Highlights of Sustainability

ISSN 2696-628X, A Peer-Reviewed Open Access Journal by Highlights of Science
https://www.hos.pub/ho/sustainability

Feasibility of Remanufacturing in Shoemaking Machines under the Trend of Net-zero Carbon Emissions

by Wan-Ju Chen, Rong-Ho Lin and Chun-Ling Chuang

This article is part of the Special Issue
Capturing the Sustainable Impact of Early-Stage Business Models

Cite this Article

Chen, W.-J., Lin, R.-H., & Chuang, C.-L. (2023). Feasibility of Remanufacturing in Shoemaking Machines under the Trend of Net-zero Carbon Emissions. *Highlights of Sustainability*, *2*(2), 110–137. https://doi.org/10.54175/hsustain2020010

Highlights of Science

Publisher of Peer-Reviewed Open Access Journals
https://www.hos.pub
Barcelona, Spain

Article

Feasibility of Remanufacturing in Shoemaking Machines under the Trend of Net-zero Carbon Emissions

Wan-Ju Chen [1], **Rong-Ho Lin** [1,*] and **Chun-Ling Chuang** [2]

[1] Department of Industrial Engineering and Management, National Taipei University of Technology, Taipei 106344, Taiwan
[2] Department of Information Management, Kainan University, Taoyuan 33857, Taiwan
* For correspondence: rhlin@mail.ntut.edu.tw

Abstract Achieving net-zero carbon emissions by 2050 has become a common goal in the world. An effective strategy to reduce carbon emissions will be the key to maintaining international competitiveness. Although green energy exchange is mature around the world, the relevant systems and regulations in Taiwan are not yet ready. This research examines the feasibility of shoemaking machines remanufacturing and tries to seek effective strategies to achieve carbon neutrality for the original equipment manufacturers (OEMs) of shoemaking machines. The evaluation of remanufacturing in a shoemaking machine is based on imprecise and fuzzy information. First, the feasibility evaluation model of remanufacturing in a shoemaking machine is established, including technical, economic, and resource environment feasibility criteria. Second, the comprehensive benefit evaluation model of the remanufacturing shoemaking machine is established, in which the weight of each criterion is determined by the Analytic Hierarchy Process (AHP). Finally, combined with the questionnaire, the evaluation method is verified and analyzed. The results show that the four criteria (clusters) for remanufacturing shoemaking machines have different weights, in descending order: Product design, Business model, Recycling system, and Corporate image. This implies that Product design is the most important factor for remanufacturing shoemaking machines, followed by the Business model, Recycling system, and Corporate image. Therefore, to succeed in the circular economy, OEMs need to rethink how to redesign their products from the beginning and create a new business model.

Keywords remanufacturing; shoemaking machine; Analytic Hierarchy Process (AHP); circular economy (CE)

1. Introduction

The European Union (EU) launched the "Fit for 55 Package" in July 2021, which includes a Carbon Border Adjustment Mechanism (CBAM, the EU's carbon tariff). The CBAM will begin to operate in 2023, become fully effective in 2027, and it will enable the EU to achieve net-zero carbon emissions by 2050 [1]. The EU attempts to control the carbon footprint of imported goods by imposing carbon tariffs. In the initial stage, 248 items of controlled products from the industries such as steel, aluminum, and power generation will be covered. Other products that possibly have indirect emissions will also be included. Following the steps of the EU, more countries will successively release similar carbon tariff policies to ensure the competitiveness of domestic industries and accelerate the rate of carbon reduction [2]. The polluter pays principle (PPP) is applied to ensure that the original equipment manufacturers (OEMs) are involved in the reduction of consumption of natural resources and pollution. According to the trend, international brand corporations require their supply chains to achieve the goal of net-zero carbon emissions. The carbon footprint of products has gained increasing attention. This has led the OEMs in the supply chain to focus on the design of their own green supply chains to achieve cost efficiency and environmental protection.

To achieve the goal of zero carbon emissions, the EU has activated the Circular Economy Action Plan (CEAP) of Europe to improve the monitoring of the transition to a more circular economy. Individual R strategies (recycle, reuse, refurbish, repair, and remanufacture) have become potential tools to use, except for energy exchange. Han et al. [3] defined remanufacturing as an industrial process that repairs, replaces, or restores used products to bring them back into like-new condition. Zhuang et al. [4] stated that remanufacturing is a process that restores a used

Open Access

Received: 15 February 2023
Accepted: 1 June 2023
Published: 17 June 2023

Academic Editors
Jan Kratzer, Karina Cagarman, and Kristina Fajga, Technical University of Berlin, Germany

product to its original performance with a warranty matching with an equivalent new product, which could maximize the values of used products. Remanufacturing can effectively reduce the energy and resource consumption, as well as environmental emission in the whole product life cycle. To achieve environmental, financial, and marketing benefits, remanufacturing has attracted a great deal of attention and interest from the machinery manufacturing industries. Government legislation, especially in the EU, the United States (US), and China, also requires the OEMs to recycle or remanufacture their used products. The remanufacturing process involves the dismantling of a product, inspection, cleaning, repairing, replacing components, and testing to ensure that the remanufactured components meet the original design specifications.

According to Technavio [5], the worldwide market share of the industrial machinery remanufacturing is projected to increase by US$304.36 billion between 2021 and 2026, with a CAGR of 16.81%. The main countries that remanufacture industrial machinery are the US, China, India, Germany, and the United Kingdom. The main growth driver in the industrial machinery remanufacturing market is the increasing awareness of asset utilization in the manufacturing industries. Most end-users of the industrial machinery improve machinery efficiency, reduce operational costs and energy consumption, and integrate all operational functions by upgrading and modernizing the existing machines. Machinery is one of the nine significantly impactful target sectors for remanufacturing [5]. It was reported that the US is the largest remanufacturer in the world. Machinery is also one of the remanufacturing-intensive sectors in the US that have positive growth potential [5]. The outlook comes from the existing incentives for OEMs to incorporate remanufacturing into their supply chains, including recycling used products, reducing lead times, and complying with the low-carbon equilibrium legislation. Global sustainability initiatives also put pressure on end-users to find ways to minimize the negative impacts of their businesses on the environment. It will directly encourage them to develop green procurement system, which will in turn grow the remanufacturing market. It will also facilitate the reverse logistics.

Xu et al. [6] mentioned that carbon emissions are associated with product life cycles, which essentially prompts a reduction of carbon emissions at different stages. Both internal and external carbon management of the OEMs influence carbon disclosure strategies. However, a correct evaluation can provide an opportunity to develop a sustainable and green supply chain. Because of the increased pressure of both the environmental protection and economic benefit, a growing number of OEMs have been devoted to collecting and remanufacturing end-of-life machinery. Ansari & Daxini [7] proposed several advantages that remanufacturing offers in a supply chain, including reducing manufacturing cost and resource consumption, restricting disposal costs, and increasing ecological benefits. Compared to traditional manufacturing, the processes of remanufacturing are more complex due to being associated with a large number of uncertainties, including the quantity of used products, stochastic recovery rate, returns–demand balancing issue, used product disassembly, requirement of a reverse logistics network, material and parts matching issue, process timings, and material routing. Sousa & Pham [8] reviewed the methods of quality control that help to check and improve the quality of manufacturing and remanufacturing. The effectiveness of quality control can reduce costs and bring benefits. Focusing on the feasibility, this research will examine whether the remanufacturing theory and practice of general machinery can be applied to shoemaking machines. The complexities of real-life remanufacturing problems have made the decision-making process challenging.

Remanufacturing reverse logistics can be an economic and social strategy to avoid waste, when the reverse flow starts from the end products used by customers, and returns to suppliers who perform remanufacturing, repairing, or disposal. There has been a rare discussion of remanufacturing in shoemaking machines in previous studies which have mostly been focused on machine tool and turbine. Taking this into account, in this paper, an Analytic Hierarchy Process (AHP) method accompanying an interview and survey to examine the feasibility of remanufacturing initiatives in the close-loop supply chain for the OEMs of shoemaking machine was presented.

The paper is structured as follows. The literature review is in Section 2. Section 2.1 discusses the current situation of remanufacturing development in major countries, including the US, China, India, and the EU. The limitation of machine remanufacturing is discussed in Section 2.2. The methodology in terms of assumption, system operation, questionnaire design, and questionnaire return is presented in Section 3. The results in Section 4 lead to the findings, and the discussion and conclusion are given in Sections 4 and 5, respectively. The study was conducted in Taiwan.

2. Literature Review

In recent years, due to the global legislation and growing public awareness, the OEMs are facing increasing pressures of incorporating the environmental and sustainability factors into their businesses; therefore, they are rethinking of strategizing their supply-chain networks. Masoumik et al. [9] mentioned that manufacturers have been forced to shift from local optimization at the firm level to the entire supply chain due to the increasing competition and globalization. At the same time, manufacturers have the opportunities to strengthen their sustainability development thanks to this operational transition in environmental practice. Ghosh et al. [10] mentioned that the environmentally conscious supply chain practices of business organizations across the globe have received increasing interest from industries. In order to minimize the detrimental impact on the environment, it is suggested to incorporate various green supply chain management (GSCM) practices into an organization's supply chain policies. Sundin & Bras [11] found that the production and processing of raw material decreases when remanufacturing hardwares. Both environmental and economic benefits can thus be achieved through a strategy for functional sales and remanufacturing of products. According to Ghoreishi et al. [12], closing, slowing, intensifying, de-materializing, and narrowing resource loops are the key strategies of circular economy (CE) business models that can contribute to sustainable development goals. The CE business models require a strategic shift in how value is created and captured, which involves designing new systems of value creation and innovative business models for products. A product should be designed and developed for circularity, meaning that it can be easily repaired, refurbished, and remanufactured to close the loop. A business model should create value by offering more innovative solutions based on the CE principles. To achieve a successful circular value creation, transparency and high-quality data are essential for the entire value chain, which can enable design optimization and management of supply chain. Artificial intelligence (AI) can be a facilitator of CE to help by OEMs to innovate circular business models. Konstantaras et al. [13] introduced a model that determines optimal inventory decisions under a manufacturing, remanufacturing, and repairing system in a closed-loop supply chain to minimize the total cost of operation when facing the carbon tax regulation. Once the main concerns are resolved, the OEMs need to take the appropriate measures to increase the value of the supply chain. Mathiyazhagan et al. [14] highlighted the reverse supply chain management for OEMs. Reverse supply chain management is a process that involves customers and suppliers/OEMs, including the activities of recycling, remanufacturing, reusing, and disposing of unacceptable items to reduce waste and improve sustainability. However, many OEMs currently do not integrate the reverse supply chain into the forward supply chain of their own internal value chains. Vlachos [15] noted that the reverse supply chain requires the same attention as the forward supply chain due to the increasing pressure of business and consumer needs, including financial factors, customer needs, sustainability, competition, and legal implications. For the sustainable design of the supply chain from a performance perspective, Oliveira & Machado [16] focused on cost control while considering economic, environmental, and social issues in a balanced way. Condeixa el al. [17] proposed an economic order quantity (EOQ) based mathematical model for the lot size in reverse logistics that includes environmental, social, and economic parameters. Xu et al. [6] reviewed the implications of carbon policies on supply chains, considering the information about drivers (carbon policies), actors (e.g., manufacturers), methodologies (mathematical models), decision-making contexts (e.g., order quantity), and emission reduction opportunities.

The technology is advancing by leaps and bounds, causing a reduction of the life cycle of products. Customers are also having a growing desire to acquire the latest technology. Both resulted in an increased volume of disposed products which have caused environmental pollution. However, this environmental problem also represents an opportunity for remanufacturing in the green supply chain. Lee et al. [18] stated that remanufacturing generates green economy, creates jobs, and also stabilizes prices. Remanufacturing reduces production costs (40–65% of producing a new product in general) by using end-of-life product parts. Producing a remanufactured product also consumes less energy (<25%) compared to producing a new one. Apart from this, the remanufacturing process requires a large amount of labor thus can create job opportunities. Remanufacturing also helps stabilize prices because it provides less cost but like-new products in terms of quality and performance. Chari et al. [19] identified that an extended shelf life of products can be achieved by the remanufacturing process, which is a value recovery option to extend the original useful life of industrial equipment. Steingrímsson et al. [20] introduced competitive business approaches in the remanufacturing market for production equipment. Okorie et al. [21]

stated that digital technologies can help OEMs achieve their sustainability goals, such as net-zero emissions and circular economy, by translating abstract concepts into concrete actions and outcomes. A resource-based view (RBV) was used to examine how digital technologies can enhance a manufacturing firm's competitive advantage by using its existing resources and core competencies to pursue net-zero manufacturing emissions and circular economy. Cunha et al. [22] established a roadmap methodology to express the interconnections between market, equipment, and technology variables in the remanufacturing process. Du et al. [23] presented that most end-of-life machines have potential problems such as deterioration of accuracy, backward level of electrical control and automation, as well as no computerized numerical control (CNC) system, resulting in high processing costs and low processing efficiency. The delay or downtime of remanufacturing is usually 75% less than new production. According to engineering practice experience, when the remanufacturing cost is less than 40% of purchasing a new machine, the customer has a higher tendency to implement machine remanufacturing; however, when the remanufacturing cost is greater than 60% of purchasing a new machine, the customer's tendency to implement remanufacturing wil be gradually reduced and they are more willing to purchase a new machine. Jiang et al. [24] proposed a multicriteria decision-making model to select remanufacturing technology. The model evaluates six main criteria, including cost, quality, time, service, resource consumption, and environmental impact. Ramírez et al. [25] proposed that the development of digital twins can reduce the impact of uncertainties in remanufacturing. Sitcharangsie et al. [26] presented a holistic way of integrating different decisions over multiple remanufacturing activities to improve remanufacturing outcomes. Remanufacturing is more complex than traditional manufacturing due to the uncertainties associated with the quality, quantity, and return timing of used products and components. Du et al. [27] mentioned that machinery has great recycling value and potential for remanufacturing, and proposed an integrated method for evaluating the remanufacturability of used machines on technology and economic feasibility, and environmental benefits.

Increased awareness of environment protection and policies related to carbon emissions have led OEMs to consider carbon emissions as one of the most critical elements that affect production decisions. As a gradually maturing mode of production, remanufacturing plays an increasingly important role in economy, environment, and society. Shu et al. [28] constructed a model for manufacturer inventory and production in the context of a cap-and-trade regime. Based on this, the manufacturer's optimal production decision and minimum cost were derived with and without considering carbon emissions. When considering remanufacturing and carbon emissions, the cost of production and environmental decreases significantly. In terms of manufacturing activities, remanufacturing can reduce both carbon emissions and total costs. Companies must control carbon emissions to reduce the uncertainty caused by fluctuation in the carbon trading market. Otherwise, the OEMs must pay for the carbon quota from the carbon exchange market at a higher price, which will increase the total cost of manufacturing. The OEMs can choose to do remanufacturing on their own or by outsourcing. Majumder & Groenevelt [29] showed that OEMs are more likely to remanufacture in a competitive environment. A decrease in remanufacturing costs can benefit customers. Compared to internal or outsourcing remanufacturing, OEMs are more advantageous in terms of technologies, rules, and regulations. Many OEMs' remanufacturing activities have made great achievements in their businesses. Chen et al. [30] used the simulation results to show that when the entry barrier to the remanufacturing industry is low, the manufacturer can develop the remanufacturing technology in a short time and the direct reverse channel outperforms the indirect reverse channel; otherwise, the manufacturer can achieve more profits under the indirect reverse channel by acquiring the remanufacturing technology directly from the remanufacturer. The indirect reverse channel is more likely to be superior for the low-barrier remanufacturing industry when the cost advantage is high as the early entry in the remanufacturing industry becomes more important than the complete control in the later stage. Table 1 summarizes aforementioned research on green supply chain, ANP, remanufacturing and other subjects.

Table 1. Summary of literature review.

References	Subject Focused	Research Briefing
Masoumik et al. [9]	green supply chain; ANP; structural equation modeling (SEM)	Mnufacturers have been forced to shift from local optimization at the firm level to the entire supply chain due to the increasing competition and globalization. At the same time, manufacturers have the opportunities to strengthen their sustainability development thanks to this operational transition in environmental practice.
Ghosh et al. [10]	green supply chain management; performance evaluation; multi-criteria decision-making (MCDM); fuzzy set theory; the Plan, Do, Check, Act (PDCA) cycle	The environmentally-conscious supply chain practices of business organizations across the globe have received increasing interest from industries. In order to minimize the detrimental impact on the environment, it is suggested to incorporate various green supply chain management (GSCM) practices into an organization's supply chain policies. practices into an organization's supply chain policies.
Sundin & Bras [11]	remanufacturing; design for environment; ecodesign; design for remanufacturing and activity-based costing (ABC)	The production and processing of raw material decreases when the hardware is remanufactured. Both environmental and economic benefits can thus be achieved through a strategy for functional sales and remanufacturing of products.
Ghoreishi et al. [12]	artificial intelligence; sustainable development goals; business model; circular economy; Industry 4.0; value creation	Circular economy (CE) business models provide solutions for sustainable development goals by closing, slowing, intensifying, dematerializing, and narrowing resource loops. In a successful circular value creation, a higher degree of transparency and high-quality data for the entire value chain is required for further development of the products and processes, hence enabling design optimization and management of supply chain. Artificial intelligence (AI) can be considered as an enabler of CE to help OEMs in innovating circular business models.
Konstantaras et al. [13]	inventory; carbon emissions; carbon tax; remanufacturing; repair; rinite horizon	A model determines optimal inventory decisions under a manufacturing, remanufacturing, and repairing system in a closed-loop supply chain to minimize the total cost of operation while facing the carbon tax regulation. Once the main concerns are met, OEMs need to take appropriate measures to increase the value of the supply chain.
Mathiyazhagan et al. [14]	reverse supply chain; rverse logistics; closed-loop supply chain; remanufacturing; product recovery system	Reverse supply chain management is a process that involves customers and suppliers/OEMs, includinges the activities of recycling, remanufacturing, reusing, and disposing of unacceptable items to reduce waste and improve sustainability, which is a process between customers and suppliers or OEMs. However, many OEMs currently do not integrate the reverse supply chain into the forward supply chain within of their own internal value chains.
Vlachos [15]	reverse logistics; firm performance; logistics capabilities; business strategy	The reverse supply chain requires the same attention as the forward supply chain due to the increasing pressure of business and consumer needs, including financial factors, customer needs, sustainability, competition, and legal implications.
Oliveira & Machado [16]	closed-loop supply chain; optimization methods; sustainability	In the sustainable design of the supply chain from a performance perspective, cost control considers economic, environmental, and social issues in a balanced way.
Condeixa et al. [17]	reverse logistics; EOQ; sustainable log-sizing; environmental costs	An economic order quantity (EOQ) based mathematical model for the lot size in reverse logistics that includes environmental, social, and economic parameters.
Xu et al. [6]	supply chain management; carbon policy; carbon emission; sustainability; green supply chains	The implications of carbon policies on the supply chains, considering the information about with drivers (carbon policies), actors (e.g., manufacturers), methodologies (mathematical models), decision-making contexts (e.g., order quantity), and emission reduction opportunities.
Lee et al. [18]	remanufacturing; eco-friendly production methods; remanufacturing technologies	Remanufacturing generates green economy, creates jobs, and also stabilizes. Remanufacturing reduces production costs by using end-of-life prod-uct parts.
Chari et al. [19]	performability; dependability; Sustainability; product life cycle; ecodesign; life cycle analysis	An extended shelf life of products can be achieved using the remanufacturing process, which is a value recovery option to extend the original useful life of industrial equipment.
Steingrímsson et al. [20]	collaboration; competition; strategies; production equipment	Competitive business approaches in the remanufacturing market for production equipment are focused on value creation strategies, competition, collaboration and their impact as drivers for technological progress.

Table 1. (*Continued*)

Okorie et al. [21]	digital transformation; resource-based view; net-zero manufacturing; circular economy; sustainable competitive advantage	Digital technologies can help OEMs achieve their sustainability goals, such as net-zero emissions and circular economy (CE), by translating abstract concepts into concrete actions and outcomes. This work uses a resource-based view (RBV) to examine how digital technologies can enhance a manufacturing firm's competitive advantage by using its existing resources and core competencies to pursue net-zero manufacturing emissions and CE.
Cunha et al. [22]	production equipment; remanufacturing; technology roadmap	A roadmap methodology expresses the interconnections between market, equipment, and technology variables in the remanufacturing process.
Du et al. [23]	heavy-duty machine tools; remanufacturing; decision making; extension theory	Most end-of-life machines have potential problems such as deterioration of accuracy, backward level of electrical control and automation, as well as no CNC system, resulting in high processing costs and low processing efficiency.
Jiang et al. [24]	remanufacturing technology; multi-criteria decision making; environmental performance; AHP	A multicriteria decision-making model evaluates six main criteria, including cost, quality, time, service, resource consumption, and environmental impact, to select remanufacturing technology.
Ramírez et al. [25]	autonomous remanufacturing; digital twins; remanufacturing	The development of digital twins can reduce the impact of uncertainties in remanufacturing.
Sitcharangsie et al. [26]	remanufacturing; core acquisition; end-of-life (EOL) option; disassembly level; cleaning; material requirements planning (MRP)	A holistic way integrates different decisions over multiple remanufacturing activities to improve remanufacturing outcomes. Remanufacturing is more complex than traditional manufacturing due to the uncertainties associated with the quality, quantity, and return timing of used products and components.
Du et al. [27]	machine tool; remanufacturability; remanufacturing	Machinery has great recycling value and potential for remanufacturing. An integrated method was proposed for evaluating the remanufacturability of used machine on the technology and economic feasibility and the environmental benefits.
Shu et al. [28]	remanufacturing; inventory control; economic order quantity; carbon quota; carbon transaction	A model of manufacturer inventory and production in the context of a cap-and-trade regime. Based on this, the manufacturer's optimal production decision and minimum cost were derived with/without considering carbon emissions. When the manufacturer consid-ers considering remanufacturing and carbon emissions, the cost of production cost and envi-ronmental cost decreases significantly.
Majumder & Groenevelt [29]	remanufacturing; competition; reverse logistics	OEMs are more likely to remanufacture in a competitive environment. A decrease in remanufacturing costs can benefit customers. Compared to internal or outsourcing remanufacturing, OEMs are more advantageous in terms of technologies, rules, and regulations.
Chen et al. [30]	closed-loop supply chain; game theory; remanufacturing; reverse channel; simulation	When the entry barrier to the remanufacturing industry is low, the manufacturer can develop the remanufacturing technology in a short time and the direct reverse channel outperforms the indirect reverse channel; otherwise, the manufacturer can achieve more profits under the indirect reverse channel by acquiring the remanufacturing technology directly from the remanufacturer. The indirect reverse channel is more likely to be superior for low-barrier remanufacturing industry when the cost advantage is high as the early entry in the remanufacturing industry becomes more important than the complete control in the later stage.

2.1. Global Remanufacturing

According to Berkel & Ramchandra [31], compared to new manufacturing, remanufacturing can save 80% to 98% of materials, reduce 79% to 99% of greenhouse gases, and achieve the cost advantage of value-retention processes (VRP) being between 15% and 80% of the cost of a new product.

The situations of remanufacturing in the US, China, India, and the EU are presented below.

2.1.1. The US

According to [32], the US is a net exporter of remanufactured goods. The US exports of remanufactured goods increased by more than 50%, from US$7.5 billion in 2009 to US$11.7 billion in 2011, while in the same period, the imports increased by 64%, from US$6.3 billion to US$10.3 billion (Table 2). Remanufactured aerospace products, heavy-duty and off-road (HDOR) equipment, and machinery accounted for the largest share of the US exports of remanufactured goods. For the size of different remanufactured goods in the US market, remanufactured machinery is the largest among all the sectors, which are likely high-value or low-volume products. Its apparent consumption is nearly five times that of consumer products, the next largest sector by this measure. Remanufactured machinery represented more than 50% of the 2011 exports, with Mexico, the EU, and Canada being the main markets. The extremely important factors that affect the ability of the US remanufacturers to compete in the US markets include the availability of skilled workers, healthcare costs, and unfavorable tax treatment, and in foreign markets, the high price of cores, transportation costs, and regulatory barriers. In terms of remanufacturing-intensive industry sectors in the US for machinery, the products include industrial valves, turbines, machine tools, textile machinery, compressors. The industry structure is fragmented, estimated to be around 1000 to 2000 firms which perform machinery remanufacturing. The type of firms includes repair shops that both repair and remanufacture, and OEMs that produce new machinery.

Foreign remanufacturers that had invested in the US accounted for about 17% of the US exports and 15% of the US imports of remanufactured goods from 2009 to 2011. The foreign direct investment (FDI) in US remanufacturing in 2011 totaled approximately US$460 million, 80% (US$378 million) of which went to the machinery remanufacturing sector, likely reflecting a foreign acquisition or other large investment in the US remanufacturing operations by one or two firms. Important foreign sources of FDI in US remanufacturing activities include Japan and the EU. The companies from Swiss, China, Mexico, Canada, India, and Singapore have also invested in the US remanufacturing activities.

In the US market, the main buyers of remanufactured machinery are end users. The main factors that influence demand include the price and lead times of new products. The price of remanufactured goods can be 30–50% lower than the new ones, and the lead times be up to 50% shorter than that of new ones.

Table 2. Remanufacturing market based on remanufactured goods in the US, 2011.

Sector (ranked by production value)	Production (US$ million)	Investment (US$ million)	Exports (US$ million)	Imports (US$ million)	Intensity (%) [a]
Aerospace	13,045,513	90,471	2,589,543	1,869,901	2.6
HDOR equipment [b]	7,770,586	162,746	2,451,967	1,489,259	3.8
Motor vehicle parts	6,211,838	105,684	581,520	1,481,939	1.1
Machinery	5,795,105	711,008	1,348,734	268,256	1.0
IT products	2,681,603	17,503	260,032	2,756,475	0.4
Medical devices	1,463,313	31,260	488,008	110,705	0.5
Retreaded tires	1,399,088	23,874	18,545	11,446	2.9
Consumer products	659,175	4948	21,151	360,264	0.1
Others [c]	3,973,923	67,537	224,627	40,683	1.3
Wholesalers	[d]	8294	3,751,538	1,874,128	[d]
Total	43,000,144	1,223,326	11,735,665	10,263,056	2.0

Source: [32].
[a] Total value of remanufactured goods as a share of total sales of all products within that sector.
[b] HDOR equipment.
[c] Includes remanufactured electrical apparatus, locomotives, office furniture, and restaurant equipments.
[d] Wholesalers do not produce remanufactured goods, but rather sell or trade (export and import) them.

2.1.2. China

According to Forward [33], the respective recycling rate of scrap iron and steel, and scrap nonferrous metals in China were only about 10% and 25% in 2019, while the recycling rate of scrap steel in the US was over 50%, the recycling rate of aluminum in Japan was over 90%, and the recycling rate of lead in the EU was more than 70%. As a major country in the production and consumption of global machinery, China has entered the peak period of scrapping mechanical and electrical products—more than 60% of the old traditional machines have been in service for over 10 years, 80% of which have exceeded the warranty life. To build an energy-saving, environmentally friendly, and sustainable industrial green model, the Chinese government has started to develop the remanufacturing industry in order to open up a circular industrial chain. Compared to manufacture of new machinery, remanufacturing can save energy by 60%, materials by 70%, more than 50% of costs, can generate almost no solid waste, and can reduce air pollutant emissions by more than 80%.

Machinery remanufacturing covers mainly the restoration and improvement of machine mechanical accuracy andmotion accuracy, the selection of the numerical control system, the servo system, the auxiliary devices, and the debugging and inspection of the entire machine. Machinery remanufacturing has good economic and environmental benefits. Old machines generally contain more than 70% of the residual value, including the value of machine steel materials and the value of the manufacturing cost of mechanical parts. The remanufacturing price of a general machine is equivalent to 1/2 to 1/3 of a new machine [33]. The remanufacturing cost of a large machine is even less than 1/3 of the purchase cost of a new machine. In terms of consumption reduction, machinery manufacturing needs to consume many ordinary steel and also some high-grade steel materials. The computerized numerical control (CNC) remanufacturing of machine tools can make full use of waste resources, such as the main body, the base, and large castings of the machine. According to a Huaxia Mould Network [34], the resource recycling rate is more than 85%, over 80% of energy-saving than manufacturing new ones. It can not only greatly save resources and energy but also realize energy and material savings on the basis of reducing the environmental pollution caused by the production of iron castings.

2.1.3. India

Sinha [35] analyzed that India has tremendous potential in remanufacturing business. The main factors of the demand for remanufactured products are the rapidly growing middle class, the market-oriented economy, the availability of trained manpower at a competitive cost, the fairly well-developed credit and financing facilities, and the competitive cost of raw materials. The customers in India are interested in operating and ownership at a low cost, which are important elements for them to make purchase decisions. India has favorable conditions to initiate remanufacturing business due to enormous market growth, demand for remanufactured goods, and market price sensitivity. Remanufacturing as a hot business opportunity worldwide is still in the initial stage in India.

Traditional manufacturing is unsustainable due to its significantly negative effect on environment caused by higher carbon emissions. Choudhary & Singh [36] indicated that manufacturing generates more than 60% of non-hazardous waste and causes pollution and shortages, leading to a high cost of landfill space and virgin materials in India. While remanufacturing consumes less energy, raw materials, water, and also reduces waste during production, thus can contribute to solid waste and environmental management. Ahuja & Terkar [37] mentioned that remanufacturing was just recognized in 2008 in India and already became to be an industry worth US$35 billion in 2019. It has a lower cost and a longer potential life of product by remanufacturing. The Associated Chambers of Commerce and Industry of India (ASSOCHAM) suggested that OEMs should boost remanufacturing businesses in India. Although being worried about by some OEMs that the remanufactured products may share the market of new products, taking into consiredation of all the benefits, the OEMs should still start to invest in remanufacturing businesses to increase their overall profit. The fears of market cannibalization by other products will be eliminated as the OEMs utilize remanufactured items under a contractual agreement.

2.1.4. The EU

The EU members use remanufacturing as a tool to protect natural resources and the environment, and reduce costs for manufacturers and customers. The European Commission (EC) has issued several mandatory legal directives to foster the growth of remanufacturing in Europe. Parker & Robinson [38] showed that most of the remanufacturing activities in the EU are from aerospace, automotive, HDOR equipment, electrical and electronic equipment (EEE), machinery, and medical equipment. At that time, remanufactiring only represented a small share of the European manufacturing output as shown in Table 3, accounting for about 1.9% of total production value. However, it still a key part for OEMs as it allows to differentiate themselves from their competitors, even the size of remanufacturing is relatively small. Remanufacturing is considered to reduce the risk of raw materials, reduce carbon emissions, increase market share, and increase profitability. According to the EC investigation in 2015 [38], the remanufacturing material and equivalent carbon dioxide savings on machinery were 76,000 tonnes and 131,000 tonnes respectively.

Table 3. Market size of remanufacturing activities by sectors in the EU, 2015.

Sector (ranked by turnover)	Turnover (€bn)	Firms	Employment (thousands)	Intensity (%)
Aerospace	12.4	1000	71	11.5
Automotive	7.4	2363	43	1.1
HDOR	4.1	581	31	2.9
EEE	3.1	2502	28	1.1
Machinery	1.0	513	6	0.7
Medical equipment	1.0	60	7	2.8
Furniture	0.3	147	4	0.4
Rail	0.3	30	3	1.1
Marine	0.1	7	1	0.3
Total	29.8	7204	192	1.9

Source: [38].

RECLAIM, the EU-funded project, assists stakeholders in making informed decisions about whether to remanufacture, upgrade, or repair the end-of-life machinery [39]. It is based on big data analytics, machine learning, predictive analytics, and optimization models using deep learning techniques and digital twin models. Different from the current economic model, the purpose of remanufacturing is to maintain the high value of products, extend the useful life of the equipment, and reduce unnecessary waste of resources.

2.2. Limitation

Remanufacturing is a way to extend the useful life of products. Kurilova et al. [40] mentioned that remanufacturing has economic, environmental, and social benefits. However, it is also associated with many challenges related to the availability, timing, and quality of the used product. Remanufacturing has become a key element of a circular economy, where products are developed, manufactured, used, and recovered to prevent any types of waste and reduce the usage of raw materials.

During the implementation of remanufacturing, there are barriers from both OEMs and end users. Table 4 summarizes the most common bottlenecks in the remanufacturing machinery industry. For OEMs, products are often not designed for remanufacturing. Designers lack the knowledge of remanufacturing to consider end-of-life issues of products because the design has traditionally focused on functionality and material cost. In addition, the high diversity of products makes it difficult to standardize remanufacturing processes. OEMs do not have sufficient knowledge, skilled employees, and capacity to remanufacture. From the point of view of administration, the cost of reverse logistics on additional transportation or communication to recover products and return them to the appropriate facility for processing is increased. When comprehensively considering profit and cost, sales of remanufactured products can replace those of the new ones, which reduce overall revenue. Furthermore, there is no officially credible quality certification for remanufacturing. For end users, customers only want to pay fewer prices for remanufactured products compared to new ones. Although the acceptance of remanufactured products for customers has increased in the past five years, there is still uncertainty. Customers are not sure about the quality of remanufactured products and are wary of purchasing them. In the machinery industry, OEMs do not want to share key information and tools on remanufacturing with third parties. Because financing remanufacturing is often seen as a higher risk, it is harder for companies to obtain financing for their remanufacturing project from a bank.

Table 4. Bottlenecks of remanufacturing in the industry of shoemaking machine.

Bottlenecks	Content	Sources
	For OEMs	
Products design	• Products are often not designed for remanufacturing. • The high diversity of products makes it difficult to standardize remanufacturing processes. • Designers may lack the knowledge of remanufacturing to consider end-of-life issues of products because design has traditionally focused on functionality and material cost. • Manufacturers do not have sufficient knowledge, skilled employees, and remanufacturing capacity.	[41–43]

Table 4. (*Continued*)

Profit and cost	• The sales of remanufactured products may replace that of the new one, reducing overall profits. • The cost of reverse logistics with additional transportation or communication to recover products and return them to the appropriate processing facility increases. • Remanufacturing requires an additional labor cost. It is difficult to introduce automation to the same extent as traditional manufacturing. • The cost of returning used products from the consumer is high. • Remanufacturing financing is often seen as a higher risk. It is harder for firms to obtain finance for their remanufacturing project from a bank.	[44–46]
Quality certification	• The US is the largest producer of remanufactured goods with the label "Remanufactured in the USA" created by the Federal Trade Commission since 1998. However, this public recognition does not represent a certification standard. • There is no credible quality certification for remanufacturing.	[47]
Product return	• The question of when a product should be returned for remanufacture is uncertainty. • Manufacturers provide less incentives to customers to return a product for remanufacturing. • The quality of each returned product may be different and unknown before acquiring it.	[41,43,48]
	For end-users	
Price of remanufactured products	• Consumers only want to pay lower prices for remanufactured products compared to new ones.	[49]
Customer's acceptance	• Consumer'sacceptance of remanufactured products has increased in the past five years. • Customers are not sure about the quality of remanufactured products and are wary of purchasing them.	[42,43]

3. Methodology

In 1971, Thomas L. Saaty, proposed a set of systematic decision-making methods to deal with complex decision-making problems under uncertain factors [50]. This system decision-making model is called Analytical Hierarchy Process (AHP), and it can solve complex decision-making problems. The AHP analysis method simplifies the complex problem system into a concise factor hierarchy system and then gathers the opinions of experts, scholars, and decision-makers at all levels, adopts a Nominal Scale to implement the Pairwise Comparison among the elements, and establishes the Pairwise Comparison Matrix after quantification. It starts by finding the Eigenvector of each matrix and calculate the maximum eigenvalue (λ_{max}), according to its Eigenvector as the priority among the elements of the level. The maximum eigenvalue is then used to evaluate the strength of the relative weight of the consistency index of the comparison matrix, which provides decision-makers with reference indicators for decision-making. This study introduces the computer-aided decision-making software SuperDecisions, which is used to assist in the calculation of the relative dominance of each criterion in the group of the AHP framework.

The main research framework of this study is based on the AHP method, and the analyzation is based on experts' opinions. The weight of each criterion is estimated through questionnaires, which are used to help the OEMs systematically make a decision on the feasibility of remanufacturing shoemaking machines.

3.1. Assumption

The concept of remanufacturing is different from that of simple recycling and reuse. Recycling is defined as the action or process of converting waste into reusable material. Reuse implies that the items are used by a second customer without prior repair operations or as originally designed. Johnson & McCarthy [51] defined remanufacturing as the process of rebuilding a product to the specifications of the original manufactured product using a combination of reused, repaired, and new parts. It is a series of processes that allow end-of-life products and parts to be re-commercialized as new products, by disassembling, cleaning, inspecting, repairing, replacing, and reassembling. Munot & Ibrahim [52] mentioned that remanufactured products are perfect substitutes for new products, which are remanufactured to a quality standard that is as good as new. Remanufactured products are popular in the secondary product market, especially for those customers who may have financial restrictions.

AHP is used to measure the feasibility of remanufacturing in a shoemaking machine under the trend of net-zero carbon emission according to human judgment. The model combines judgment and data to effectively rank options and predict outcomes, which can help the OEM decision-makers find a solution that best suits their goal and understanding of the problem. The research measures tangible and intangible factors through paired comparisons using judgments from a 1 to 9 fundamental scale and results in priorities for the factors by structuring a hierarchical process of benefits, opportunities, costs, and risks with a goal, criteria/sub-criteria, and alternatives from which they are connected at the above level. In the end, the priorities of all elements are synthesized to rank the alternatives.

This study is composed of two levels, and AHP is used to link each level. The priority and relative weight of each factor in the AHP level relative to the whole level is calculated. Furthermore, AHP is used to establish the Consistency Index ($C.I.$) and Consistency Ratio ($C.R.$) that connect all the Pairwise Comparison matrices. Based on the results, the level of consistency of the entire hierarchy is evaluated, the complex decision-making problem is solved by introducing expert opinions through AHP, and the relative weight of various influencing factors is determined by Pairwise Comparison and Eigenvector. The research mainly presents the feasibility evaluation and optimization model for shoemaking machine remanufacturing in a closed-loop supply chain that integrates manufacturing, remanufacturing, and repairing activities to meet the demand of customers under the carbon tax regulation. The assumption includes qualitative and quantitative ones:

- Qualitative assumptions:
    - The inventory system only discusses a single product.
    - All used items are collected and remanufactured to become new ones.
    - The planning cycle is made from manufacturing to repair and from remanufacturing to repair.
    - The quality of the repaired and remanufactured items is the same as that of the new ones.
    - There are no defective products during the repair process.
    - OEMs will be taxed per unit while having carbon emissions under the carbon tax regulation.
    - There is satisfied demand, zero lead time, and no shortages.
- Quantitative assumptions:
    - A system can be decomposed into many classes or components to form a directional hierarchical structure.
    - In the hierarchical structure, the elements at each level are assumed to have independence.
    - Elements within each level can be evaluated using some or all elements of the next level as evaluation criteria.
    - For comparative evaluation, the absolute numerical scale can be converted to a ratio scale.
    - After pairwise comparison, the positive reciprocal matrix can be used for processing.
    - The preference relation satisfies Transitivity, not only the superiority relation satisfies Transitivity (a is better than b, b is better than c, then a is better than c), and the intensity relationship also satisfies Transitivity (a is twice better than b, b is three times better than c, then a is six times better than c).
    - The degree of dominance of elements is obtained through the weighting principle.
    - As long as any element appears in the hierarchical structure, no matter how small its weight or dominant degree is, it is considered to be related to the entire evaluation structure.

3.2. System Operation

The EU launched the "Fit for 55" package in July 2021, which includes the carbon tariff CBAM. It is expected to be piloted in 2023 and fully effective in 2027 (originally scheduled to take effect in 2026, and extended for one year in June 2022). The EU declared to achieve net-zero carbon emissions by 2050, with the help of the introduced carbon tariffs to control the carbon footprint of imported goods. Under this wave, the EU countries, the US, mainland China, Japan, South Korea, Indonesia, Vietnam, Thailand, etc., have all successively developed their carbon tax policies. In addition, under the promotion of international shoe brand customers, the shoemaking factories, their suppliers and brand customers all will implement "green manufacturing" and pursue ESG (Environmental, Social, and Governance) beliefs to maintain international competitiveness by formulating long-term carbon emission reduction plans.

To reduce the carbon footprint of the shoemaking machine manufacturing process, countermeasures such as purchasing green energy, setting up power generation systems, carbon trading, and developing energy-saving shoemaking machines have become the means at present. However, green energy is in short supply, and solar energy can also be insufficient because of the limited plant space for solar panels. Although energy-saving measures may save energies for shoemaking machines at a maximum level, the energy generated by mechanical operation cannot be avoided. There has to be energy consumption, and thus the bottlenecks exist.

"Remanufacturing" has been existing in European and the US for many years. The so-called "remanufacturing" is based on the product life cycle. It makes the quality or performance of the products that have reached their service life in the traditional mode reach or exceed the original one through "remanufacturing" technology. This research evaluates the feasibility of "remanufacturing" shoemaking machines from the perspective of experts in various fields, and prepares for planning the next-generation green and circular economy shoemaking machine business model.

AHP is a systematic analysis method that is used to deal with complex problems. This method gives a hierarchical decomposition from different levels, and comprehensively evaluates the context found through quantitative judgment to provide decision-makers with information for choosing better solutions. It can reduce the risk of decision-making errors and gather experts' opinions to make a pairwise comparison of the relative weights of each evaluation index with a nominal scale. By establishing a comparison matrix, the AHP framework can calculate its eigenvalues and eigenvectors, and use the eigenvectors to represent a certain order of precedence of elements in the hierarchy. Finally, after the consistency test is performed by the largest eigenvector, the relative weight of each evaluation criterion can be obtained, which can be used as a reference index for decision-making.

The implementation of AHP is based on the following steps and methods innovated by Saaty [53]:

I. Create a pairwise comparison matrix for each level: A pairwise comparison matrix is established to evaluate the relationship between two factors at the same level. The Pairwise Comparison Matrix is measured by nine evaluation scales, which are divided into Equal Importance, Moderate Importance, Essential Importance, Very Importance, and Extreme Importance. The rest of the evaluation scales fall between these five scales. Use the obtained Pairwise Comparison Matrix to calculate the eigenvectors and eigenvector values according to the theoretical basis of eigenvectors and obtain the relative weights between factors. The criterion of a certain level is compared with the criterion of the previous level as the evaluation benchmark. If there are n criteria at a certain level, the decision maker must perform $(n(n-1)) / 2$ times pairwise comparisons. The evaluation scale of the pairwise comparison is represented by 1, 2, …, 8, 9 (Table 5), and the results of the comparison yield a comparison matrix $\boldsymbol{A}$, expressed as Equation 1:

Table 5. Bottlenecks of remanufacturing in the industry of shoemaking machine.

Important Ratio										
	Absolutely important	Extremely important	Quite important	Slightly important	Equally important	Slightly important	Quite important	Extremely important	Absolutely important	
Evaluation Items	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	Evaluation Items
a	1	2	3	4	5	6	7	8	9	b

$$A = \begin{bmatrix} 1 & \dots & a_{1n} \\ \vdots & 1 & \vdots \\ 1/a_{1n} & \dots & 1 \end{bmatrix}_{n \times n} \tag{1}$$

where $a_{ij} = \frac{1}{a_{ij}}, i, j = 1,2, \dots, n;\ a_{ii} = 1, i = 1,2, \dots, n.$

Notation	*Description*
A	A comparison matrix
n	Criteria at a certain level;
a_{ij}	The value of the degree to which element i is more important than element j;
a_{ii}	The value of the degree to which element i is more important than element i;
w_i	Features vectors (weights);
i	The number of elements in a column (1,2,3, … , n);
j	The number of elements in a row (1,2,3, … , m);
$C.I. = 0$	The judgments before and after are completely consistent;
$C.I. > 0.1$	There is a deviation and incoherence before and after;
$C.I. \leq 0.1$	The judgments before and after are not consistent, but are within the allowable range of deviation.

II. Compute maximum eigenvalues and eigenvectors: This study adopts the average of normalized columns (ANC) proposed by Saaty [53] to calculate the eigenvector and the maximum eigenvalue. The ANC operation method first normalizes each row and then divides the normalized column elements by the number of elements in each column, as shown in Equation 2. The method of finding the maximum eigenvalue is to multiply the pairwise comparison matrix by the eigenvector $\boldsymbol{w}$ to obtain a new vector $\boldsymbol{W}$, each value of which corresponds to the one divided by the original vector $\boldsymbol{w}$. Hereafter, all the values obtained must be calculated, and its arithmetic mean shall be solved to obtain the maximum eigenvalue λ_{max} (Equation 3).

$$w_i = \frac{1}{n}\sum_{j}^{n} \frac{a_{ij}}{\sum_{j}^{n} a_{ij}} \tag{2}$$

$$\begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & 1 & \vdots \\ {}^{1}/_{a_{1n}} & \cdots & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix}, \lambda_{max} = \frac{1}{n}\left(\frac{w_1}{w_1} + \frac{w_2}{w_2} + \cdots + \frac{w_n}{w_n}\right) \tag{3}$$

III. Consistency check: Consistency means the judgment made by decision-makers in the evaluation process is reasonable, and there is no obvious inconsistency. When the pairwise comparison matrix has complete consistency, it will lead to $\lambda_{max} = n$; otherwise, $\lambda_{max} \geq n$ must be satisfied. Therefore, the closer λ_{max} to n, the higher the degree of consistency is. The Consistency Index ($C.I.$) is defined as Equation 4.

$$C.I. = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

IV. Level Weight Calculation: Based on the above, after calculating the weights among the elements of each level, the weights of the entire level can be obtained. Finally, they are prioritized according to their respective weight to assist decision-makers in decision-making process.

3.3. Design of Questionnaire

In this study, four major clusters and 10 nodes are compared in pairs, and the quantitative explanations are given through human perception and judgment to present the relative importance a_{ij} between the i^{th} and the j^{th} elements among the four major clusters and 10 nodes. Matrix $\boldsymbol{A} = (a_{ij})$, is the comparison matrix after pairwise comparison of the founr major clusters and 10 nodes. The eigenvector and the maximum eigenvalue λ_{max} can be calculated from $\boldsymbol{A}$, and λ_{max} is used as a benchmark to assess whether the decision-maker's judgment on the pairwise comparison benchmark is consistent. When decision-makers have inconsistent judgments, the element a_{ij} in matrix $\boldsymbol{A}$ will slightly change, so does the λ_{max}. This change can be evaluated by the Consistency Index.

The operation flow of the AHP is shown in Figure 1. The establishment of the hierarchical structure consists of establishing various clusters and nodes through literature collection, brainstorming, and expert consultation. The clusters and nodes of each level are controlled to facilitate pairwise comparison. By setting "Feasibility of remanufacturing on a shoemaking machine" as the goal, the research is divided into four levels. The first level is the goal, the second level is the key evaluation clusters, and the third level is the detailed evaluation nodes. The fourth level is for alternatives to make decisions. As shown in Figure 2, clusters are used as the basis for evaluating the nodes. Pairwise comparisons are made between each two factors, resulting in $(n(n-1))/2$ comparisons when there are n factors in the hierarchy.

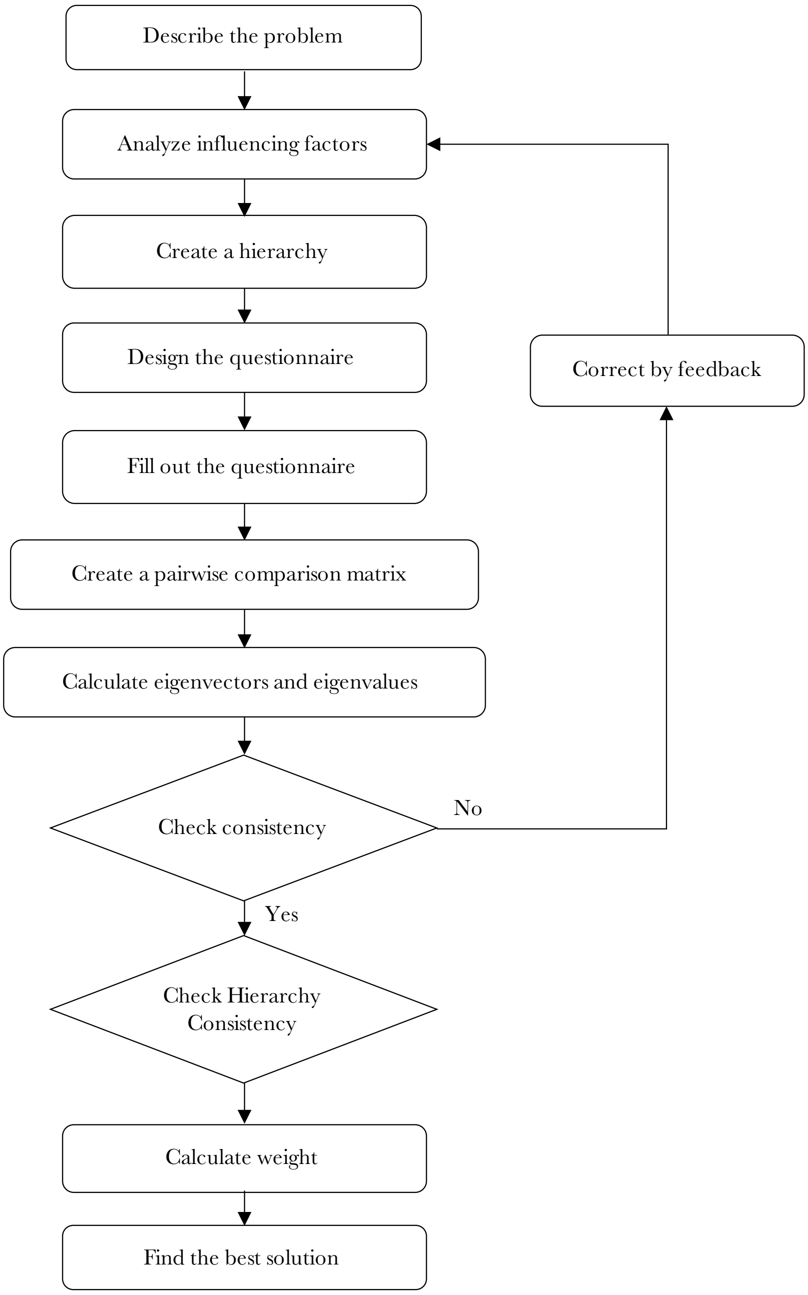

Figure 1. Steps for applying AHP.

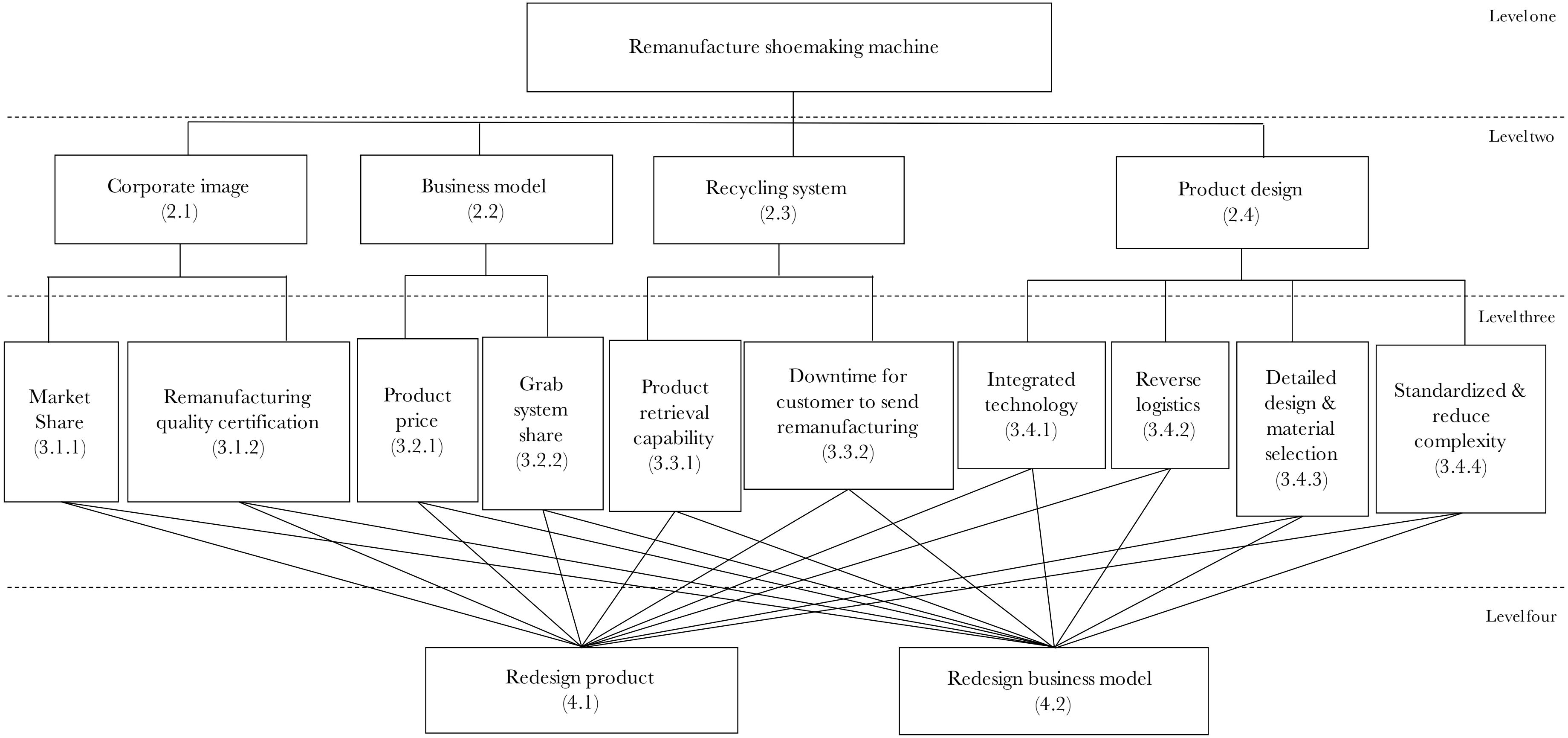

Figure 2. Hierarchical structure for feasibility of remanufacturing in shoemaking machine. Level one is the level of the final goal. Level two is the level of major factors. Level three is the level for the sub-factors. Level four is the level for alternatives to make decisions.

Developing an expert questionnaire designed for the feasibility of remanufacturing shoemaking machines under the global trend of net-zero carbon emissions is helpful for shoemaking machine manufacturers to find an alternative solution in addition to the current countermeasures such as purchasing green energy, setting up their power generation systems, carbon trading, shoemaking machine energy savings to reduce carbon emissions. The "remanufacturing" experience from European and the US can be borrowed to plan the next generation green and circular economy shoemaking machine business model. The questionnaire was completed by experts in various fields who provide professional insights to improve the objectivity and professionalism of this research. Finally, the weighted options of the AHP experts in different fields are used as a reference to determine the feasibility of remanufacturing shoemaking machines.

3.4. Questionnaire Return

The information of the respondents based on the returned questionaries is summarized in Table 6. The total number of the returned valid questionaries is 110, among which, 27 were returned from the shoemaking machine industry. The rest were from other industries. The Consistency Index test was applied to all the returned questionnaires.

Table 6. Background of the respondents and number of returned questionnaires.

Respondents' Background Area	Rank of Job Title	No. of Responses	Sub-total
	Shoemaking machine industry		
Shoemaking machine supplier	Senior executives (chairman, general manager, president, director, assistant, etc.)	1	11
	Middle-level supervisors (managers, team leaders, directors, etc.)	5	
	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	5	
Distributor/agent	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	1	1
Shoe manufacturer (equipment user)	Middle-level supervisors (managers, team leaders, directors, etc.)	3	3
Research institute	Middle-level supervisors (managers, team leaders, directors, etc.)	2	4
	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	2	
Marketing media	Senior executives (chairman, general manager, president, director, assistant, etc.)	1	2
	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	1	
Green energy/carbon reduction consultant	Senior executives (chairman, general manager, president, director, assistant, etc.)	3	6
	Middle-level supervisors (managers, team leaders, directors, etc.)	1	
	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	2	
	Non-shoemaking machine industry		
General machinery manufacturer	Senior executives (chairman, general manager, president, director, assistant, etc.)	9	29
	Middle-level supervisors (managers, team leaders, directors, etc.)	12	
	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	8	
Other manufacturer	Senior executives (chairman, general manager, president, director, assistant, etc.)	15	54
	Middle-level supervisors (managers, team leaders, directors, etc.)	17	
	Basic-level staff (commissioner, staff, engineer, assistant, etc.)	22	
	Total	110	

3. Results

SuperDecisions [54] was used to analyze the returned questionnaires. For the first step, based on the information in Figure 2, the network of each cluster and node was created for each influencer illustrated in Figure 3. Second, comparisons between each pair of the cluster and node were performed according to the returned questionnaires. To ensure the accuracy of the AHP analysis, only a subset of the returned questionnaires were used, namely, those from middle-level supervisors and senior executives of the shoemaking machine industry. The total number of the selected questionnaires is 16, details shown in Table 7.

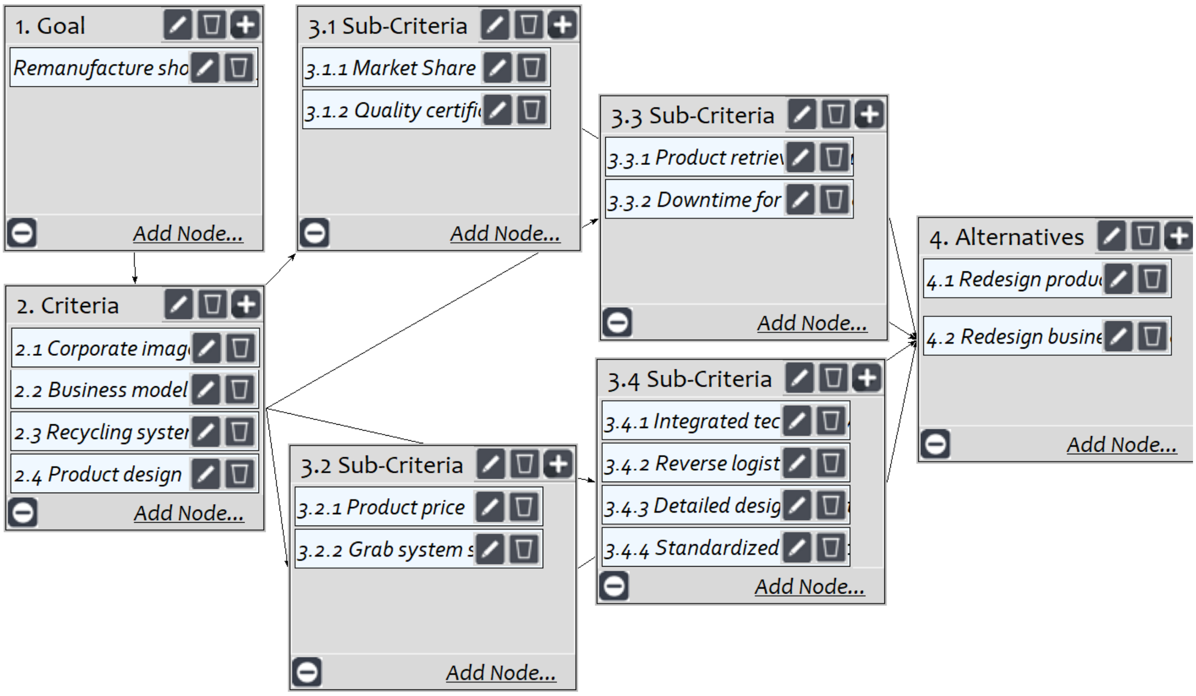

Figure 3. The network of each cluster and node for shoemaking machine remanufacturing.

Table 7. Returned questionnaires from middle-level supervisors and senior executives of the shoemaking machine industry.

Respondents' Background Area	Rank of Job Title	No. of Responses	Sub-total
	Shoemaking machine industry		
Shoemaking machine supplier	Senior executives (chairman, general manager, president, director, assistant, etc.)	1	6
	Middle-level supervisors (managers, team leaders, directors, etc.)	5	
Shoe manufacturer (equipment user)	Middle-level supervisors (managers, team leaders, directors, etc.)	3	3
Research institute	Middle-level supervisors (managers, team leaders, directors, etc.)	2	2
Marketing media	Senior executives (chairman, general manager, president, director, assistant, etc.)	1	1
Green energy/carbon reduction consultant	Senior executives (chairman, general manager, president, director, assistant, etc.)	3	4
	Middle-level supervisors (managers, team leaders, directors, etc.)	1	
	Total	16	

When performing the pairwise comparison in the AHP analysis, the consistency test must be performed. As the $C.I.$ can help to find out the criteria that do not meet the consistency test standard ($C.I. \leq 0.1$). If the consistency test standard is not met, i.e., $C.I. > 0.1$, it is necessary to reevaluate whether there is a logical error. Equivalently, the inconsistency test of inconsistency is used in SuperDecisions. The corresponding test criteria for the Inconsistency Index ($InC.I.$) is the same as the Consistency Index ($C.I.$), i.e., $C.I. = InC.I. \leq 0.1$. This means that the before and after judgments are within the acceptable range or are consistent. This study adopts the Inconsistency Index ($InC.I.$), and the key value of the inconsistency should be less than 0.1. If it is greater than 0.1, the criterion of inconsistency must be found.

The main purpose of decision-making is to find out the best solution to a problem. However, due to limited resources, most OEMs of shoemaking machines use sensitivity analysis to find the second best or alternative solutions. The values obtained from the analysis can be used as the basis for OEMs to effectively allocate resources. In Figure 4, the x-axis represents the weight ratio of the variables selected for the criterion, and the y-axis represents the weight ratio of priority decisions. According to the sensitivity analysis, the weight ratio of the "Redesign Product" is 0.574, and the weight ratio of the "Redesign Business Model" is 0.426. Based on the weight ratio, the "Redesign Product" is selected as the best alternative option (0.574 > 0.426, the higher the better). Table 8 shows the results of the final analysis.

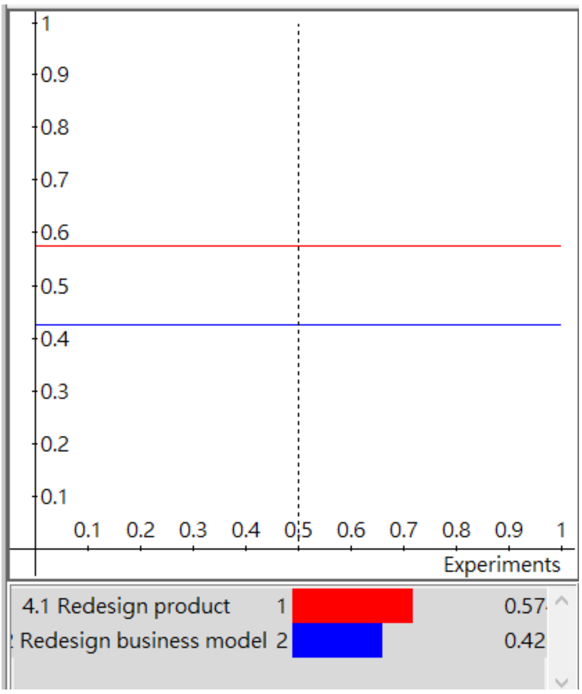

Figure 4. Sensitivity analysis for the study.

Table 8. The overall synthesized priority for the alternatives.

Name	Graphic	Ideals	Normals	Raw
4.1 Redesign product		1.000000	0.573897	0.191299
4.2 Redesign business model		0.742474	0.426103	0.142035

To include the mutual influence of all elements in the AHP system, this research added priority weight vectors to the appropriate columns in the matrix to form a supermatrix. The supermatrix is a decomposition matrix which represents the relationship between two elements. The decomposition matrix can be found through SuperDecisions. The type of hierarchical supermatrix is shown in Equation 5 [55]. In that, $\boldsymbol{w_{21}}$ is a vector formed to represent the impact of the importance of the goal on various criteria; $\boldsymbol{w_{32}}$ is a matrix formed by the impact of the criteria on the importance of each feasible alternative, and $\boldsymbol{I}$ is the identity matrix, while $\mathbf{0}$ means that there is no interaction between elements. The supermatrix can be divided into three forms: unweighted supermatrix, weighted supermatrix, and limit matrix. When the sum of the columns in the supermatrix is greater than 1 without random effects, this matrix is an "unweighted supermatrix", as shown in Table 9. A "weighted supermatrix" is a matrix that the sum of the columns can be up to 1 and it has random effects, as shown in Table 10. Saaty [56] believed that by assigning a relative importance to the element in each column of the supermatrix, each element in the column of the matrix can be converted to a value with proportional standardized characteristics according to the importance of each element in the column. The "Limit matrix" makes the weighted supermatrix present the relationship between elements of convergence with stability and consistency in long-term equilibrium. Therefore, Saaty [56] proposed to take the weighted supermatrix to the power of $(2k+1)$ to make it a limit matrix, where k is a subjectively determined value. Since the limit matrix is transformed from the weighted supermatrix, its form remains unchanged. However, the limit matrix has the same weight for a certain element in each column. After standardizing the weights of elements in different columns, the sum of the weights of the elements in each column is equal to 1. All the weights of the elements and the values of the evaluation schemes can be obtained for convergence effects.

$$w = \begin{matrix} \\ \text{Goal} \\ \text{Criteria} \\ \text{Alternative} \end{matrix} \begin{matrix} \textit{Goal} & \textit{Criteria} & \textit{Alternative} \\ \left[\begin{matrix} 0 \\ w_{21} \\ 0 \end{matrix}\right. & \begin{matrix} 0 \\ 0 \\ w_{32} \end{matrix} & \left.\begin{matrix} 0 \\ 0 \\ I \end{matrix}\right] \end{matrix} \quad (5)$$

According to Table 11, the weights of the four "Criteria (clusters)" in the "Remanufacture shoemaking machine are prioritized. According to the value, the order of the four "Criteria (clusters)" from high to low is: Product design (0.190016), Business model (0.062301), Recycling system (0.056145), and Corporate image (0.024871). That is to say, for the respondents, the importance of "Remanufacture shoemaking machine" is: "Product design" > "Business model" > "Recycling system" > "Corporate image". Concerning the corporate image criteria, market share and quality certification of remanufacturing are equally important. For business model criteria, the price of the product and the share of the grab system are of equal importance. In terms of the recycling system, the downtime the customers send the machines for remanufacturing is more important than the product retrieval capability. With respect to product design, the order of importance is "standardized & reduce complexity", "integrated technology", "reverse logistics", and "detailed design & material selection". In the meantime, "reverse logistics" and "detailed design & material selection" share equal importance. In conclusion, the OEMs should start with the redesign of the product when initiating the shoemaking machine remanufacturing business.

Table 9. Unweighted supermatrix for remanufacturing shoemaking machines.

Clusters	Nodes	Remanufacture Shoemaking Machine	2.1 Corporate Image	2.2 Business Model	2.3 Recyling System	2.4 Product Design	3.1.1 Market Share	3.1.2 Quality Certification	3.2.1 Product Price	3.2.2 Grab System Share	3.3.1 Product Retrieval Capability	3.3.2 Downtime for Customer to Send Remanufacturing	3.4.1 Integrated Technology	3.4.2 Reverse Logistics	3.4.3 Detailed Design & Material Selection	3.4.4 Standardized & Reduced Complexity	4.1 Redesign Product	4.2 Redesign Business Model
1. Goal	Remanufacture shoemaking machine	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2. Criteria	2.1 Corporate image	0.074614	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.2 Business model	0.186904	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.3 Recyling system	0.168436	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.4 Product design	0.570047	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.1 Sub-Criteria	3.1.1 Market share	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.1.2 Quality certification	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.2 Sub-Criteria	3.2.1 Product price	0.000000	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.2.2 Grab system sahre	0.000000	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.3 Sub-Criteria	3.3.1 Product retrieval capability	0.000000	0.000000	0.000000	0.250000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.3.2 Downtime for customer to send remanufacturing	0.000000	0.000000	0.000000	0.750000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.4 Sub-Criteria	3.4.1 Integrated technology	0.000000	0.000000	0.000000	0.000000	0.276243	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.2 Reverse logistics	0.000000	0.000000	0.000000	0.000000	0.118154	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.3 Detailed design & material selection	0.000000	0.000000	0.000000	0.000000	0.118154	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.4 Standardized & reduce complexity	0.000000	0.000000	0.000000	0.000000	0.487448	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4. Alternatives	4.1 Redesign product	0.000000	0.000000	0.000000	0.000000	0.000000	0.166667	0.900000	0.166667	0.166667	0.500000	0.166667	0.900000	0.125000	0.900000	0.900000	0.000000	0.000000
	4.2 Redesign business model	0.000000	0.000000	0.000000	0.000000	0.000000	0.833333	0.100000	0.833333	0.833333	0.500000	0.833333	0.100000	0.875000	0.100000	0.100000	0.000000	0.000000

Table 10. Weighted supermatrix for remanufacturing shoemaking machines.

Clusters	Nodes	Remanufacture Shoemaking Machine	2.1 Corporate Image	2.2 Business Model	2.3 Recyling System	2.4 Product Design	3.1.1 Market Share	3.1.2 Quality Certification	3.2.1 Product Price	3.2.2 Grab System Share	3.3.1 Product Retrieval Capability	3.3.2 Downtime for Customer to Send Remanufacturing	3.4.1 Integrated Technology	3.4.2 Reverse Logistics	3.4.3 Detailed Design & Material Selection	3.4.4 Standardized & Reduced Complexity	4.1 Redesign Product	4.2 Redesign Business Model
1. Goal	Remanufacture shoemaking machine	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2. Criteria	2.1 Corporate image	0.074614	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.2 Business model	0.186904	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.3 Recyling system	0.168436	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.4 Product design	0.570047	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.1 Sub-Criteria	3.1.1 Market share	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.1.2 Quality certification	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.2 Sub-Criteria	3.2.1 Product price	0.000000	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.2.2 Grab system sahre	0.000000	0.000000	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.3 Sub-Criteria	3.3.1 Product retrieval capability	0.000000	0.000000	0.000000	0.250000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.3.2 Downtime for customer to send remanufacturing	0.000000	0.000000	0.000000	0.750000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.4 Sub-Criteria	3.4.1 Integrated technology	0.000000	0.000000	0.000000	0.000000	0.276243	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.2 Reverse logistics	0.000000	0.000000	0.000000	0.000000	0.118154	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.3 Detailed design & material selection	0.000000	0.000000	0.000000	0.000000	0.118154	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.4 Standardized & reduce complexity	0.000000	0.000000	0.000000	0.000000	0.487448	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4. Alternatives	4.1 Redesign product	0.000000	0.000000	0.000000	0.000000	0.000000	0.166667	0.900000	0.166667	0.166667	0.500000	0.166667	0.900000	0.125000	0.900000	0.900000	0.000000	0.000000
	4.2 Redesign business model	0.000000	0.000000	0.000000	0.000000	0.000000	0.833333	0.100000	0.833333	0.833333	0.500000	0.833333	0.100000	0.875000	0.100000	0.100000	0.000000	0.000000

Table 11. Limit matrix for remanufacturing shoemaking machines.

Clusters	Nodes	Remanufacture Shoemaking Machine	2.1 Corporate Image	2.2 Business Model	2.3 Recyling System	2.4 Product Design	3.1.1 Market Share	3.1.2 Quality Certification	3.2.1 Product Price	3.2.2 Grab System Share	3.3.1 Product Retrieval Capability	3.3.2 Downtime for Customer to Send Remanufacturing	3.4.1 Integrated Technology	3.4.2 Reverse Logistics	3.4.3 Detailed Design & Material Selection	3.4.4 Standardized & Reduced Complexity	4.1 Redesign Product	4.2 Redesign Business Model
1. Goal	Remanufacture shoemaking machine	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2. Criteria	2.1 Corporate image	0.024871	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.2 Business model	0.062301	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.3 Recyling system	0.056145	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	2.4 Product design	0.190016	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.1 Sub-Criteria	3.1.1 Market share	0.012436	0.250000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.1.2 Quality certification	0.012436	0.250000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.2 Sub-Criteria	3.2.1 Product price	0.031151	0.000000	0.250000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.2.2 Grab system sahre	0.031151	0.000000	0.250000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.3 Sub-Criteria	3.3.1 Product retrieval capability	0.014036	0.000000	0.000000	0.125000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.3.2 Downtime for customer to send remanufacturing	0.042109	0.000000	0.000000	0.375000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3.4 Sub-Criteria	3.4.1 Integrated technology	0.052490	0.000000	0.000000	0.000000	0.138121	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.2 Reverse logistics	0.022451	0.000000	0.000000	0.000000	0.059077	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.3 Detailed design & material selection	0.022451	0.000000	0.000000	0.000000	0.059077	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	3.4.4 Standardized & reduce complexity	0.092623	0.000000	0.000000	0.000000	0.243724	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
4. Alternatives	4.1 Redesign product	0.191299	0.266667	0.083333	0.125000	0.404215	0.166667	0.900000	0.166667	0.166667	0.500000	0.166667	0.900000	0.125000	0.900000	0.900000	0.000000	0.000000
	4.2 Redesign business model	0.142034	0.233333	0.416667	0.375000	0.095785	0.833333	0.100000	0.833333	0.833333	0.500000	0.833333	0.100000	0.875000	0.100000	0.100000	0.000000	0.000000

4. Discussion

To prevent climate change, achieving net-zero emissions by 2050 has become a common global goal. As of 2021, 64 carbon pricing mechanisms are in place around the world, regulating about 21.5% of the world's carbon emissions. The EC officially announced the CBAM regulation on 14 July 2021. A trial implementation stage of CBAM will be started in 2023, levying taxes on products from five major energy-intensive industries. Similar discussions and even specific proposals have been seen in the US, Japan, and South Korea. If CBAM is implemented broadly by the main trading partners, it will significantly negatively impact Taiwan's exports, which will further hurt the economy in Taiwan. As international trade plays a vital role in Taiwan's economy. For instance, the total exports account for 65% of Taiwan's GDP.

On 22 April 2021, the Taiwan government stated "2050 net-zero transformation is the goal of the world and also the goal of Taiwan". The administration already began to assess and plan a possible path for Taiwan to reach its net-zero emissions target by 2050. GreenPeace [2] proposed four scenarios for the carbon pricing system to analyze Taiwan's production values, GDP, and carbon reduction performance to find the best alternative for future government policy. The result showed that the minimum levy rate for the carbon pricing system is US$10.71 (NT$300) per ton and will be gradually increased to the EU pricing level. The European Union Emission Trading Scheme (EU ETS) controls 39% of greenhouse gas emissions throughout the EU. On 1 April 2021, the real-time carbon market transaction price was US$49.8 per ton. According to recommendations by the World Bank and the IMF [57], to achieve the carbon reduction targets of the Paris Agreement, the global effective carbon price must be raised to at least US$50 per ton by 2030.

Shoemaking is a typical small-scale manufacturing. Its manufacturing process poses many threats to the environment and also consumes high energy. Fast fashion causes even more pollution. All of these have made the industry players to rethink the impact of industrial activities on the environment. In order to reduce corporate pollution and contribute to the goal of global net-zero carbon emissions, NIKE has been continuing to innovate materials and reduce industrial carbon, and became to be the first fashion company who released a Corporate Social Responsibility (CSR Report) in 2001. Furthermore, in 2019, NIKE started the Move to Zero Action and comprehensively reformulated the process of production and material selection. Similarly, the two main footwear manufacturers, Pou Chen Group and Feng Tay Group, also announced their strategies to achieve net-zero carbon emissions. Pou Chen planned to set 2019 as the base year and achieve the goal of "zero carbon emission growth" in 2025. Feng Tay promised that by 2030 its absolute total carbon emission will drop by 46.2% compared to the base year of 2019. The shoemaking machine manufacturers will have to face the zero emissions issue as the international brands and major footwear manufacturers released their green announcements. They have to reevaluate their supply chain decision to ensure that their products meet the environmental protection needs.

There are several ways to achieve low carbon emissions in the supply chain, including purchasing carbon credits and introducing green energy equipment. However, currently there is no carbon exchange platform in Taiwan. Because the carbon exchange market in Taiwan is relatively small and carbon emissions are concentrated in a few companies, if the exchange is established, liquidity problems and insufficient participants may occur. Furthermore, Taiwan is not a member of the United Nations, carbon exchange can thus only be performed domestically and cannot be integrated into the international market. In addition, Taiwan has geographical restrictions, and restrictions on generation or afforestation also exist. Carbon credits earned from green energy in Taiwan still have a great gap compared to those in foreign countries. Because the carbon exchange price is determined by supply and demand dynamics, they are always sold to the highest bidders. Many uncertainties can increase the overall cost of OEMs spent in the carbon exchange. So, the remanufacturing business model has become a potential option for shoemaking machine manufacturers to achieve the carbon emissions reduction goal under the trend of CBAM. Taiwan is the world's third-largest exporter of shoemaking machines, with high-level machinery technology next to Italy. In line with the current trends of technology and fast fashion, shoemaking machines have now been developed and designed for small-volume and diverse shoe manufacturing. Ninety-five percent of Taiwan's shoemaking industry are exported overseas, and most of them carry out mechanical research and development for customization in accordance with customer needs. Although the shoemaking is not the first target of net-zero carbon emissions and carbon border tax, international brands and footwear manufacturers have gradually increased the demand for machinery to achieve carbon reduction.

Artificial Neural Networks (ANNs) is a popular topic in enhancing decision-making in recent years. ANNs can capture and model the complex and nonlinear interactions existed in the inputs and outputs in real-life scenarios. In the work by Saha [58], ANNs was described as a type of machine learning that serves as the basis of deep learning techniques. Artificial intelligence can take benefit of ANNs in various ways, for example, by having the ability to infer from large datasets. ANNs can learn to recognize patterns and relationships in data, and can also be trained to perform complex calculations in a fast and accurate fashion. Table 12 shows the differences between AHP and ANN models.

Table 12. Comparison of AHP and ANN.

Criteria	AHP	ANN	Resources
Definition	A structured technique for organizing and analysing complex decisions, based on mathematics and psychology.	A computing system inspired by the biological neural networks that constitute animal brains, based on a collection of connected units or nodes called artificial neurons.	en.wikipedia.org
Purpose	To help decision-makers find the decision that best suits their goal and their understanding of the problem by decomposing the problem into a hierarchy of sub-problems and evaluating them by pairwise comparisons.	To perform tasks by considering examples, generally without being programmed with task-specific rules, such as machine vision and speech recognition.	en.wikipedia.org
Methodology	To use concrete data and human judgments to perform the evaluations, to derive numerical values that can be processed and compared over the entire range of the problem, and to synthesize the results to determine the best alternative.	To use a set of adjustable weights that are tuned by a learning algorithm based on examples, to estimate or approximate nonlinear functions of the input data, and to propagate signals through multiple layers of artificial neurons.	en.wikipedia.org
Advantages	To provide a comprehensive and rational framework for structuring a decision problem, to represent and quantify its elements, to relate those elements to overall goals, and to evaluate alternative solutions.	To learn from data without relying on rule-based programming, to handle complex and high-dimensional problems, to generalize well from training data to unseen data, and to adapt to changing inputs.	en.wikipedia.org
Limitations	To require subjective judgments from decision makers, to be sensitive to the consistency and accuracy of the pairwise comparisons, to be computationally intensive for large-scale problems, and to lack a clear theoretical basis for some aspects.	To require a large amount of training data and computational resources, to suffer from overfitting and local minima issues, to be prone to adversarial attacks and noise, and to lack interpretability and explainability.	tandfonline.com wallstreetmojo.com onlinelibrary.wiley.com zh.wikipedia.org ibm.com

According to Schultz et al. [59], training for ANN models usually needs relatively large datasets, and the training itself is an iterative process for many rounds or epochs. There are only 50 OEMs in the shoemaking machine industry in Taiwan, which makes it difficult for generating a large dataset to be used for training a reliable ANN model. Coming back to this study, the questionnaires collected from the 16 middle-level supervisors and senior executives of the shoemaking machine industry for analysis can only represent 32% of the total OEMs in Taiwan, making it an even smaller dataset. Nevertheless, Singh & Sarkar [60] suggested that ANNs can be a useful tool to incorporate sustainability aspects into the early stages of product development that help OEMs understand how to effectively plan a sustainable product life cycle. This can be done by integrating the sustainability considerations into the decision-making process of a company in the early design phases. ANNs can be used as a supplementary to the AHP model to help OEMs conduct effective green redesign in the initial stage of the product for remanufacturing.

In addition, it is difficult to find out other solutions to remanufacturing-related problems because they are complex and have many aspects to consider. Sarkar et al. [61] tested an ANN model that can manage different products in different situations, which can find the best solution even changes and challenges are existing in each situation. Guchhait et al. [62] introduced a model that can control the quality and profit of products using a buyback contract. This contract reduces the cost of losing customers. The model sells products through two channels: retail and online. The demand for products depends on many factors, such as price, advertising, service level, and the delivery cost. The online channel has more demand than the retail channel. Guchhait et al. [63] mentioned that the market demand for a single type of product depends on many factors too. These factors change because of globalization, customer choice, and priorities. Sangal et al. [64] stated that the environment is an important issue for industries as well as the economy. They showed a model that considers system reliability, inspection errors, and carbon emissions. The model aims to find the best investment, shipment size, reliability, and lead time for a system that has errors. The model uses a cost that depends on the system reliability to improve itself, and a policy that reduces carbon emissions by delivering products in different amounts.

5. Conclusions

According to Xiang & Ming [65], many firms have successfully adopted remanufacturing as a business model. Remanufacturing not only provides a profit opportunity but also an excellent mechanism for reducing the environmental impact of end-of-use products. OEMs take back the used products, restore their functions, and provide the same services as the original ones. To promote remanufacturing, business models, recycling systems, and product design are key factors. Regardless of material cost or energy consumption, the price of remanufactured products will be lower than the new ones. The market's perception of "nonnew products" means that the price of remanufactured goods must be lower than that of new ones to increase the willingness of customers to buy. This enables remanufactured products to be a tool for OEMs to gain system market share. Because once a customer adopts the system, it is easy to become a long-term customer. Although remanufacturing has been around for a few years, OEMs not only sell new machines but also remanufactured machines and services to cover different groups of customers. At the same time, OEMs use remanufactured machines and services to develop new machine customers.

The research demonstrates that OEMs should begin with product redesign to achieve the goal of remanufacturing shoemaking machines. During the redesign process, the "feasibility of standardized & reduce complexity" must be considered first. Consideration of "integrated technology", "detailed design & material selection", and "reverse logistics" can make the product redesign more perfect. When redesigning the business model, the key factors are how to increase market share, formulate attractive product prices, expand the share of the system, shorten the downtime for customers during remanufacturing, and plan reverse logistics. According to the analysis, the key to the success of the circular economy is to start thinking the redesign at the early stage of manufacturing. In the redesign of the shoemaking machine, there are three key points, namely:

- Standardization and complexity reduction: Simplify product design with modular components and design standards.
- Integration technology: Make the product modular and upgradeable, including integration with software and hardware to reduce obsolescence problems.
- Design details and material selection: Choose corrosion-free, wear-resistant, and durable materials to ensure that fasteners and connectors do not interfere with disassembly and reassembly.

The purpose of this research is to contribute to the shoemaking machine industry by examining the feasibility of remanufacturing. The objective of the proposed model is to determine the optimal strategies to minimize the total cost of the trend of carbon emissions. From a practical point of view, the study can serve as a decision-making tool for providing optimal strategies on the options for reducing carbon emissions for the shoemaking machine. In future research, the analytic network process (ANP) decision-making model can be considered to make the decision-making process more precise because it is closer to the decision-making process of humans. In practice, there is often an interactive relationship between the various decision-making elements, rather than a purely top-to-bottom linear relationship. ANP can alleviate the limitation of AHP which simply uses a hierarchical structure to solve decision-making problems.

Acknowledgments

The authors wish to thank the two anonymous professionals from the Industrial Development Bureau, Ministry of Economic Affairs (MOEA), and one OEM of shoemaking machines in Taiwan for initially reviewing the content of the questionnaire.

Author Contributions

Conceptualization: W.-J.C., & R.-H.L.; Data curation: W.-J.C.; Formal analysis: W.-J.C.; Funding acquisition: W.-J.C., & R.-H.L.; Investigation: W.-J.C.; Methodology: W.-J.C.; Project administration: W.-J.C.; Resources: W.-J.C., R.-H.L., & C.-L.C.; Software: W.-J.C.; Supervision: R.-H.L.; Validation: W.-J.C., & R.-H.L.; Visualization: W.-J.C.; Writing – original draft: W.-J.C.; Writing – review & editing: W.-J.C., R.-H.L., & C.-L.C.

Conflicts of Interest

The authors have no conflict of interest to declare.

References

1. Council of the EU. (29 June 2022). *Fit for 55 package: Council reaches general approaches relating to emissions reductions and their social impacts*. https://www.consilium.europa.eu/en/press/press-releases/2022/06/29/fit-for-55-council-reaches-general-approaches-relating-to-emissions-reductions-and-removals-and-their-social-impacts (accessed 9 January 2022).
2. GreenPeace. (2021). *The Net Zero Game is Coming: Report on the Impact of International Carbon Border Tax on Taiwan.*
3. Han, X., Yang, Q., Shang, J., & Pu, X. (2017). Optimal strategies for trade-old-for-remanufactured programs: Receptivity, durability, and subsidy. *International Journal of Production Economics*, *193*, 602–616. https://doi.org/10.1016/j.ijpe.2017.07.025
4. Zhuang, X., Song, X., Yang, H., Zhao, D., Wu, W., & Zhao, J. (2023). The energy saving and GHG mitigation benefits assessment of product remanufacturing from a multi-life cycle perspective: A case study of spark plug. *Environmental Impact Assessment Review*, *99*, 107018. https://doi.org/10.1016/j.eiar.2022.107018
5. Technavio. (2022). *Industrial Machinery Remanufacturing Market by End-user and Geography - Forecast and Analysis 2022–2026*. Infiniti Research Limited. https://www.technavio.com/report/industrial-machinery-remanufacturing-market-industry-analysis (accessed 9 January 2022).
6. Xu, Z., Elomri, A., Pokharel, S., & Mutlu, F. (2019). The Design of Green Supply Chains under Carbon Policies: A Literature Review of Quantitative Models. *Sustainability*, *11*(11), 3094. https://doi.org/10.3390/su11113094
7. Ansari, Z. N., & Daxini, S. D. (2022). A State-of-the-Art Review on Meta-heuristics Application in Remanufacturing. *Archives of Computational Methods in Engineering*, *29*(1), 427–470. https://doi.org/10.1007/s11831-021-09580-z
8. Sousa, S. D., & Pham, D. T. (2023). Quality Control in Remanufacturing: Distinguishing Features and Techniques. In K.-Y. Kim, L. Monplaisir, & J. Rickli (Eds.), *Flexible Automation and Intelligent Manufacturing: The Human-Data-Technology Nexus*. Springer Cham. https://doi.org/10.1007/978-3-031-17629-6_57
9. Masoumik, S. M., Abdul-Rashid, S. H., & Olugu, E. U. (2015). The Development of a Strategic Prioritisation Method for Green Supply Chain Initiatives. *PLoS ONE*, *10*(11), 1–33. https://doi.org/10.1371/journal.pone.0143115
10. Ghosh, S., Mandal, M. C., & Ray, A. (2023). A PDCA based approach to evaluate green supply chain management performance under fuzzy environment. *International Journal of Management Science and Engineering Management*, *18*(1), 1–15. https://doi.org/10.1080/17509653.2022.2027292
11. Sundin, E., & Bras, B. (2005). Making functional sales environmentally and economically beneficial through product remanufacturing. *Journal of Cleaner Production*, *13*(9), 913–925. https://doi.org/10.1016/j.jclepro.2004.04.006
12. Ghoreishi, M., Treves, L., Teplov, R., & Pynnönen, M. (2023). The Impact of Artificial Intelligence on Circular Value Creation for Sustainable Development Goals. In F. Mazzi & L. Floridi (Eds.), *The Ethics of Artificial Intelligence for the Sustainable Development Goals* (pp. 347–363). Springer Cham. https://doi.org/10.1007/978-3-031-21147-8_19
13. Konstantaras, I., Skouri, K., & Benkherouf, L. (2021). Optimizing inventory decisions for a closed–loop supply chain model under a carbon tax regulatory mechanism. *International Journal of Production Economics*, *239*, 108185. https://doi.org/10.1016/j.ijpe.2021.108185
14. Mathiyazhagan, K., Rajak, S., Sampurna Panigrahi, S., Agarwal, V. & Manani, D. (2021). Reverse supply chain management in manufacturing industry: a systematic review. *International Journal of Productivity & Performance Management*, *70*(4), 859–892. https://doi.org/10.1108/IJPPM-06-2019-0293
15. Vlachos, I. P. (2016). Reverse logistics capabilities and firm performance: the mediating role of business strategy. *International Journal of Logistics: Research & Applications*, *19*(5), 424–442. https://doi.org/10.1080/13675567.2015.1115471
16. Oliveira, L. S., & Machado, R. L. (2021). Application of optimization methods in the closed-loop supply chain: a literature review. *Journal of Combinatorial Optimization*, *41*(2), 357–400. https://doi.org/10.1007/s10878-020-00677-y
17. Condeixa, L. D., Silva, P., Moah, D., Farias, B., & Leiras, A. (2020). Evaluating cost impacts on reverse logistics using an Economic Order Quantity (EOQ) model with environmental and social considerations. *Central European Journal of Operations Research*, *30*, 921–940. https://doi.org/10.1007/s10100-020-00707-4
18. Lee, C.-M., Woo, W.-S., & Roh, Y.-H. (2017). Remanufacturing: Trends and issues. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *4*, 113–125. https://doi.org/10.1007/s40684-017-0015-0
19. Chari, N., Diallo, C., & Venkatadri, U. (2014). State of the Art on Performability across the Sustainable Value Chain. *International Journal of Performability Engineering*, *10*(6), 543–556.
20. Steingrímsson, J. G., Bilge, P., Heyer, S., & Seliger, G. (2011). Business Strategies for Competition and Collaboration for Remanufacturing of Production Equipment. In G. Seliger, M. Khraisheh, & I. Jawahir (Eds.), *Advances in Sustainable Manufacturing*. Springer. https://doi.org/10.1007/978-3-642-20183-7_14

21. Okorie, O., Russell, J., Cherrington, R., Fisher, O., & Charnley, F. (2023). Digital transformation and the circular economy: Creating a competitive advantage from the transition towards Net Zero Manufacturing. *Resources, Conservation and Recycling*, *189*, 106756. https://doi.org/10.1016/j.resconrec.2022.106756
22. Cunha, V. P., Balkaya, I., Palacios, J., Rozenfeld, H., & Seliger, G. (2011). Development of Technology Roadmap for Remanufacturing Oriented Production Equipment. In G. Seliger, M. Khraisheh, & I. Jawahir (Eds.), *Advances in Sustainable Manufacturing* (pp. 203–208). Springer. https://doi.org/10.1007/978-3-642-20183-7_30
23. Du, Y., Zheng, Y., Wu, G., & Tang, Y. (2020). Decision-making method of heavy-duty machine tool remanufacturing based on AHP-entropy weight and extension theory. *Journal of Cleaner Production*, *252*, 119607. https://doi.org/10.1016/j.jclepro.2019.119607
24. Jiang, Z., Zhang, H., & Sutherland, J. W. (2011). Development of multi-criteria decision making model for remanufacturing technology portfolio selection. *Journal of Cleaner Production*, *19*(17), 1939–1945. https://doi.org/10.1016/j.jclepro.2011.07.010
25. Ramírez, F. J., Castellani, M., & Xu, W. (2023). Autonomous remanufacturing for sustainability. *The International Journal of Advanced Manufacturing Technology*, *124*(9), 2969–2970. https://doi.org/10.1007/s00170-022-10680-8
26. Sitcharangsie, S., Ijomah, W., & Wong, T. C. (2019). Decision makings in key remanufacturing activities to optimise remanufacturing outcomes: A review. *Journal of Cleaner Production*, *232*, 1465–1481. https://doi.org/10.1016/j.jclepro.2019.05.204
27. Du, Y., Cao, H., Liu, F., Li, C., & Chen, X. (2012). An integrated method for evaluating the remanufacturability of used machine tool. *Journal of Cleaner Production*, *20*(1), 82–91. https://doi.org/10.1016/j.jclepro.2011.08.016
28. Shu, T., Wu, Q., Chen, S., Wang, S., Lai, K. K., & Yang, H. (2017). Manufacturers'/remanufacturers' inventory control strategies with cap-and-trade regulation. *Journal of Cleaner Production*, *159*, 11–25. https://doi.org/10.1016/j.jclepro.2017.05.021
29. Majumder, P., & Groenevelt, H. (2001). Competition in remanufacturing. *Production and Operations Management*, *10*(2), 125–141. https://doi.org/10.1111/j.1937-5956.2001.tb00074.x
30. Chen, S., Pan, Y., Wu, D., & Dolgui, A. (2023). In-house versus outsourcing collection in a closed-loop supply chain with remanufacturing technology development. *International Journal of Production Research*, *61*(6), 1720–1735. https://doi.org/10.1080/00207543.2022.2045376
31. Berkel, R. V., & Ramchandra, R. (21 September 2020). *India: Building back better through remanufacturing*. United Nations Industrial Development Organization (UNIDO). https://www.unido.org/stories/india-building-back-better-through-remanufacturing (accessed 4 February 2022).
32. U.S. International Trade Commission. (2012). *Remanufactured Goods: An Overview of the U.S. and Global Industries, Markets, and Trade* (USITC Publication 4356). http://www.usitc.gov/publications/332/pub4356.pdf (accessed 4 February 2022).
33. Forward. (2020). *Report of Prospect and Investment Forecast Analysis on China Remanufacturing Industry (2022–2027)*.
34. National Center for Climate Change Strategy and International Cooperation (NCSC). (2018). *The People's Republic of China Third National Communication on Climate Change*. https://unfccc.int/sites/default/files/resource/China_NC3_Chinese_0.pdf (accessed 4 February 2022).
35. Sinha, A. K. (2013). Feasibility of remanufacturing in india a study of automobile sector [Ph.D Thesis, IIT (ISM) Dhanbad]. Shodhganga@INFLIBNET. http://hdl.handle.net/10603/32886
36. Choudhary, N., & Singh, N. (2011). Remanufacturing in India: Approaches, Potentials & Technical challenges. *International Journal of Industrial Engineering and Technology*, *3*, 223–227.
37. Ahuja, V., & Terkar, R. (2020). Remanufacturing Benefits: An Analysis of Recent Trends in Indian Context. *IOP Conference Series: Materials Science and Engineering*, *810*, 012068. https://doi.org/10.1088/1757-899X/810/1/012068
38. Parker, D., & Robinson, S. (2015). *Remanufacturing Future Market Report* (Ref. Ares (2016) 217725 - 15/01/2016). European Commission.
39. Zacharaki, A., Vafeiadis, T., Kolokas, N., Vaxevani, A., Xu, Y., Peschl, M., et al. (2021). RECLAIM: Toward a New Era of Refurbishment and Remanufacturing of Industrial Equipment. *Frontiers in Artificial Intelligence*, *3*, 570562. https://doi.org/10.3389/frai.2020.570562
40. Kurilova, J., Sundin, E., & Poksinsha, B. (2018). Remanufacturing challenges and possible lean improvements. *Journal of Cleaner Production*, *172*, 3225–3236. https://doi.org/10.1016/j.jclepro.2017.11.023
41. Golinska-Dawson, P., & Kubler, F. (Eds.). (2018). *Sustainability in remanufacturing operations*. Springer Cham. https://doi.org/10.1007/978-3-319-60355-1
42. Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007). Development of design for remanufacturing guidelines to support sustainable manufacturing. *Robotics and Computer-Integrated Manufacturing*, *23*(6), 712–719. https://doi.org/10.1016/j.rcim.2007.02.017
43. Lindkvist, L., & Sundin, E. (2016). The role of Product-Service Systems regarding information feedback transfer in the product life-cycle including remanufacturing. *Procedia CIRP*, *47*, 311–316. https://doi.org/10.1016/j.procir.2016.03.088
44. Vogt Duberg, J., Johansson, G., Sundin, E., & Kurilova-Palisaitiene, J. (2020). Prerequisite factors for original equipment manufacturer remanufacturing. *Journal of Cleaner Production*, *270*, 122309. https://doi.org/10.1016/j.jclepro.2020.122309
45. Ekins, P., Domenech, T., Drummond, P., Bleischwitz, R., Hughes, N., & Lotti, L. (2019). The Circular Economy: What, Why, How and Where. In *Managing Environmental and Energy Transitions for Regions and Cities*. Organisation for Economic Co-operation and Development (OECD).
46. Dils, E. (2021). *ETC/WMGE Report 10/2021: Contribution of remanufacturing to circular economy*. The European Environment Information and Observation Network (Eionet).
47. Guidat, T., Seidel, J., Kohl, H., & Seliger, G. (2017). A Comparison of Best Practices of Public and Private Support Incentives for the Remanufacturing Industry. *Procedia CIRP*, *61*, 177–182. https://doi.org/10.1016/j.procir.2016.11.265
48. Östlin, J., Sundin, E. & Björkman, M. (2008). Importance of Closed Loop Supply Chain Relationships for Product Remanufacturing. *International Journal of Production Economics*, *115*(2), 336–348. https://doi.org/10.1016/j.ijpe.2008.02.020
49. Bauer, T. (2020). Characterization of circular strategies to better design circular industrial systems. *Journal of Remanufacturing*, *10*(3), 161–176. https://doi.org/10.1007/s13243-020-00083-x
50. Chang, K.-F. (2017). *Super Decisions Software Operation Manual: Using ANP to break through the research limitations of AHP*. Dingmao Book Publishing.

51. Johnson, M. R., & McCarthy, I. P. (2014). Product recovery decisions within the context of Extended Producer Responsibility. *Journal of Engineering and Technology Managemen*t, *34*, 9–28. https://doi.org/10.1016/j.jengtecman.2013.11.002
52. Munot, M. A., & Ibrahim, R. N. (2013). Remanufacturing Process and Its Challenges. *Journal of Mechanical Engineering and Sciences*, *4*, 488–495. https://doi.org/10.15282/jmes.4.2013.13.0046
53. Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical Modelling*, *9*(3), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8
54. Super Decisions Creative Decisions Foundation. (2023). *SuperDecisions* (Version 3.2) [Decision support software that implements the AHP and ANP]. https://www.superdecisions.com
55. Momoh, J. A., & Zhu, J. (1999). Multiple indices for optimal reactive power pricing and control. *Decision Support Systems*, *24*(3), 223–232. https://doi.org/10.1016/S0167-9236(98)00076-1
56. Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process* (Vol. 4922). RWS publications Pittsburgh.
57. Stretton, S. (2020). *A Simple Methodology for Calculating the Impact of a Carbon Tax In* (p. 32). World Bank Group.
58. Saha, N., Swetapadma, A., & Mondal, M. (2023). A Brief Review on Artificial Neural Network: Network Structures and Applications. In *2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS)* (pp. 1974–1979). IEEE. https://doi.org/10.1109/ICACCS57279.2023.10112753
59. Schultz, C., McNinch, C., Qi, J., Smith, M., & Barclay, N. (2023). Culvert Condition Prediction via Artificial Neural Network Machine Learning-Based Models using SMOTE. In *SoutheastCon 2023* (pp. 618–625). IEEE. https://doi.org/10.1109/SoutheastCon51012.2023.10115085
60. Singh, P. K., & Sarkar, P. (2023). An artificial neural network tool to support the decision making of designers for environmentally conscious product development. *Expert Systems with Applications*, *212*, 118679. https://doi.org/10.1016/j.eswa.2022.118679
61. Sarkar, A., Guchhait, R., & Sarkar, B. (2022). Application of the Artificial Neural Network with Multithreading Within an Inventory Model Under Uncertainty and Inflation. *International Journal of Fuzzy Systems*, *24*(5), 2318–2332. https://doi.org/10.1007/s40815-022-01276-1
62. Guchhait, R., Pareek, S., & Sarkar, B. (2018). Application of Distribution-Free Approach in Integrated and Dual-Channel Supply Chain Under Buyback Contract. In N. H. Shah & M. Mittal (Eds.), *Handbook of Research on Promoting Business Process Improvement Through Inventory Control Techniques* (pp. 388–426). IGI Global. https://doi.org/10.4018/978-1-5225-3232-3.ch021
63. Guchhait, R., Sarkar, M., Sarkar, B., & Pareek, S. (2017). Single-vendor multi-buyer game theoretic model under multi-factor dependent demand. *International Journal of Inventory Research*, *4*(4), 303–332. https://doi.org/10.1504/ijir.2017.090384
64. Sangal, I., Shaw, B. K., Sarkar, B., & Guchhait, R. (2020). A joint inventory model with reliability, carbon emission, and inspection errors in a defective production system. *Yugoslav Journal of Operations Research*, *30*(3), 381–398. https://doi.org/10.2298/YJOR190415020S
65. Xiang, W., & Ming, C. (2011). Implementing extended producer responsibility: vehicle remanufacturing in China. *Journal of Cleaner Production*, *19*(6), 680–686. https://doi.org/10.1016/j.jclepro.2010.11.016