconsistencies in the preferences. Inconsistencies exist because of the redundant information relating to the priorities in each decision matrix. If the inconsistency exceeds 0.10, some revisions of the judgments may be required. When the inconsistency ratios (IR) are below 10%, the decision matrices that are prepared for the criteria are consistent. The quality of the output of the AHP is strictly related to the consistency of the pair-wise comparison judgments (Saaty, 1980).

The geometric mean is calculated for each one of the matrix cells by Equation (3) (Saaty, 2000).

Group judgments $a_{ij} = (a_{ij}1 \times a_{ij}2 \times \ldots \times a_{ij}N)^{1/N} \qquad i, j = 1, 2, \ldots N$ (3)

where a_{ij} represents the comparison ratios between element i^{th} row and element j^{th} column in the pairwise comparison matrices, and N is the number of decision-makers.

2.5 Sensitivity analysis

Since there may be different judgments about the comparison of priority rates of main criteria or their sub-criteria, a sensitivity analysis was applied to achieve stability and compatibility (see Saaty, 2001). To perform a sensitivity analysis, we applied the software developed by Saaty and Cho (2001).

2.6 Midpoint method

The midpoint method is one of the methods used in LCA, which is used to calculate the environmental effects of processes and products. The midpoint method divides the product life cycle into different stages. Then, for each stage, the consumption of resources and publications is calculated at the middle point of that stage. The advantage of this method over other methods is that calculating environmental impacts at intermediate points can provide a more accurate estimate of the entire life cycle. The midpoint method is considered an efficient approach to comprehensively evaluating the

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environmental impacts of products and processes. The midpoint method or weighted average is used in life cycle assessment to quantitatively estimate various effects during the life cycle of a product or system. Considering the importance and weight of different life cycle stages, this method helps determine each stage's impact on the total environmental, economic, and social effects. To use the midpoint method, a weight value must be determined for each life cycle stage. This weighted value is usually determined based on each step's relative importance and considers various factors such as resource consumption, environmental impacts, costs, and health. Then, the environmental, economic, and social effects are calculated for each stage. These effects can include energy consumption, air and water pollution, waste production, greenhouse gas emissions, production and maintenance costs, job creation, health and social impact, and other factors related to the desired stage. In the next step, the weighted average is calculated using the calculated weighted value and each step's environmental, economic, and social effects. This average shows how much each step affects the total effects and which has the most impact. The midpoint method is helpful in LCA because it helps compare the impact of different stages according to their importance in the life cycle. This method can help organizations and decision-makers apply focused improvements at the stages of a given life cycle that have the most significant impact and promote improved product or system sustainability.

2.7 Sima Pro

Sima Pro is a life cycle management software used to evaluate the environmental impacts of products and services during their life cycle. By using Sima Pro software, companies can determine the environmental impact of their products and make the necessary improvements in their design and production. Also, this software helps companies adhere to relevant environmental standards (such as ISO 14040).

3. Results and data analysis

3.1 Prioritizing the main effective indicators

Figure 4, a summary of the experts' opinions, shows the prioritization of indicators affecting the life cycle of classic furniture which is that among the main indicators, the raw material index with a relative weight of 0.282 is the most crucial priority of the hierarchical tree, followed by the production process index. The technical, human capital, economic, and recycling indices are the most effective indices in terms of their effect on the life cycle of classic furniture. Also, the inconsistency rate in prioritizing the most effective indicators is 0.02.

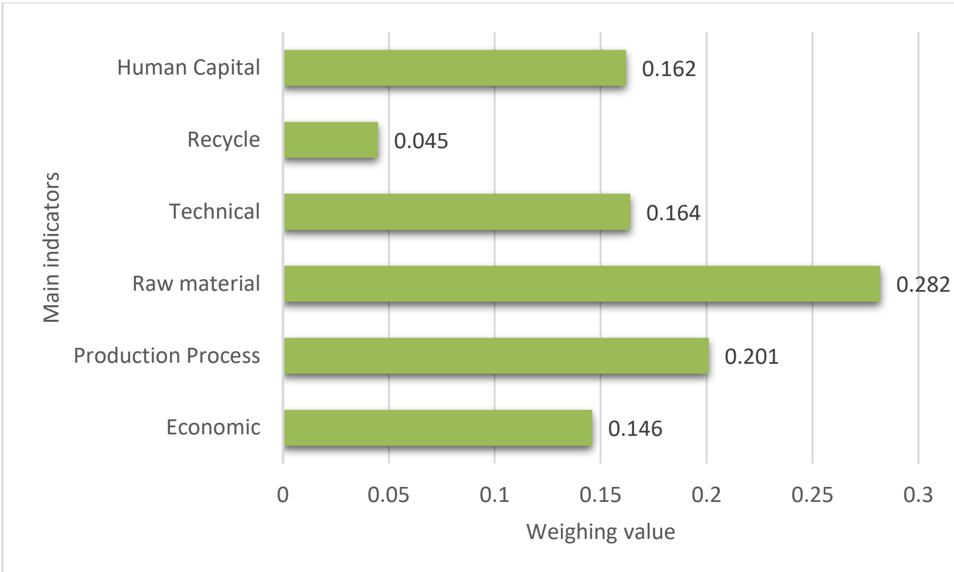

Figure 4 Prioritization of the main effective indicators

3.2 Prioritization of sub-criteria of raw material

Figure 5, the summary of experts' opinions, shows the prioritization of indicators affecting the life cycle of classic furniture, which is that the wood quality sub-index of the raw material index with a relative weight of 0.416 is the most crucial priority in the hierarchical tree, followed by the sub-index sustainable supply; raw material access sub-index and fabric quality sub-index are the most effective sub-indices in order of effect in the life cycle of classic furniture. Also, the inconsistency rate in prioritizing the raw material indicators is zero.

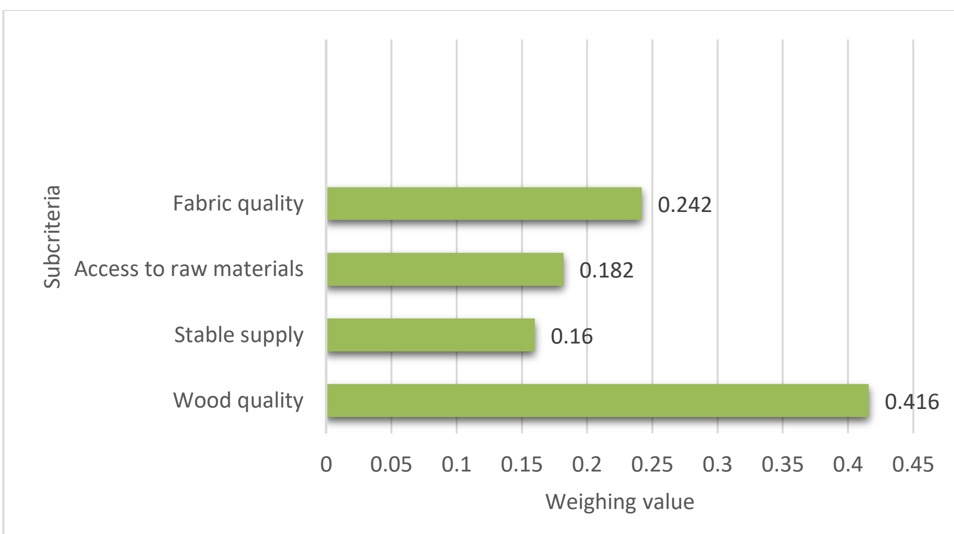

Figure 5 Prioritization of raw material sub-criteria

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3.3 Prioritizing the sub-criteria of the economic index

Figure 6, a summation of experts' opinions, shows the prioritization of indicators affecting the life cycle of classic furniture is as follows: the sub-index of the cost of raw materials with a relative weight of 0.574 is the most crucial priority of the hierarchical tree, and then the sub-index of labor cost, cost of maintenance and the cost of advertising and marketing are effective sub-indices, respectively. Also, the rate of inconsistency in prioritizing economic sub-indices is zero.

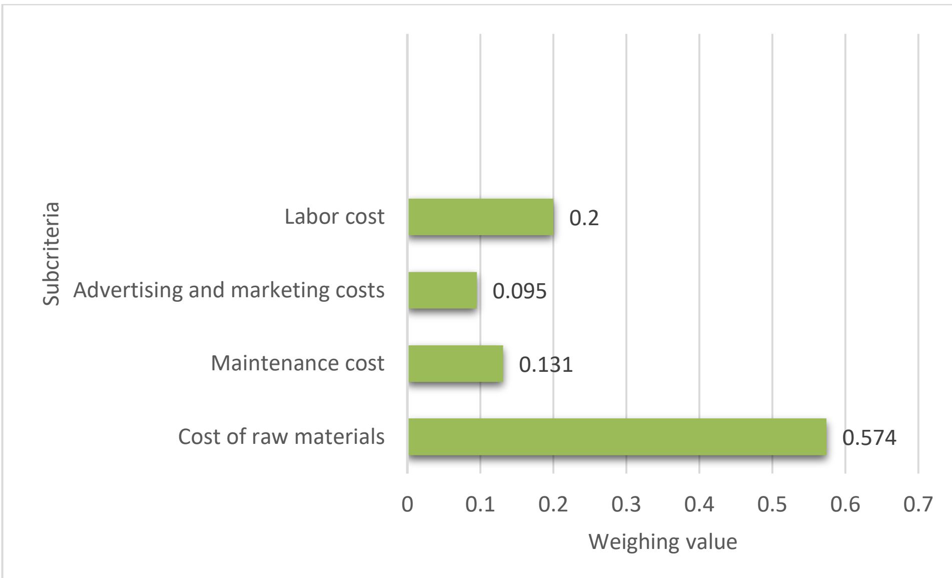

Figure 6 Prioritization of economic sub-criteria

3.4 Prioritizing production process sub-criteria

The connections sub-index of the production process index with a relative weight of 0.338 is the most crucial priority of the hierarchical tree, followed by the hammering process sub-index, the painting and cutting sub-index are the most effective sub-indices in order of effect in the life cycle of classic furniture (Figure 7). Also, the rate of inconsistency in prioritizing the sub-indices of the production process is 0.02.

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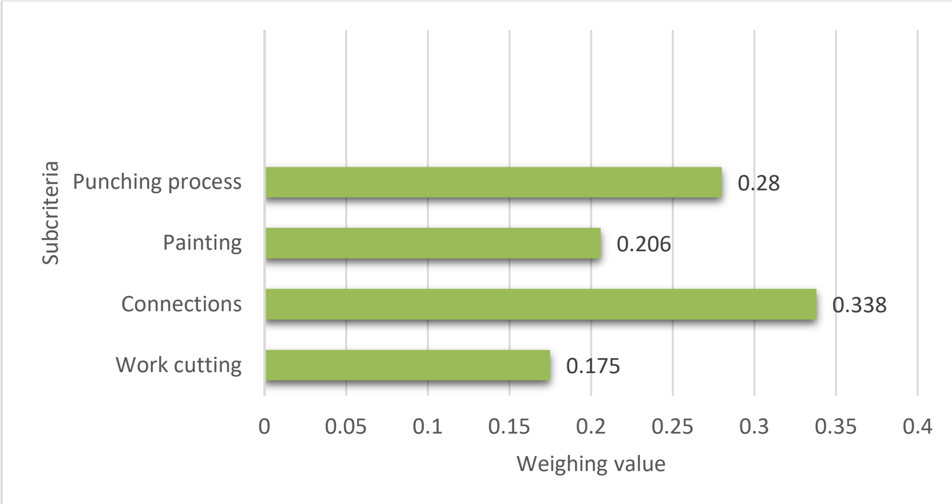

Figure 7 Prioritization of production process the sub-criteria

3.5 Prioritizing technical sub-criteria

Figure 8, a summation of the experts' opinions, shows the prioritization of indicators affecting the life cycle of classic furniture which is that the sub-index of product design with a relative weight of 0.273 is the most crucial priority of the hierarchical tree, followed by the sub-index of research and development, technology upgrade and quality control sub-index are the most effective sub-indices in order of effect in the life cycle of classic furniture. Also, the rate of inconsistency in prioritizing technical sub-indices is zero.

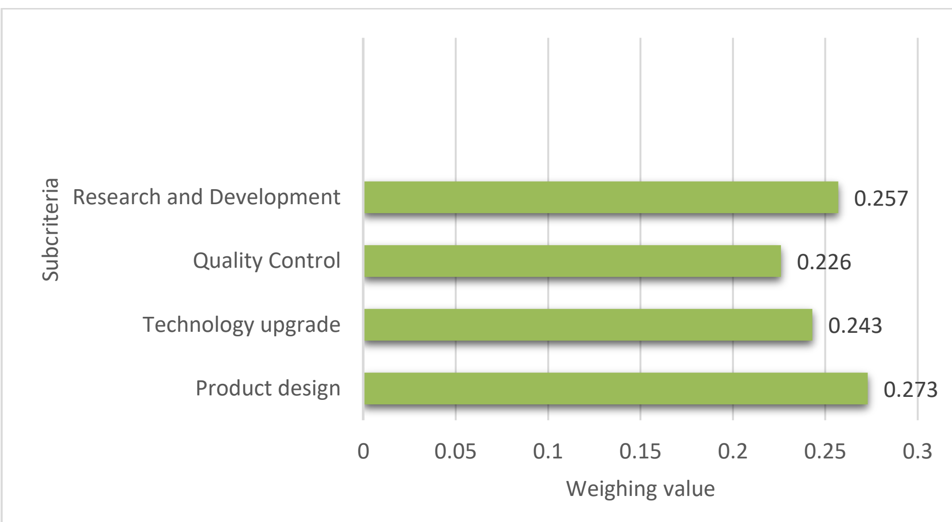

Figure 8 Prioritization of technical sub-criteria

3.6 Prioritizing the recycling sub-criteria

The reuse sub-index of 0.382 is the most crucial priority of the hierarchy tree, followed by the waste utilization sub-index, the product disposal sub-index, and the energy recycling sub-index as the most effective sub-indices in order of effect in the life cycle of

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classic furniture (Figure 9). Also, the rate of inconsistency in prioritizing recycling sub-indices is zero.

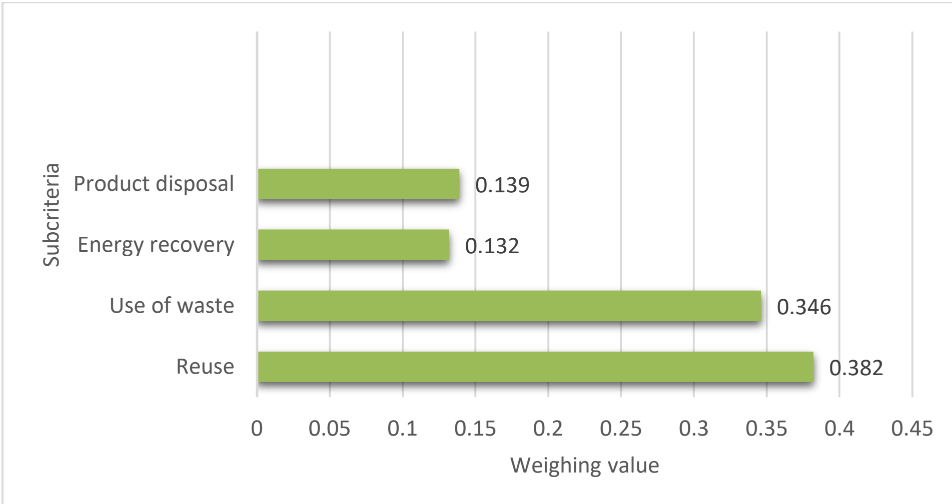

Figure 9 Prioritization of recycling sub-criteria

3.7 Prioritizing the human resource management sub-criteria

The sub-index of education level with a relative weight of 0.300 is the most crucial priority of the hierarchy tree, followed by the sub-index of work experience, the sub-index of skill improvement and human resource management, the most effective sub-indices in order of effect in the life cycle of classic furniture (Figure 10). Also, the rate of inconsistency in prioritizing human management sub-indices is zero.

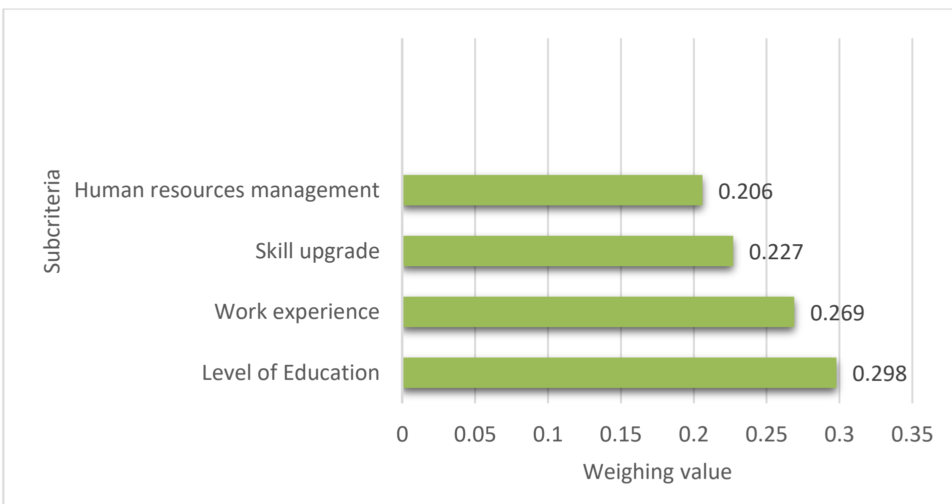

Figure 10 Prioritization of human resources sub-criteria

3.8 Results on all the influential sub-criteria in the production of classic furniture

The study's results on the sub-indices affecting the production of classic furniture showed that the sub-index of wood quality with a weight of 0.096 among all the indicators would most significantly impact the life cycle of classic furniture. The sub-index of connections with a weight of 0.074, the sub-index of the punching process with a weight of 0.064, and the sub-index of education level with a weight of 0.061 were ranked second to fourth. Among the mentioned sub-indices, the product disposal index, with a weight of 0.006, and energy recovery index, with a weight of 0.005, are the least important. Also, the inconsistency rate in prioritizing sub-indices is 0.02 (see Figure 11).

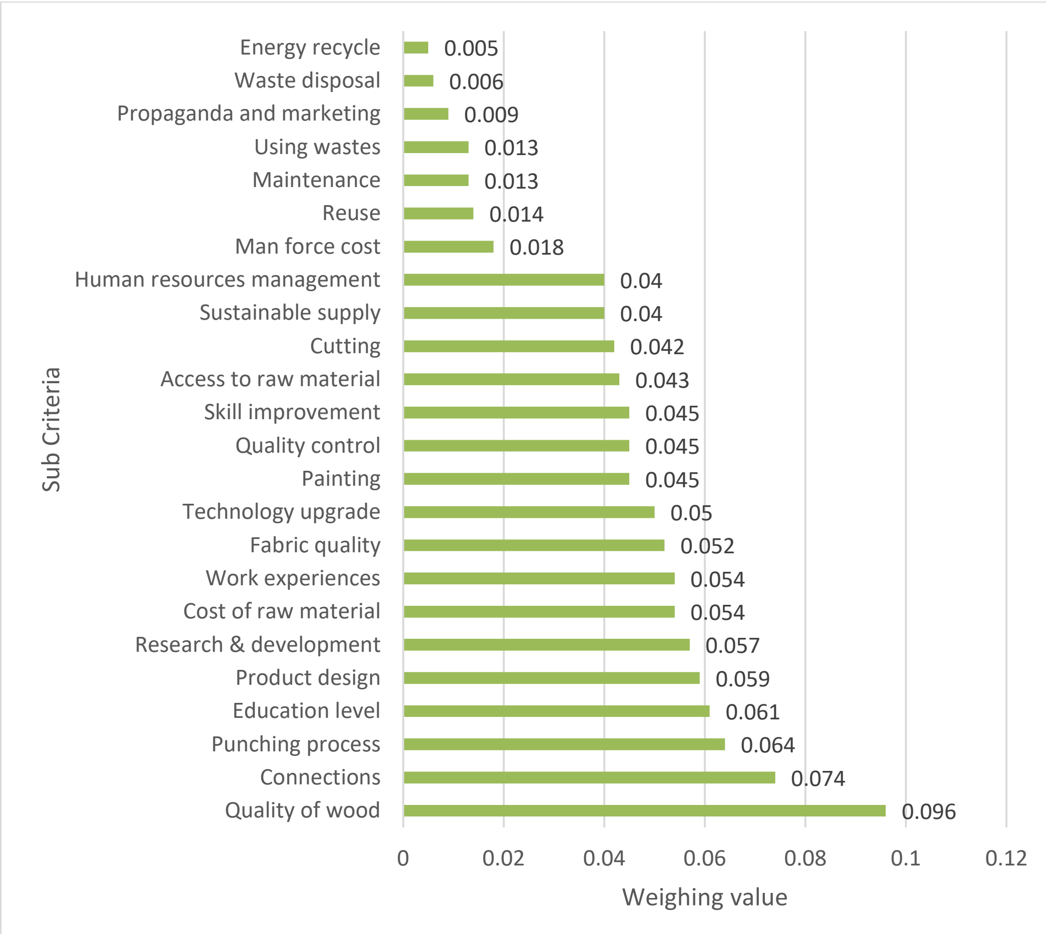

Figure 11 Prioritizing all sub-criteria affecting the life cycle of classic furniture

3.9 Prioritizing the options

The comparison and prioritization of options (Figure 12) show that producing furniture using birchwood or other woods rather than beechwood with a relative weight of 0.426 is preferable to different options, followed by using ready-made parts instead of buying lumber which has a relative weight of 0.301. Finally, the option of producing furniture with recycled parts (about 10% in the production of classic furniture, 50% in the production of comfortable furniture, and up to 100% for chipboard factories) with a relative weight of 0.273. Also, the rate of inconsistency in prioritizing options is 0.01.

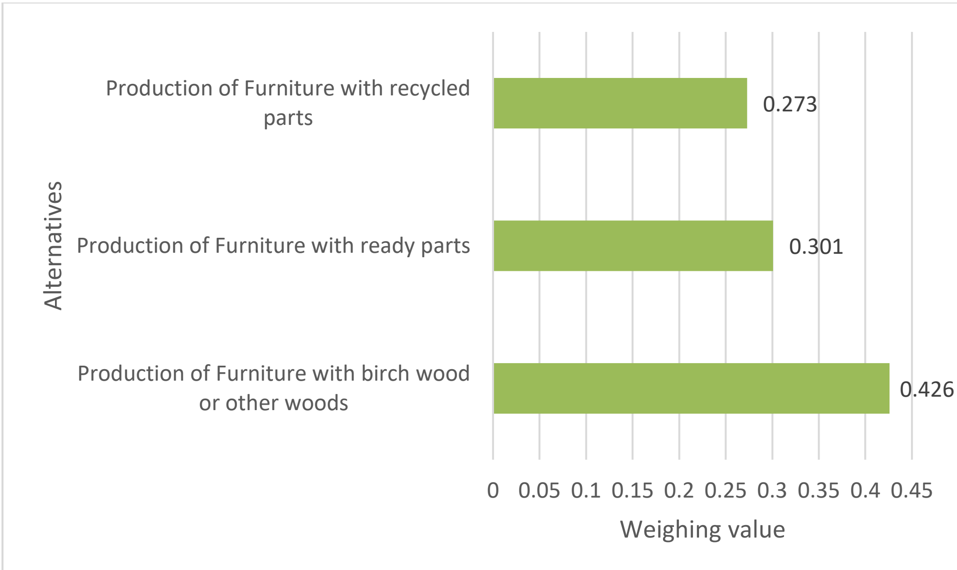

Figure 12 Prioritizing the options

3.10 Results of sensitivity analysis

The hierarchy options are coded as follows:

T: Economic design of classic furniture production using birch or other wood
A: Classic furniture design with ready-made pieces
B: Furniture production design with recycled parts (about 10% for making classic furniture, 50% for comfortable furniture and 100% for making chipboard)

Table 2
Results of sensitivity analysis

Alternatives	Initial prioritization: T> A> B				
	Main criteria	Basic priority	New Priority	New prioritization	Number of prioritization changes
	Raw material	0.282	0.372	T> A> B	-
	Economic	0.146	0.224	T> A> B	-
	Production process	0.201	0.596	T> B> A	1
	Technical	0.164	0.653	T> B> A	1
	Recycle	0.045	0.119	T> A> B	-
	Human capital	0.162	0.540	T> B> A	1
	Initial prioritization: T> A> B				

According to the sensitivity analysis and results (Table 2), a change in the weight of the indicators of the production process and technical and human capital causes a one-time change in the prioritization of the options. Therefore, these three indicators are sensitive.

3.11 Evaluating the environmental effects of classic furniture production

The furniture industry is one of the most essential and popular industries in various societies and it is very important to estimate the pollutants created in this industry and their effects on humans and nature. Using furniture with chemical materials can lead to different health effects in humans. Some chemicals used in the furniture industry can cause nausea, headaches, lung inflammation, and skin allergies. Therefore, estimating pollutants created in the furniture industry can help identify and reduce these health effects. Also, the furniture industry can contribute to the destruction of the environment. The use of different chemicals in the production of furniture can lead to air, water, and soil pollution. Burying and burning old furniture can lead to the production of greenhouse gases and air pollutants. Estimating the pollutants created in the furniture industry can also help identify and reduce these environmental impacts. Estimating the pollutants created in the furniture industry is essential for maintaining human health, protecting the environment and helping develop sustainable industries and green products.

The effect groups used in this research include global warming, destruction of the ozone layer, ionizing radiation, formation of the ozone layer and its effect on human health, formation of suspended particles, formation of the ozone layer in terrestrial ecosystems, acidification of the earth, eutrophication of water, eutrophication of the sea, Earth toxicity, water toxicity, sea toxicity, carcinogenic toxicity for humans, non-carcinogenic toxicity for humans, land use, lack of mineral resources, lack of fossil resources and water consumption, which can be calculated with the help of Sima Pro software. According to the models created in Sima Pro, and with the help of the midpoint method, Figure 13 shows each of the three types of classic furniture groups, including classic furniture made from birchwood, furniture made from ready-made parts, and furniture made with recycled wood. The production of furniture with recycled parts has the most significant impact on the environment and the release of environmental pollutants. The production of furniture with birchwood or other woods ranks second, and the production of furniture with ready-made parts has the most negligible effect on the emission of pollutants and other effect groups. Therefore, the production of furniture with ready-made parts has less impact on the environment and reduces pollutants due to less consumption of wood resources, as well as the reduction of the use of machinery and, consequently, energy.

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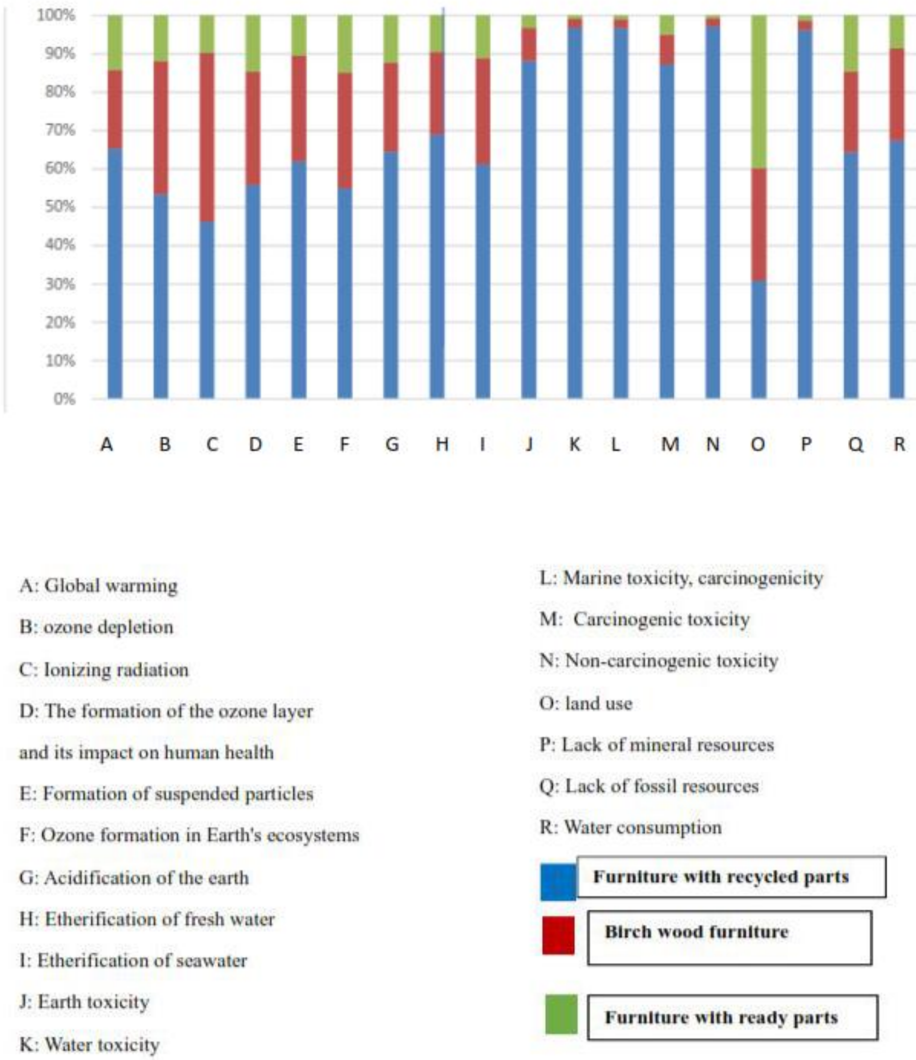

Figure 13 Comparing the relative share of three options of classic furniture concerning nineteen factors (A-R)

4. Discussion

Currently, the life cycle of a product, especially furniture and wooden artifacts, is significant and can help reduce furniture's environmental impact. This research showed that raw materials have the most significant impact on the life cycle of classic furniture, followed by the production process. Technical, human capital, economics, and recycling were ranked from third to sixth as priorities. The findings underscore the critical basis of these results and provide good insight into the integration of sustainable strategies into the production and distribution of wood materials, paving the way for a greener and more responsible furniture industry. This study also highlights that as environmental concerns intensify, adopting sustainable practices is not just a moral obligation but also a strategic necessity for long-term success. The results aim to help companies thrive in an increasingly environmentally conscious marketplace. By proactively embracing sustainability, the furniture manufacturing industry can play a crucial role in creating a more sustainable and resilient future for all. By focusing on both environmental and economic factors based on the results of this research, industrial managers can make informed decisions that promote sustainability without compromising economic viability. Choosing eco-friendly finishes and adhesives is a critical part of this process, as these decisions directly impact both the environmental footprint and the overall cost of the product.

4.1 Criteria

The index of raw materials, such as quality wood and fabric, is the most important factor in the life cycle of furniture. Quality wood and fabric are produced from natural resources, and trees and plants are needed for production. Due to the reduction of natural resources and climate change, preserving and using these resources sustainably is very important. Wood and fabric production requires complex processes which results in high energy consumption. Therefore, the optimal use of these raw materials and the reduction of wastage and energy consumption in the production process can help preserve the environment. Furniture is made of wood and fabric and is usually used for a long period of time. This means that the raw materials must be of good quality, resistant to being ruined from use over time, and they must not require frequent repairs and replacements. If the furniture is no longer usable, it must be disposed of properly. If raw materials can be recycled and reused, this can help conserve natural resources and reduce waste generation.

High-quality wood is usually more substantial and durable. This means classic furniture using high-quality wood can last longer and requires less maintenance and replacement. This reduces the consumption of natural resources and energy needed to produce new products. High-quality wood usually requires less energy-intensive processes to produce. Also, using high-quality wood makes it possible to use wood resources more efficiently and avoid cutting down more trees. Finally, high-quality wood is usually more recyclable and reusable.

The index of connections has a significant impact on the life cycle of furniture. Strong and stable joints in furniture can strengthen its overall structure. Weak and inappropriate connections can cause premature failure of furniture. Strong connections can also give the furniture more stability and prevent it from moving and sliding. which can increase the useful life of furniture. When solid and durable joints are used in furniture, the furniture can usually withstand repeated use, average pressure, and stress and therefore last longer. Strong and correct connections can also contribute to the safety of furniture users. If the connections are unstable and slip or break when the furniture is in use, it can create hazards for users. Strong and reliable connections can simplify the process of furniture maintenance. If the connections are weak, they may be more complicated to repair, requiring frequent replacement of parts or repairs. Proper connections and a beautiful appearance can add to the overall look and style of the furniture. Fittings that are designed and implemented correctly can help the appearance and beauty of furniture and give it better quality and a cleaner feeling. The punching process has a significant impact on the life of the furniture. Punching can give the furniture more resistance to

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abrasion and daily use. Considering that the punching is a part that is in direct contact with users, long-term use of furniture and frequent use can cause abrasion and erosion of the surface. Resistant and durable punching provides repair against abrasion and tear and can extend the useful life of furniture.

Punching can add resistance to stains, dirt, and dust on the furniture. During the life of the furniture, there is a high possibility of stains and contamination, so the punching surface should be easy to wash and clean so that stains and contamination can be easily removed from the surface and protect the appearance and style of the furniture. Punching can also help with color stability throughout the life of the furniture as well as preserve furniture color against sunlight and other environmental factors by using high-quality materials and appropriate production processes. This helps the furniture remain beautiful over time. The punching surface allows the furniture to be easily replaced and restored; if the punching surface is removable, it can easily be removed and a new surface be put on. This allows the furniture to be renovated and revised in a way that can be upgraded and changed during its useful life.

4.2 Alternatives

Birchwood production is less expensive than beechwood. This is due to the lower price of birchwood and the high growth rate of birch trees. This makes the production of furniture using birchwood more economical. Birchwood can be used to make various products due to its good physical and mechanical properties which allows furniture manufacturers to create designs and styles that meet customer needs. Birchwood is obtained from cultivated trees and does not need to be harvested from natural forests. This preserves biodiversity and conserves natural resources. The production of birchwood requires less energy and natural resources than beechwood which means less fossil fuel consumption and greenhouse gas emissions. As a result, using birchwood instead of beechwood can help reduce air pollution and climate change. Birchwood can be recycled and reused. This means reusing birchwood to produce new products and reducing the consumption of natural resources, which also helps reduce the amount of solid waste and environmental pollution.

The production of furniture with recycled parts may cost more than the production of furniture with new raw materials because of the costs associated with the collection, recycling, and provision of recycled materials. Some manufacturers may not be able to recover this cost and, hence, prefer to use new raw materials. Recycled parts may be of lower quality and strength than new raw materials which can result in brittleness and weakness in the furniture structure, causing manufacturers to not use this method to maintain the quality of their products. The production of furniture with recycled parts requires unique technology and equipment. Some manufacturers may not have this technology and equipment or have not been able to fully implement the equipment they do have. The production of furniture with recycled parts requires a suitable sales market, which if it does not exist for these types of products, manufacturers may prefer to use new raw materials to sell their products quickly.

In the current research, the results indicate that the use of ready-made parts instead of timber in the design and production of classic furniture can lead to a reduction in the wastage of resources and energy, an increase in the durability of products, and a decrease in maintenance costs. These results are consistent with the research done by Brown and

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Davis (2018). The use of ready-made parts instead of lumber means that the parts that are made and available in the market are used instead of creating new parts from wooden lumber. This method reduces the time, cost, and energy needed to produce furniture. Also, due to the use of ready-made parts that are made under controlled conditions, the assurance of the high quality and durability of the product increases. By using ready-made parts, maintenance costs are also significantly reduced because ready-made parts are usually manufactured under strict standards and are easy to move and replace. In the case of failure or a need for repair, only the defective part can be replaced, which saves maintenance costs and also reduces repair time.

In the AHP, the relative contribution of each effect group in the life cycle of classic furniture with birchwood or other woods is more significant than in the production of classic furniture with ready-made parts. The reason for the difference can be attributed to the fact that classic furniture producers pay less attention to environmental issues. Of course, other factors are also influential in this difference, which include:
Raw materials: Classic furniture with birchwood requires harvesting wood from forests, which can decrease biodiversity. In contrast, producing finished parts using materials such as fiberglass, foam, or metals may require less use of natural resources.
Production process: The production of classic furniture with birchwood requires energy-intensive and water-intensive processes. Processes such as cutting, turning, and dyeing may use fossil energy sources and need more water consumption. Also, protecting and covering wood requires the use of polluting chemicals. In contrast, producing finished parts uses modern industrial methods and less exploitative processes, which can lead to reduced energy and water consumption and reduced polluting chemicals.
Product lifespan: Classic birchwood furniture requires frequent maintenance and may be less resistant to damage and wear. This issue can lead to frequent furniture replacement and increased waste production. Instead, off-the-shelf parts are usually replaceable and recyclable and can extend the product’s useful life. In general, using furniture with ready-made parts can help reduce environmental liability, but it should be noted that the type of materials, production methods, and the product’s life cycle also affect environmental liability.

4.3 Testing hypotheses

The first hypothesis is that the raw material index will be more critical than other indices. Also, raw material recycling is the most important solution for reducing environmental effects. According to the findings obtained from this research and the investigations carried out on the most critical indicators affecting the life cycle of furniture, the index of raw materials by weight is the most critical index affecting the life cycle of classic furniture among all the indicators studied in this research. Therefore, the first part of the first hypothesis is confirmed. However, based on the investigations conducted in this research, the most important solution to reduce the environmental effects of furniture production is to replace beechwood with birchwood or other woods. Therefore, the second part of the first hypothesis, which considers recycling as the most important solution to reduce environmental effects, is not confirmed.

The second hypothesis states that investigating and identifying indicators affecting the life cycle of classic furniture can determine the most critical indicators affecting the life cycle of classic furniture at each stage of the life cycle process. By using the AHP, the most critical indicators affecting the life cycle of classic furniture can be identified at

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each stage of the life cycle process based on prioritization; therefore, the second hypothesis is confirmed.

5. Conclusion

The evaluation of the life cycle assessment of classic furniture using the AHP and LCA reveals the importance of wood quality and material choice in reducing environmental impacts. The results of this study showed that several key factors emerged as top priorities such as bio-economic considerations, the production process, wood quality, a stable supply of raw materials, technical aspects, and recycling processes. A pairwise comparison of 24 sub-criteria highlighted the importance of wood quality as a raw material, wood supply management and logistics, the punching process, user education and skilled labor, and process design. Focusing on these factors not only aids in pollutant removal but also enhances the LCA framework within the furniture industry.

When considering alternative methods for furniture production, the use of birchwood was identified as the highest priority. Production using ready-made parts and recycled components ranked second and third, respectively. A comparative study conducted using SimaPro LCA software further supported these findings. The LCA results indicated that scenario 1, which involves designing recyclable furniture, significantly impacts water toxicity and CO_2 emissions. Scenario 2, which substitutes birchwood as an imported raw material, effectively mitigates ionizing radiation. Meanwhile, scenario 3, which focuses on using recycled wood in the manufacturing process, has a substantial effect on land use and emissions. Regarding the alternatives, AHP-producing furniture with solid birchwood is the most crucial solution. Sima Pro software showed making furniture with prefabricated parts had the most negligible impact in categories such as global warming potential and ozone layer depletion. Overall, the evaluation with SimaPro revealed that producing furniture with ready-made parts has the least environmental impact, and minimizes pollution emissions by reducing wood resource consumption, machinery use, and, consequently, energy demand. Finally, considering both environmental and economic factors based on the findings of this research, industrial managers can make informed decisions that balance sustainability with economic viability. Selecting eco-friendly finishes and adhesives is crucial in this process, as these choices significantly affect both the product's environmental impact and overall cost.

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