sustainability

Review

Management and Logistics of Returnable Transport Items: A Review Analysis on the Pallet Supply Chain

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Abstract: Pallets are among the most used returnable transport items (RTIs), and they are critical assets for a supply chain as they have significant environmental and economic impacts during their whole life cycle. Differently from other packaging products, pallets are specifically designed to be repeatably repaired and reinjected for use. While this environmentally is beneficial as it reduces waste, it can create complex interactions between the stakeholder-involved manufacturers, pallet providers, users and recyclers. Further, the number of different actors is usually high, and the flow of materials among them needs to be coordinated. In addition, different business models can be implemented (such as internal management versus outsourcing) as well as logistics alternatives (closed- versus open-loop). Thus, the aims of this study are first to propose a systematization of design and management decisions regarding the pallet supply chain; next, to review the state of the art models and tools adopted to support each decision process relying on an analysis of the archival literature published between 1978 and 2021 on pallet management, to summarize the main decision problems addressed by the different stakeholders involved in the pallet life cycle and the adopted methods, and, finally, to highlight potential existing research gaps. This effort helps to outline potential contributions towards more sustainable pallet supply chains and can support pallet operators and companies in evaluating solutions to increase the economic and environmental sustainability of their pallet management. Results show that the perspectives of the pallet provider and of the supply chain are the most widely addressed in the existing literature, while those of pallet manufacturers and repairers should be further analyzed.

Keywords: pallet logistics; pallet management; systematic literature review; returnable transport items; reusable packaging; sustainable supply chain

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1. Introduction

Pallets are key elements of global supply chains and are one of the most used returnable transport items (RTIs), carrying about 80% of all world trade [1]. These seemingly simple products support the transport and storage of goods and have enabled the development of the efficient and standardized material handling and logistic systems used worldwide. Pallets are characterized by a simple design structure that is also standardized. This has led to the repair of pallets for reuse being a common practice. This is environmentally promising but also creates additional logistics and management complexities. First, pallet supply chain management is affected by typical problems of RTI's supply chains, specifically, the coordination and trade-off challenges where forward and reverse logistics coexist with returned flows. The industry is fragmented, resulting in the number of stakeholders involved usually being high: from pallet manufacturers to users, including several other actors (remanufacturers, repairers, pallet providers, etc.). The logistics alternative, closed- versus open-loop, can depend on several decision variables (such as the availability of repair facilities, their distances from user locations, etc.) and can result in different economic and environmental outcomes along the supply chain: the environmental impacts of different pallet types and models have been explored in the last few years to assess the sustainability of logistic systems [2,3], and some attempts to analyze the cost dimension are also available in the literature [4]. Moreover, the reverse logistics of pallets can be handled directly by the user, outsourced to pallet providers, and/or through ad hoc third-party operators. Despite these logistical and management complexities of pallet supply chains and their relevance for the stakeholders involved, a systematization of the pallet supply chain together with the definition of decision problems affecting each involved stakeholder is still missing in the literature.

Some of the problems related to pallet management can apply to any kind of RTI (e.g., repositioning policies). Recently, two literature reviews on RTIs and returnable packaging management were provided by [5,6]: the first centers the analysis on the decision support models for RTI management in closed-loop supply chains, while the second focuses on the impacts of reusable packaging on supply chains. However, the peculiarities of the pallet life cycle (and especially the complexity created in that pallets are RTIs that are specifically designed to be repeatably repaired and reinjected for use), as well as the variety and interaction of stakeholders associated with the pallet supply chain, provides a fertile domain for applied research, and, indeed, the body of literature devoted to the study of pallets and their supply chains has grown dramatically in recent years [7]. Thus, the scope of the work is twofold: proposing a systematization of decision problems affecting the logistics and management of pallets, and evaluating, through a literature review, how these problems are currently solved, considering environmental and economic objectives aiming to design more sustainable supply chains. The adoption of the stakeholders' perspective helps the reader framing these problems and decisions highlighting the actors involved and the targets (economic, environmental or both) to be reached. This can support academics in planning future research on pallet management, as well as technicians in improving their environmental and economic performance in the design and management of their pallet supply chains.

The paper is organized as follows: in Section 2, the pallet supply chain and some critical decisions associated to its design and management are described. The research methodology adopted is described in detail in Section 3, while the descriptive and content analysis is presented in Section 4. Finally, a critical discussion about emerging issues and further research developments is proposed in Section 5, and concluding remarks are included in Section 6.

2. The Pallet Supply Chain: Decision Problems and Involved Stakeholders

Pallet supply chains can involve several tiers and multiple interconnected stakeholders. Figure 1 shows two possible general configurations, an open-loop and a closed-loop system [8], and the stakeholders that are generally involved.

In an open-loop system, pallets are viewed as disposable assets, and they are disposed after the final use. In this supply chain, manufactured pallets are distributed to users (i.e., companies that use pallets as transportation items) that employ them for transportation and storage along their supply chain. When the pallet is delivered to the final user, different end-of-life alternatives can be adopted: pallets can be either shredded and separated for recycling or disposed directly in a landfill. In the first case, for wood pallets the steel from nails can be recycled and the wood material can be incinerated with/without energy recovery or used for mulch/animal bedding/wood pellets; for plastic pallets the plastic material and the steel from any inserts can be recycled. The stakeholders typically involved in an open-loop supply chain are the pallet manufacturer, the users and the end-of-life managers. Pallet manufacturers produce the pallets and deal with sourcing raw materials and optimizing production processes to meet the demand. Manufacturing operations can vary greatly, especially with respect to the level of automation. Finished pallets are then distributed to users through appropriate transportation networks. In the use phase, pallets experience highly variable duty cycles, depending on the needs of the particular user. End-of-life can be managed by recyclers or landfills, according to the local context.

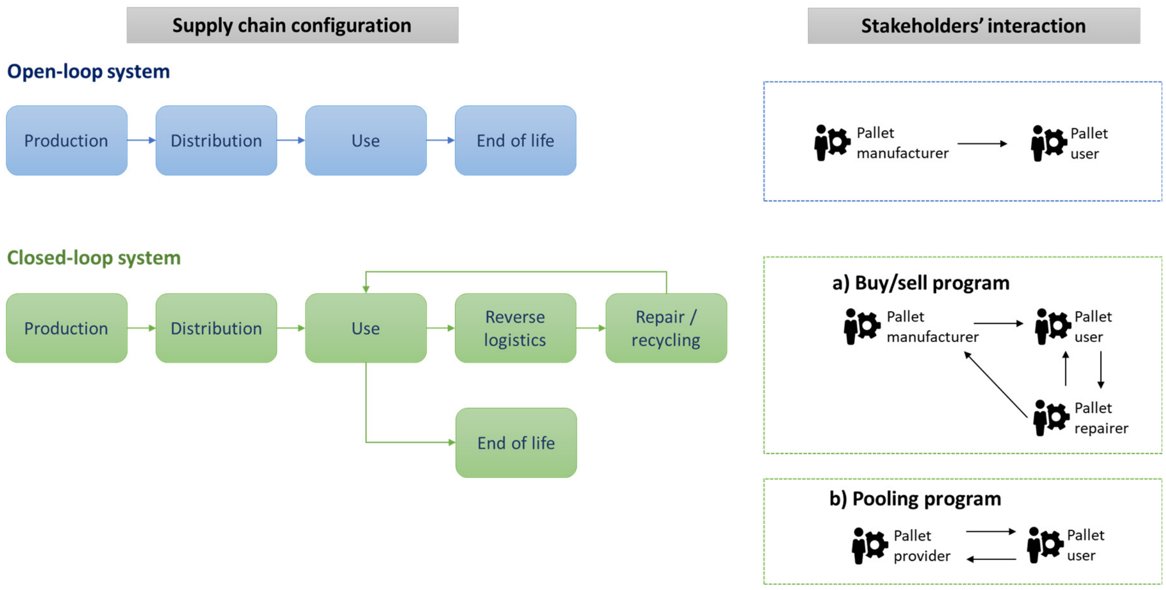

Figure 1. Open- and closed-loop models in the pallet supply chain.

In contrast, in a closed-loop system used pallets are recovered to be repaired (when possible) and/or used again in a new transportation cycle. After the use phase, that usually includes several duty cycles, they are transported to a recovery center, where they will be repaired and returned to service. When the pallet is too damaged to be recovered, it is sent to landfill for disposal, or to recycling plants, according to the waste management system in place in that area. From an organizational point of view, a closed-loop supply system can involve different stakeholders, depending on the scheme adopted. One possible system is the "buy/sell" one, in which each phase of the pallet life cycle is managed by a different stakeholder, and the ownership of pallets is transferred from one stakeholder to the next. Together with the pallet manufacturer and the pallet user, the supply chain includes pallet repairers and recyclers, managing repair/recycling operations.

A different closed-loop scheme is the pallet pooling or rental systems, where another stakeholder (the pallet provider) has the ownership of the asset throughout the whole supply chain. Pallet providers typically take a holistic perspective, as they are usually responsible for several or all phases of the pallet life cycle: they manage the production phase, then supply pallets for their customers with different types of contracts to users (e.g., rental, leasing, pooling), and, finally, they manage the reverse logistics to recover pallets and the repair/recycling process, sending to disposal those that are no more viable. Therefore, a pooling system usually involves only two stakeholders: pallet providers and users. These descriptions depict the general condition of typical pallet supply chain configurations. However, in real-world cases, actors could cover different rules in the supply chain. For instance, it is not uncommon for pallet manufacturers to also engage in repair operations or for pallet providers to externalize repair operations as well as some pallet collection operations to third-party companies.

The complexity characterizing the closed-loop systems is usually higher than open-loop systems, as they include all the criticalities related to the reverse logistics activities, which require a higher level of coordination among the involved stakeholders. As an example, due to challenges with asset tracking, quality and quantity of the remaining pool, as well as the economics of the operation, uncertainty often characterizes the last phases of the pallet life cycle. The flow of returned pallets is affected by variability: in terms of quality, the state of a pallet at the end of the use phase can vary a lot according to handling and loading conditions, so affecting the remaining life of the pallet; in terms of quantity, variability occurs as a user may return a pallet with delay, or pallets can get lost. Moreover, there is often uncertainty in where the pallet ends up at the end of its use phase.

Each of these systems can entail different challenges and decisions for the stakeholders involved, who must deal with several decisions regarding the management of pallets and their supply chain. A summary of these decisions, which represent different research problems, is reported in Figure 2.

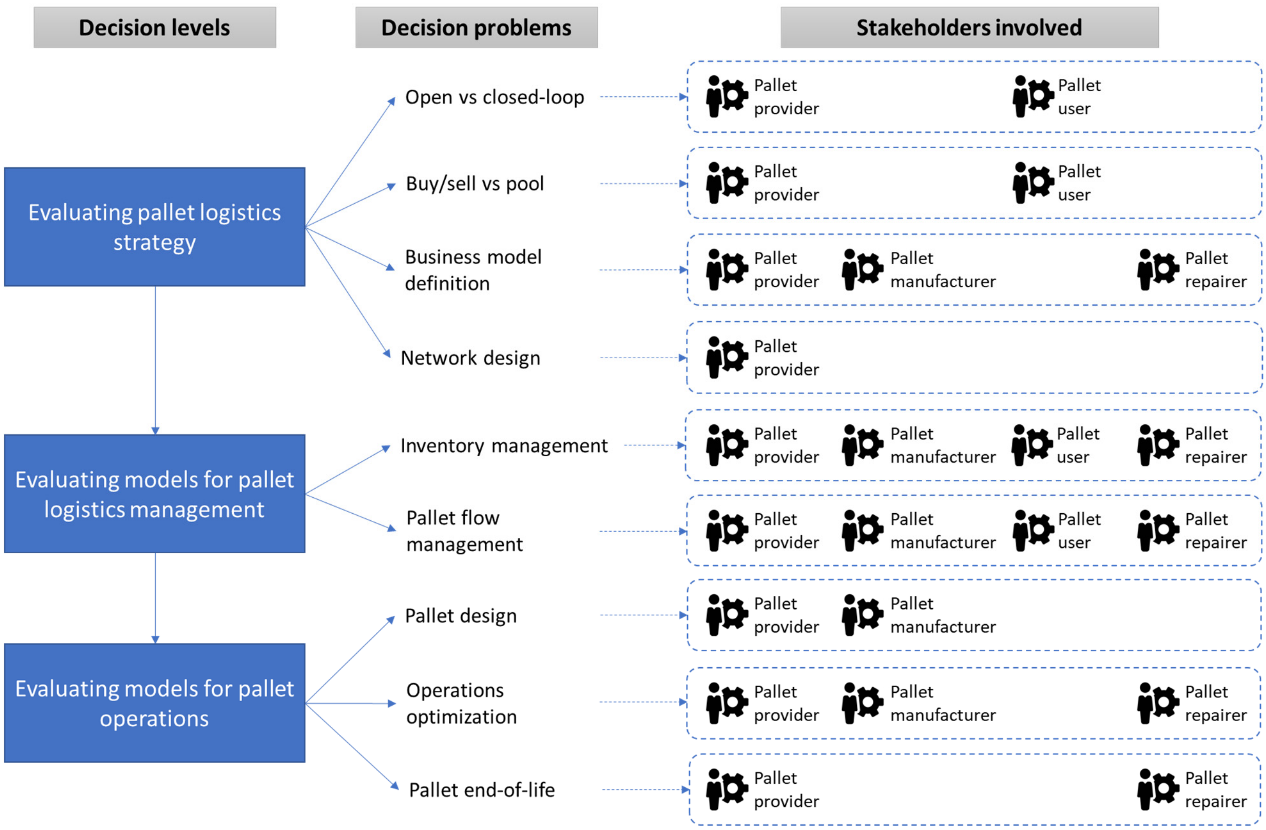

Figure 2. Summary of the main decision levels in pallet management and stakeholders involved.

A first decision level involves strategic problems such as the choice between an open-loop and a closed-loop system, the definition of a business model (market positioning, partnerships, pricing, etc.), the "buy or rent" decision, and the problems of network design. While this last decision only regards the pallet provider, who has to design its network of facilities, the other decisions can be looked at from different perspectives. As an example, the buy/sell versus pool decision involves the user that must decide which pallet system to adopt, but it can also refer to the pallet provider who, under certain circumstances, can find it more convenient to sell pallets to a customer rather than recover them after use. Similarly, the open- versus closed-loop decision can be analyzed from the perspective of a user choosing the most convenient pallet scheme, or from a provider deciding what kind of strategy to implement for its business.

After strategic decisions have been determined, management level decisions are made. This includes both internal material handling and external management along the supply chain, with problems such as inventory management and pallet flow management (meaning pallet traceability, recovery and allocation, dispatching, etc.). These decisions can affect all the actors involved, except for users, who only deal with pallet flow management (an example is the implementation of an internal tracking system).

The next decision level regards the evaluation of pallet operation models, including decisions about the pallet design (e.g., the choice of the material), the problems related to the efficiency of manufacturing and repair processes, and the pallet end-of-life.

All these decisions can be evaluated in light of the environmental and/or economic impacts that each alternative generates, aiming to optimize the overall level of sustainability.

While some of these decisions explicitly regard only one of the stakeholders involved in the supply chain, some others can be analyzed by different perspectives. As an example, the design of a traceability system can be faced by the pallet provider, to track the pallets of its pool along the customers' supply chains, and by the user, to track pallets with goods along its own supply chain or in its facilities. The objective of this study is to analyze the existing literature on pallet management in order to understand which problems and decisions have been discussed so far, and from which perspective, with the aim of providing a framework of the main decisions for each stakeholder and identify eventual research gaps.

3. The Research Methodology

A three-step systematic literature review methodology was followed, as shown in Figure 3. This established methodology can help researchers, practitioners and policy-makers, to build a base for decision making and further research [9].

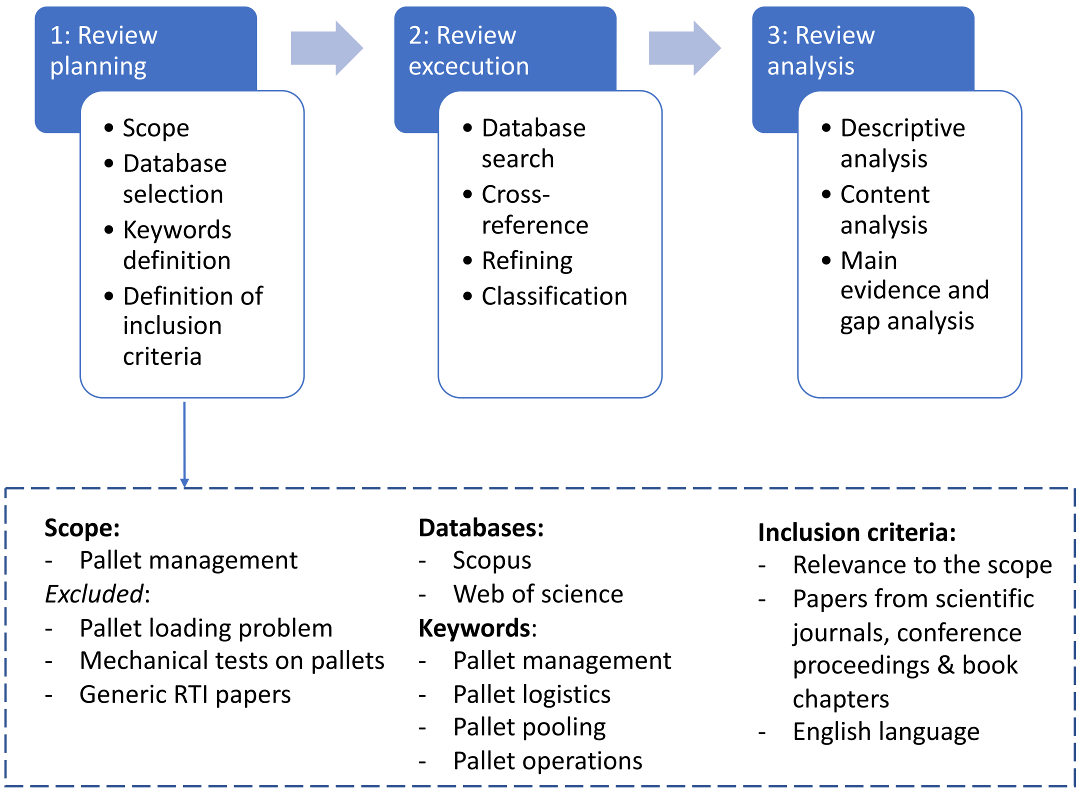

Figure 3. Steps of the research methodology (adapted from [9]).

The first step is to plan the review by defining the scope and search methods. As previously stated, the objective of this work is to highlight the main problems and challenges encountered in pallet management by the different stakeholders involved, outlining how they have been addressed in the literature so far, and to identify eventual research gaps. Given this scope, the research focuses on pallet management papers, thus excluding works related to the pallet loading problem, pallet mechanical properties and tests, and work that analyzes returnable transport items (RTIs) or reusable packaging in general but not pallets in particular.

The research was conducted utilizing two databases, Scopus and Web of Science, which are among the most complete sources for peer-reviewed literature used by researchers in engineering and science. Searches were performed for the following combinations of keywords: "pallet management", "pallet logistics", "pallet pooling" and "pallet operations". Only papers written in English and published in scientific journals, conference proceedings and book chapters were included, thus excluding white papers, website articles, trade magazines and commercial literature.

This process led to the selection of 85 articles published between 1978 and February 2021 (the list of papers is available in Table A1, in the Appendix A). The chosen articles were classified according to the following factors.

- Year and Journal of publication.
- Objectives or benefits pursued in the analysis: the studies are classified in terms of whether they evaluate economic aspects, environmental impacts, social outcomes and technical performance (or efficiency) of the product/system.
- Methodology adopted for the analysis: this factor identifies the type of method the authors used to address the problem presented in their study.
- Perspective adopted in the study: the perspectives have been identified considering the stakeholders involved in the pallet supply chain (as explained in Section 2):

- Pallet manufacturer;
- Pallet provider;
- Pallet recycler/repairer;
- Pallet user;
- Supply chain: this category includes the works considering the performance of the whole pallet supply chain rather than of a single stakeholder.

The content analysis was conducted and presented highlighting the different perspectives of the stakeholders involved: for each of them, a particular attention was given to the problems researched and the main findings, considering also the objectives pursued. This allowed the focus to be specifically on the objective of the study, which is to highlight the main decision problems and eventual gaps in the different levels of the pallet supply chain.

The results of the review analysis are presented in the following sections.

4. Overview of Research on Pallet Supply Chain

4.1. Descriptive Analysis

Of the 85 papers included in this review, 57 were published in 39 different peer-review journals, with the remaining 28 being conference papers in 23 different proceedings. Table 1 shows the journals or proceedings with three or more articles published. This list includes only three scientific journals and two proceedings of the same conference. Instead, the topic is treated only once or twice in most of the collections, thus showing that there is not a single, prominent journal/conference for pallet management, but, instead, papers on this topic are found broadly in a number of outlets.

Table 1. Journals/proceedings with 3 or more papers included in the review.

Journal/Proceeding	#Papers
Forest Products Journal	6
Journal of Cleaner Production	6
Sustainability	4
ICLEM 2010: Proceedings of the 2010 International Conference of Logistics Engineering and Management	3
ICLEM 2012: Proceedings of the 2012 International Conference of Logistics Engineering and Management	3
Other (63 papers)	≤2

Figure 4 shows the distribution of the papers analyzed over time. Interest in the field of pallet management has grown substantially in the last 15 years, with 90% of the papers analyzed being published after 2006, while only a few contributions appeared before that, and most of those are related to pallet manufacturing and recycling [10–12]. In particular, almost 40% of the works in the sample were published in the last 5 years, showing an increasing trend.

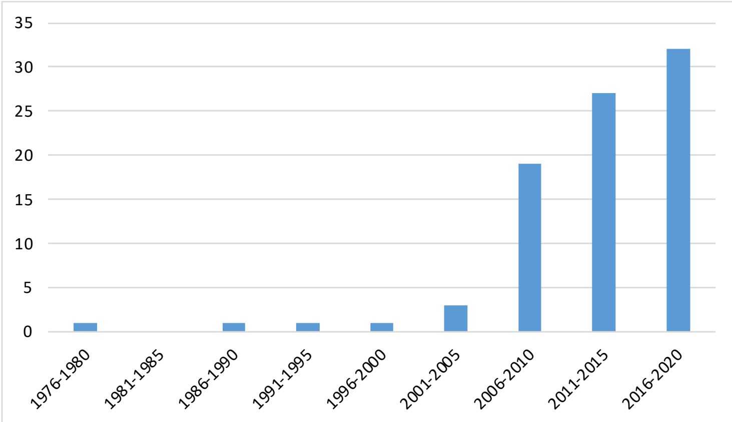

Figure 4. Publication year of pallet management papers analyzed.

Next, we classified the papers according to the objectives or benefits pursued in the analysis: the studies reviewed could include economic aspects, environmental impacts, social outcomes and technical performance (or efficiency) of the product/system considered. The frequency of each of these objectives is shown in Figure 5, considering that each article can include more than one objective in the study: the most diffused objectives are the environmental and economic aspects of pallet logistics and management, but also the technical efficiency is often considered to assess the performance of the systems analyzed.

Concerning the methodologies applied in the studies, we find that the most adopted is optimization, followed by conceptual models. Field studies, test cases and simulation models are also often used. Among the environmental assessment methods, Life Cycle Assessment (LCA) and Carbon Footprint estimations are the most found (Table 2).

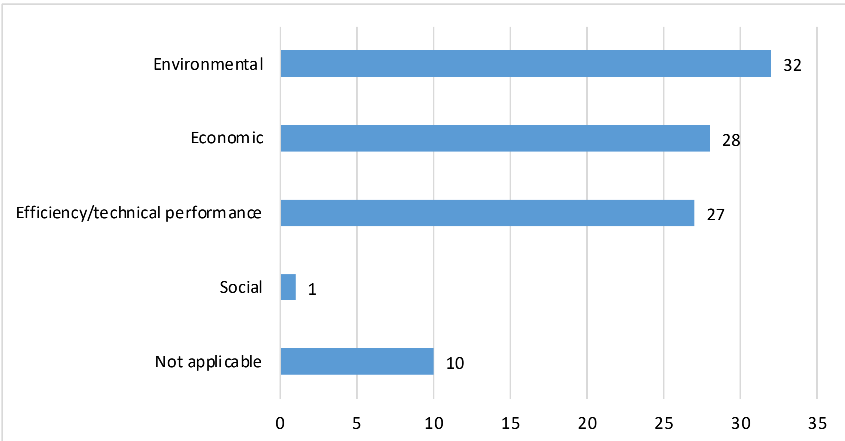

Figure 5. Classification according to the main objectives of the analysis.

Table 2. Classification according to the methodology applied.

Methodology	Frequency
Optimization model	18
Conceptual model	10
LCA	10
Field study	9
Test case	8
Simulation model	7
LCA (Carbon footprint)	4
Other (19 papers)	≤2
Total	85

Finally, Figure 6 shows the classification based on the stakeholders' perspective adopted: about two thirds of the studies adopt either the perspective of the pallet provider or that of a whole supply chain. This might be due in part to the diffusion of pallet models managed by the provider (such as rental or pooling). Issues faced by manufacturers are explored in 15 papers, while the pallet user perspective is analyzed in 11 studies. The perspective of recyclers and repairers is the least investigated, with only 5 papers focusing on the challenges related to their activity. In particular, Figure 7 shows the distribution over time of the papers considering the different perspectives identified. It is interesting to observe that the few articles published before 2006 are distributed in the five categories and there is no trend to highlight. After 2006, research on pallet management has increased, in particular for the perspectives of the pallet provider and the supply chain.

4.2. Content Analysis

To describe the results of the literature analysis, we consider the different perspectives adopted and describe the main problems and challenges addressed for each of them.

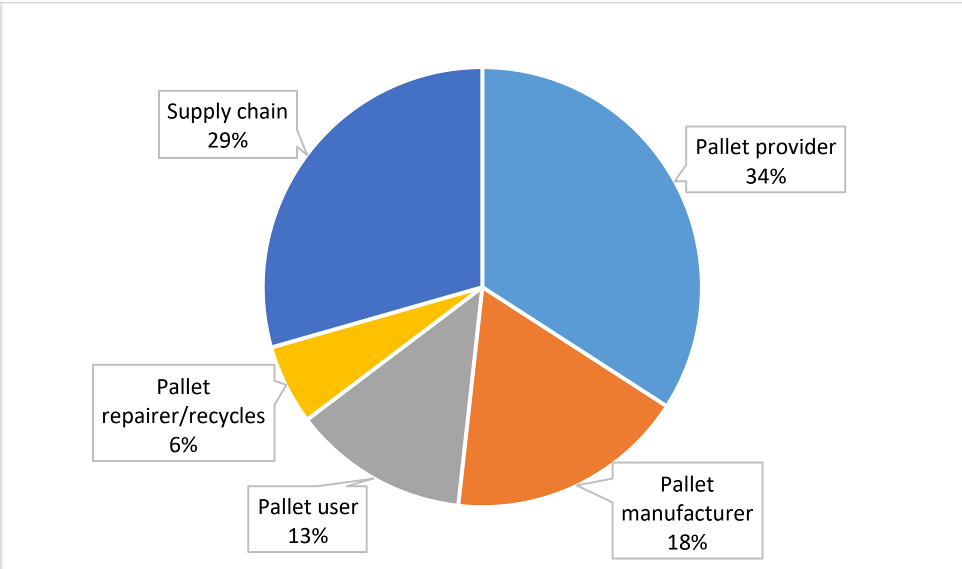

Figure 6. Classification according to the perspective adopted.

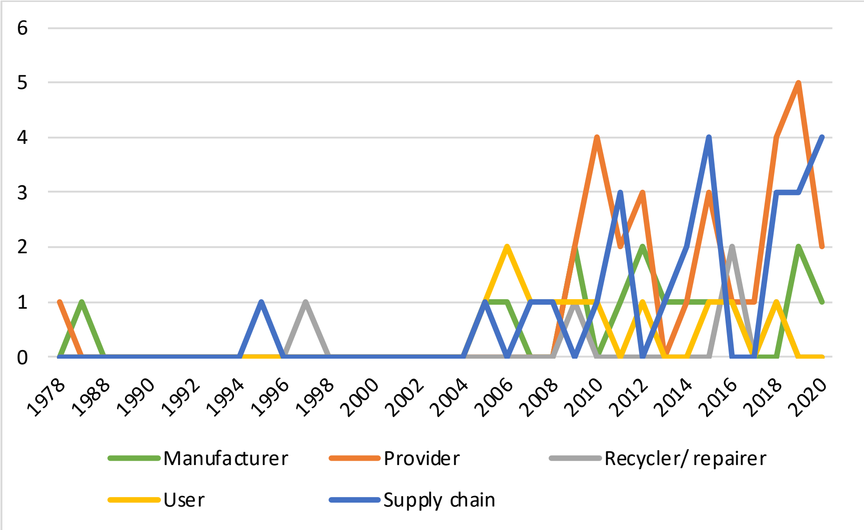

Figure 7. Distribution over time of papers considering the different perspectives adopted.

4.2.1. Pallet Manufacturer

The perspective of the pallet manufacturer is adopted mostly in papers dealing with issues related to pallet operations, particularly with pallet design and production. Despite the existence of several standards that define the specifications of pallets, a few works focus on pallet design and how it impacts the asset's functionality and performance. For wood pallets, [12] investigates through a statistical analysis the effect of design on the structural durability of the pallet, identifying some factors that can influence significantly the pallet service life, such as: wood species (softwood vs. lumber) and density, moisture content, number and type of fasteners, etc. The authors of [13] focus on plastic pallets instead, developing a conceptual model for the modular design of standardized platforms. Although the market is dominated by wood pallets, with a small share of plastic ones, these are not the only possible materials to produce pallets. A few authors discuss the problem of the choice of the material: the authors of [14] use finite element analysis (FEM) to assess different materials for cold room applications, demonstrating that pallets in plywood, corrugated paperboard and some composite materials are more suitable for these work environments. FEM is also used by [15] to develop optimal design specifications for wood–plastic composite pallets, proposing a product that guarantees a high mechanical resistance with a considerably lower mass compared to wood pallets (less than 20 kg). The authors of [16] study the use of recycled and biomass materials to produce green composite pallets, showing that the controlled use of paper-sludge in the manufacturing process of some pallet components can ensure mechanical properties similar to those of wood composite.

A few more papers focus on problems related to the production phase. Due to pallets being reusable, the sanitation process is crucial for the use of wood pallets in supply chains. This issue is analyzed by [17], who evaluate the vacuum-steam treatment in a test case, as an alternative to other phytosanitation methods. Moreover, improving the performance of the pallet manufacturing process is a common objective of several articles in this cluster. The authors of [18] address the cutting-stock problem, in order to minimize the waste of raw materials in the pallet production process. The authors of [19] adopt a simulation model to evaluate the production process of deck and stringers boards in a case study, with the objective of identifying inefficiencies: as they verify that the bottleneck was the cut-saw machine, they propose some changes in the manufacturing line, improving the productivity by up to 50%. The authors of [20] analyze the relationship between pallet cant quality and the efficiency of the pallet manufacturing process, elaborating on some cant grading rules to help manufacturers and suppliers. The production process of bamboo–wood pallets is studied by [21] adopting the Analytic Hierarchic Process to compare the impact of this material on performance with those of wood and plastic, while [22] performs a survey to identify best practices and promote resource efficiency and cleaner production among small and medium pallet manufacturers.

Only one work focuses on a problem that is common among industrial actors, which is the demand forecast: [23] presents a methodology combining fuzzy time series and clustering techniques to support pallet manufacturers with accurate forecasts on demand, with the aim of improving the efficiency and sustainability of pallet supply chains. The authors underline the importance of information sharing along the supply chain to improve its overall efficiency.

Three of the works adopting the manufacturer perspective consider the environmental performance. Two of them focus on the assessment of the environmental impact of pallet manufacturing operations: [24] evaluated the impact of the coniferous wood supply chain, finding that the electricity consumption due to the sawing and thermal treatment processes is the major environmental concern. The authors suggest some strategies to mitigate the problem (e.g., using wood residues to recover energy, increasing green electricity consumption). The authors of [25] compared the carbon footprint of recycled versus virgin wood for pallet production, showing that the former allows a reduction in CO2eq of about 11%. Finally, [26] uses the test case of a pallet manufacturer to compare two methods to assess the carbon footprint.

4.2.2. Pallet Provider

Most of the works from the pallet provider perspective address problems related to the logistics of pallet movement along the supply chain.

First of all, the choice of a pallet management strategy has economic and environmental implications for the pallet provider that can vary according to the type of supply chain and organizational model chosen. The authors of [8] focus on the challenges related to the design of closed-loop pallet management systems by means of a simulation model, underlining the difficulty related to the integration of forward and reverse flows in the supply chain due to uncertainty in the quantity and quality of reverse flows. By means of a simulation model, they compare a few scenarios with different strategies for pallet recovery (direct or postponed interchange), showing that integrating the direct and reverse flows of pallets through a direct interchange allows them to reduce internal costs.

A closer look at the reverse logistics in a pallet rental system is given by [27], who adopt an analytical model to optimize reverse pallet flows minimizing transportation costs, under circumstances of uncertain demand and transport capacity.

A relevant number of works focus on the design and analysis of pallet systems. Some of these provide conceptual models or field studies of pallet pooling systems, to identify the main issues and challenges. The authors of [28] analyze the business model of a pallet pooling system, considering market analysis, service offer, cost structure and pricing strategy. The authors of [29] consider the case of a railway pallet pool focusing on the architecture of the information system. The authors of [30,31] present the national pallet pooling system in China, while [32] focuses on the pricing strategy. The performance of the pallet provider is also investigated: [33] focuses on the environmental and economic impact of different design options and customer characteristics in pallet pooling systems, concluding that the user's behavior in pallet handling and loading can have a great influence on the environmental and economic performance of the provider. The authors of [34] show how the efficiency of a pallet pooling system can be improved by using spatial data mining, which can help with extracting knowledge about the resource used and the distribution of customers. The authors of [35,36] propose a data envelope analysis model that can be used to assess the performance of pallet rental companies. The network design problem for a pallet pool is studied by [37], who apply an analytical model to optimize the location of pallet service centers.

The optimization of pallet allocation over a system is another critical issue for pallet providers since the efficiency of this activity can greatly impact the overall performance determining the availability of pallets where they are needed and contributing to transportation costs. The authors of [38] propose a model to minimize costs considering the case of multiple pallet types in a pool, as do those of [39], who perform a multi-scenario analysis and suggest that providers should invest in demand forecasting to maximize the reliability of this kind of study. The model proposed by [40] aims at maximizing the profit of a pallet rental company while also minimizing CO_2 emissions, considering both environmental and economic costs in the objective function. The empty pallet dispatching problem in a pallet pool is addressed by [41] through an optimization model that minimizes costs, and by [42] by means of an algorithm of fractal data mining that can improve the efficiency of the pallet system. Although pallet allocation and dispatching can be a critical source of emissions if not well managed, most authors, so far, focused solely on the economic outcomes for the pallet provider, neglecting the environmental aspects of these activities.

Another problem that pallet providers must face is the traceability of pallets in a closed-loop system since high loss and damage rates of pallets can significantly increase management costs. Several authors analyze the application of RFID technology for tracing pallets in a pool: [43] details the architecture and the functions of an RFID-base pallet pool information system, while [44,45] present the related benefits through a case study. Two other works analyze, in particular, the economic efficiency of this technology, through a scenario analysis [46] or an optimization model [47], both concluding that the investment to implement an effective RFID system for pallet tracing can be repaid by lower operation costs.

The problem of traceability is strictly connected with the wider issue that three authors explore of different IT solutions for data sharing in a pallet system: [48] considers the problem of pallet exchange among different owners that relies on different platforms, and they propose a system based on the blockchain technology to facilitate trade; [49] proposes the adoption of XML technology to support information sharing along the pallet supply chain; [50] presents a pallet pooling information platform based on cloud computing architecture.

A few works consider the issue of pallet recycling in a pallet pooling system: [51] presents an optimization model to minimize the operation costs related to transportation and recycling in a closed-loop supply chain. Two papers focus on how to improve the pallet recycling process: [52] explores the impacts of preemptive remanufacturing on the economic and environmental performance of a pallet provider through an optimization model; their results show that preemptive policies can have benefits for the provider, which depend also on how well the user handles the pallet. Similarly, [11] proposes a model to develop an optimal repair–replacement strategy for damaged pallets to ensure savings for the provider.

Finally, one of the articles focuses on the environmental impact of pallet management in a pool, performing a simulation based on GIS and comparing different management scenarios: their results stress the relevance of the transportation phase, which has a high impact on the environmental performance, suggesting the importance of the integration between the pooler's and the retailer's networks [53].

4.2.3. Pallet User

The perspective of the user is adopted in several works dealing with pallet logistics problems: the user can be any actor involved in a supply chain requiring pallets to move their goods.

A first important issue addressed in the pallet literature is how a user can choose the best pallet management alternative. In [4], the authors use both analytical and simulation models to evaluate the economic side of this decision, comparing the cost for the user in three common pallet management systems (single-use expendable pallet system, buy/sell program and leased pallet pooling program), showing that a single-use expendable pallet system presents the lowest cost for the user, followed by the pooling system. However, the authors specify that their results are sensitive to cost parameters related to the user's network and the fee structure. A similar outcome is found by [54] in their study: they analyze the cost of rental and purchase pallet systems for the user through a simulation model, finding that rental pallet systems are more costly on average than purchase systems.

With a broader perspective, [55] examines the differences between US and Canadian retailers concerning their perception of pallet systems, showing how socio-political and cultural factors can influence the choice of a specific pallet system.

The problem of pallet traceability and localization is examined also from the point of view of the pallet user, with the aim of tracking their goods for preventing inefficiencies along the supply chain (e.g., bottlenecks, goods drops, etc.): several technological solutions are presented in the literature. A pallet throughout system based on RFID is proposed by [56] to improve the logistic efficiency, while [57] tests the effectiveness of an RFID system in the case study of postal logistics. The authors of [58] investigate the logistic cost associated to this solution through an activity based costing model in different scenarios. The pallet localization problem in the logistics environment is studied by [59,60], who propose, respectively, the implementation of wireless sensors networks and a Zigbee network. The authors of [61] present a system for the localization of pallets during handling operations through a camera for forklifts.

Reference [62] presents the case study of a user renting pallets for its products, with the objective of reducing the total costs related to pallets: a simulation analysis on different scenarios shows that slow-moving products can generate high costs occupying pallets for long time, suggesting that in these cases different strategies should be considered.

Finally, the economic aspects of different pallet standards are studied by [63], concluding that a standardization of types and sizes of pallets would have a positive economic impact, decreasing trade costs.

4.2.4. Pallet Repairer/Recycler

A few of the papers analyzed adopt the perspective of a pallet repairer or recycler, focusing either on the operations, or on the related environmental impacts. The authors of [10] were the first to focus on this phase of a pallet life cycle, taking a picture of the pallet recycling industry in the US at the time and of the different uses of recycled pallet materials. Reference [64] explores the recycling capacity of the industry in North Carolina, while [65] documents the status of wood pallet repair practices and equipment in the US.

The environmental impacts are investigated by [66], who assess the carbon footprint of pallet remanufacturing, showing that the behavior of the pallet user has an influence on the carbon equivalent emissions generated in the repair phase, (poorly handled pallets having a heavier impact). Finally, [67] develops a life cycle inventory (LCI) for the wood pallet repair process in the US.

4.2.5. Supply Chain

Of the 85 articles selected, 25 consider the perspective of the holistic supply chain instead of focusing on a single actor, most of them dealing with logistics problems. Three works focus on the design and analysis of pallet systems: [68] tries to analyze the complex dynamics of a pallet supply chain through an agent-based simulation model, investigating the relationship between pallet demand from users (retailers and manufacturers of goods) and the characteristics of the pallet repair market (number and capacity of repairers). The authors of [69] propose a pallet bank model describing its architecture and the management information system based on RFID. Reference [70] considers a pallet system consisting of three main components, packaging, pallets and handling equipment, they underline the importance of adopting a system-based design perspective rather than a component-based perspective, explaining the economic advantages for the whole supply chain.

The problem of selecting a pallet management strategy is investigated also from a supply chain perspective. In [71] the authors perform a simulation analysis to assess the overall economic convenience of different pallet recovery models, highlighting the need for coordination among actors in the supply chain to improve the performance, while [7] analyzes the total supply chain cost of three management alternatives (rental, transfer of pallet ownership and extensive management of pallets) through simulation. Their results show that pallet rental is more convenient in the short run, while transfer of pallet ownership is suggested otherwise. This problem is addressed also from an environmental point of view: [72] propose a model to minimize the carbon equivalent emissions related to the pallet life cycle considering three different pallet management systems, while [73] use LCA to compare the impacts of pallets of different materials in two pallet systems. Both studies highlight that the best solution has to be chosen case by case, according to several influencing factors, such as transportation distance, handling and loading conditions.

The cost of pallet management in a closed-loop supply chain is studied and optimized by [74], who use simulation and multicriteria optimization to assess different scenarios of pallet purchase and retrieving along the supply chain. The authors of [75] deal with pallet traceability in a supply chain, proposing the architecture of a collaborative platform based on IoT technologies, aiming to enable pallet tracing and information sharing along the supply chain.

Reference [76] focuses specifically on the reverse logistics of plastic pallets, proposing an optimization model to identify the optimal network design in a case study.

Several authors have performed studies on the environmental analysis of pallet management from a supply chain perspective. The authors of [77,78] proposed an analytical model to define the optimal mix of pallet types and pallet management systems to minimize the related impacts. Reference [79] addresses the issue of minimizing the environmental impact of a pallet closed-loop supply chain by means of simulation in a multi-objective optimization model. Most of the environmental analysis papers of the sample are carried out with a cradle-to-grave approach, which is typical of environmental studies (although there are economic analyses that employ the life cycle costing technique, which considers life cycle wide economic impacts [80]). This approach considers the environmental impacts related to the whole life cycle of the product (from materials extraction to end-of-life management).

Reference [2] describes the environmental concerns along the pallet life cycle, highlighting the critical issues in each phase, while [3] characterizes each phase quantitatively by using the carbon footprint method: they provide some guidelines to support the different stakeholders in improving their environmental impact. The authors of [81] present a methodology for standardizing LCA for wood pallets, aiming at providing the basis for the environmental product declaration (EPD) in the US.

Four works focus specifically on the impacts of packaging of different materials: [82] compares disposable wood pallets with reusable steel cradles through LCA, showing the advantages of this latter option. The comparison between plastic and wood pallets is performed in five LCA studies: [83,84] underline the lower environmental impacts related to wood pallets, while [85] points out that the results depend on the type of plastic and wood considered. The author of [1] focuses on the impacts during transportation and confirms the better performance of wood versus plastic. Reference [86] reviews all of the LCA studies on wood and plastic pallets, confronting methodological assumptions, and inventory data and results, concluding that plastic pallets generally have higher impacts across the different categories.

Reference [87] investigates the impact of different reuse intensities for wood pallets, recommending maintenance and reuse along the life cycle for as long as possible, as the policy with the lowest impact. Finally, two works use the pallet test case to evaluate environmental assessment tools: [88] proposes a material flow-based approach to assess sustainability of the bioeconomy, while [89] develops and tests a parametric LCI model.

5. Discussion

This review shows that pallet management research currently involves many perspectives and span different research areas. In the next subsections, we highlight a few more points specific to the stakeholder's perspective and found from the previous section analysis (see Table 3).

Table 3. Summary of the main problems addressed, decision levels involved and research gaps for each stakeholder.

Perspective	Commonly Investigated Problems	Prevailing Objectives	Prevailing Decision Levels	Research Gaps
Pallet manufacturer	Alternative materials for pallet production Efficiency of production operations	Economic Environmental Efficiency	Operational	Demand forecast Production capacity planning Evaluation of strategic partnerships
Pallet provider	Design and analysis of pallet systems IT for pallet traceability Pallet allocation problem	Economic Efficiency	Operational Tactical Strategic	Pool sizing Inventory management Real-time data management (dynamic decision making) Business model definition Network design
Pallet recycler/repairer	Assessment of recycling industry Environmental analysis of repair and recycling operations	Environmental	Operational Strategic	Economic performance of recycling operations Evaluation of strategic partnerships
Pallet user	Selection of alternative pallet systems Pallet traceability	Economic Efficiency	Operational Tactical	Inventory models for owned pallets Environmental assessment of user's decisions
The whole supply chain	Selection of alternative pallet systems Design and analysis of pallet systems Environmental impact of pallet management alternatives Environmental impact of different pallet materials	Environmental	Strategic	Design of pallet management system Network design

5.1. The Stakeholders' Perspectives

The literature on pallet management is predominantly focused on the perspective of the pallet provider (34%) and of the whole supply chain (29%), reflecting the growing diffusion of closed-loop pallet management models worldwide [33] and the need to improve supply chain efficiency [7].

Research on pallet providers' problems mostly explores the economic performance and efficiency of logistic processes, ranging from strategic level decisions regarding the design and analysis of pallet systems, to tactical and operational issues such as the adoption of IT systems for enabling pallet traceability and the pallet allocation problem, respectively. From a supply chain point of view, much attention is given to the selection of a pallet system considering economic and/or environmental objectives, the environmental impact of pallet management alternatives and of different pallet materials, and the design and analysis of pallet systems, with the main goal to minimize costs and environmental emissions.

The pallet manufacturer's perspective has been receiving discrete attention so far, with researchers focusing primarily on issues regarding the design and production phases, and exploring the related environmental impacts: in particular, typical problems affecting this stakeholder are the choice of alternative materials used for pallet production, considering their technical performance, and the improvement in the efficiency of production operations, denoting a prevailing attention for operational decisions.

The point of view of a pallet user has been explored mainly in relation to two problems: the selection of the most convenient and effective pallet system, and the opportunity to implement pallet traceability methods for a better management of the stock keeping units. The primary attention of pallet users seems to be the cost related to pallet use and the effectiveness of the pallet system adopted, while none of the works analyzed focused specifically on the environmental impacts generated by this stakeholder.

Little attention is given to the perspective of pallet recyclers/repairers (6% of the articles), with a few studies related to the assessment of the pallet recycling industry (strategic level) or the environmental analysis of repair and recycling operations (operational level). It is worth mentioning that all of these studies are focused on the US recycling/repair industry [10,64,65,67] or use data from US sites [66].

5.2. Research Gaps

Comparing the literature analysis to our domain knowledge of the pallet supply chain and operations, we identify a set of research gaps.

The perspective of pallet manufacturers is currently focused mostly on production operations, while strategic decisions are not discussed in the literature. As an example, we did not find studies on production capacity specific for pallet manufacturers, and only one article focuses on demand forecasts, despite the high variability and uncertainty related to flows of returned and repaired pallets that increase the complexity of production planning. Effective demand forecast methods could improve the economic efficiency of manufacturers and of the whole supply chain, and could also contribute to a better planning and management of resources, leading to environmental benefits and increased sustainability [23]. Another possible decision for a pallet manufacturer regards their market strategy: the increasing demand for pallet pooling can push towards strategic partnership with pallet providers in need of extra production capacity, and this choice should be evaluated in the light of its potential economic and environmental impacts.

This strategic decision can apply also to pallet recyclers/repairers, who find little space in the literature, and for which economic and efficiency objectives are completely missing in the studies reviewed: despite the increase in pallet repair practices due to the diffusion of closed-loop systems [8,65], a gap remains in the analysis of the economic performance of pallet repair and recycling operations, considering the variability of the demand and the uncertainty of pallet return flows, as well as in the evaluation of strategic partnerships.

On the pallet user side, all of the efforts analyzed are related to logistics decisions. For users, pallets are not a core competence, but assets that are functional to manage their flows, and a poor management of pallets can generate unquantified costs (economically and environmentally) [54]. However, while the externalization of pallet management to a provider and the traceability are well-studied problems for users, models to optimize the internal pallet management (for instance in a buy/sell program, or in an open-loop system) are missing. Decisions about the procurement, temporary storage and eventual disposal of owned pallets are not currently investigated. Moreover, an analysis of the environmental impacts of the use phase of pallets is missing: while the costs and efficiency of different pallet solutions are investigated in the literature from the user’s perspective, the related environmental outcomes are not analyzed nor used to support specifically the user’s decisions.

Finally, the pallet provider perspective is the most investigated so far, and yet we can identify several research gaps. Given the high uncertainty characterizing pallet flows, both in terms of demand and return flows, it could be useful for practitioners to obtain support on the decisions related to inventory management, such as pool sizing and inventory safety stock, as well as advanced forecast methods based on real-time data management. While applications of information technology for pallet tracing are presented in a few studies, the impact of the use of the collected data on pallet management efficiency has not been quantified. Most studies also take a static approach to decision making (recommending a single decision/policy), and an open research area is proposed to create new methods for stakeholders’ to instead be able to dynamically make decisions based on updated information about where pallets ended up, their repair state and where they are needed. In particular, using IoT devices that are embedded on the pallets, real-time location of the pallets can be determined, leading to a better estimation of pallet availability, minimizing of loss, and prediction of the demand for new pallets. The problem of demand estimation lies at the core of most pallet management problems such as empty pallet repositioning, pallet pricing and pallet distribution in the network. This area is evolving and researchers are developing data-driven approaches using big data for predicting demand for products in the network [90]. On the strategic level, research on network design for pooling systems is very limited. The performance of a pallet provider can be highly influenced by the characteristics of the market (demand and location of customers, as well as variability of demands), therefore models for the optimization of network design and capacity of the facilities (for pallet manufacturing and repair) could support providers on these decisions, considering that forward and reverse logistics flows must be managed at the same time [37]. Another possible research challenge is the definition and analysis of pallet pooling business models: while several case studies have been presented in literature, an analysis of the strategic decisions has not been performed yet. In particular, the process of price definition is crucial to ensure the economic sustainability of the business, but this issue has not received enough attention by researchers so far. Similarly, the relationship with key partners and stakeholders, such as smaller recyclers, producers or 3PLs that can be contracted as partners to increase the capacity of logistics and operations, should be further explored.

Finally, considering that competition in this sector happens on a supply chain level, adopting a supply chain perspective when designing a pallet management system could improve the whole system's performance [7]. However, a few works have focused on the design of a pallet management system from a supply chain point of view, and even traditional problems such as network design and facility location are not treated from this perspective.

6. Conclusions

This study systematically reviews literature in the pallet management field, with a particular focus on the perspective of the different stakeholders involved in the pallet supply chain and their economic and environmental performance. In total, 85 articles were classified and analyzed: results summarize the main problems and decisions addressed for each stakeholder in open- and closed-loop supply chains, with a further classification related to the objective pursued (economic, environmental, efficiency). The discussion section presents studied and open considerations for each stakeholder, highlighting the differences among their interests and objectives. While some of the problems described can apply to other returnable transport items, the peculiarity of the pallet life cycle and supply chain solicits the need to explore the literature focusing on this asset, and the results of the literature review provide a novel perspective based on the stakeholders' needs and decisions. This review offers valuable insights to both practitioners and academics. Practitioners can use it as a guide to the most investigated problems and decisions in the pallet management field, which could be useful to review and improve their economic and environmental performance. As an overview of what has been studied in pallet management and how it has been studied, researchers can use this review to frame future research directions to undertake.

A limitation is related to the scope of the analysis: choosing to leave some potentially interesting topics out of the boundaries of the research (e.g., pallet loading problems, mechanical tests, etc.) may have left some open research questions and insights unanswered. However, it was the authors' intent to focus specifically on logistics issues, while other type of pallet-related problems can be included in further research.

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Appendix A

Table A1. List of the papers included in the review and classification.

Authors, Year [Reference]	Perspective	Methodology	Objective
Accorsi et al., 2019 [53]	pallet provider	GIS-based simulation	environmental + efficiency
Alanya-Rosenbaum et al., 2018 [81]	supply chain	LCA	environmental
Alvarez and Ryubio, 2015 [26]	pallet manufacturer	Compound method + Carbon Footprint	environmental
Anil et al., 2020 [84]	supply chain	LCA	environmental
Bengtsson and Logie, 2015 [73]	supply chain	LCA	environmental
Bhattacharjya and Kleine-Moellhoff, 2013 [2]	supply chain	N/A	environmental
Bottani and Casella, 2018 [79]	supply chain	Simulation model + multicriteria optimization	environmental + efficiency
Bottani et al., 2015 [74]	supply chain	Simulation model + multicriteria optimization	economic
Buehlmann et al., 2009 [64]	pallet recycler/repairer	Field study	N/A
Bush et al., 1997 [10]	pallet recycler/repairer	Field study	N/A
Carrano et al., 2014 [3]	supply chain	LCA (Carbon Footprint)	environmental
Carrano et al., 2015 [72]	supply chain	Optimization model + Carbon Footprint	environmental
Chen et al., 2011 [42]	pallet provider	Optimization model	efficiency/technical performance
Chen et al., 2012 [17]	pallet manufacturer	Test case	efficiency/technical performance
Chen et al., 2019 [48]	pallet provider	Conceptual model	efficiency/technical performance
Chen et al., 2020 [35]	pallet provider	Optimization model	efficiency/technical performance
Chen et al., 2015 [34]	pallet provider	GIS spatial data mining	efficiency/technical performance
Chen and Liu, 2015 [28]	pallet provider	Conceptual model	efficiency/technical performance
Choi et al., 2020 [82]	supply chain	LCA	environmental
Deviatkin and Horttanainen, 2020 [83]	supply chain	LCA (Carbon Footprint)	environmental
Deviatkin et al., 2019 [86]	supply chain	Review	environmental
Ding and Xu, 2010 [43]	pallet provider	Field study	N/A
Doungpattra et al., 2012 [62]	user	Simulation model	economic
Duraccio et al., 2015 [58]	user	Activity Based Costing	economic
Elia and Gnoni, 2015 [8]	pallet provider	Simulation model	economic
Ewbank et al., 2020 [23]	pallet manufacturer	Fuzzy time series + clustering techniques	environmental

Table A1. *Cont.*

Authors, Year [Reference]	Perspective	Methodology	Objective
García-Duranona et al., 2016 [24]	pallet manufacturer	LCA	environmental
Gasol et al., 2008 [87]	supply chain	LCA	environmental
Gnimpieba et al., 2015 [75]	supply chain	conceptual model	N/A
Gnoni and Rollo, 2010 [46]	pallet provider	Scenario analysis	economic
Gnoni et al., 2011 [71]	supply chain	Simulation model	efficiency/technical performance
Grigolato et al., 2011 [19]	pallet manufacturer	Simulation model	efficiency/technical performance
Guzman-Siller et al., 2010 [55]	user	Field study	N/A
Hassanzadeh Amin et al., 2018 [76]	supply chain	Optimization model	economic
Jin et al., 2007 [69]	supply chain	conceptual model	N/A
Kim et al., 2009 [16]	pallet manufacturer	Test case	efficiency/technical performance
Kočí, 2019 [1]	supply chain	LCA	environmental
Li et al., 2009 [60]	user	Test case	efficiency/technical performance
Li et al., 2018 [50]	pallet provider	Test case	efficiency/technical performance
Liu and Peng, 2009 [44]	pallet provider	Test case	efficiency/technical performance
Lu et al., 2007 [56]	user	conceptual model	efficiency/technical performance
Masood and Haider Rizvi, 2006 [14]	pallet manufacturer	Finite element analysis	efficiency/technical performance
Mazeika Bilbao et al., 2010 [77]	supply chain	Optimization model	environmental
Mazeika Bilbao et al., 2011 [78]	supply chain	Optimization model	environmental
Mitchell et al., 2005 [20]	pallet manufacturer	Field study	efficiency/technical performance
Molter and Fottner, 2018 [61]	user	Test case	efficiency/technical performance
Ng et al., 2014 [25]	pallet manufacturer	LCA (Carbon Footprint)	environmental
Niero et al., 2014 [89]	supply chain	LCA	environmental
Ou and Ma, 2012 [27]	pallet provider	Optimization model	economic
Pang and Zhu, 2013 [21]	pallet manufacturer	AHP	economic + efficiency + environmental
Park et al., 2016 [65]	pallet recycler/repairer	Field study	N/A
Park et al., 2018 [67]	pallet recycler/repairer	LCA	environmental
Qinghua et al., 2009 [45]	pallet provider	conceptual model	N/A
Raballand and Aldaz-Carrol, 2005 [63]	user	Field study	economic
Ray et al., 2006 [54]	user	Scenario analysis	economic
Ren et al., 2010 [29]	pallet provider	conceptual model	efficiency/technical performance
Ren et al., 2017 [38]	pallet provider	Optimization model	economic

Table A1. *Cont.*

Authors, Year [Reference]	Perspective	Methodology	Objective
Ren et al., 2018 [47]	pallet provider	Optimization model	Economic
Ren et al., 2019 [36]	pallet provider	Optimization model	efficiency/technical performance
Ren et al., 2019 [7]	supply chain	Simulation model	economic
Ren et al., 2020 [40]	pallet provider	Optimization model	environmental + economic
Roy et al., 2016 [4]	user	Analytical model	economic
Ruebeck and Pfaffmann, 2011 [68]	supply chain	Simulation model	environmental + economic
Schweinle et al., 2020 [88]	supply chain	Material Flow Analysis	environmental + economic + social
Singh and Walker, 1995 [85]	supply chain	LCA	environmental
Soury et al., 2009 [15]	pallet manufacturer	Finite element analysis	efficiency/technical performance
Spieker and Rohrig, 2008 [59]	user	Test case	efficiency/technical performance
Tepic et al., 2012 [13]	pallet manufacturer	conceptual model	efficiency/technical performance
Tornese et al., 2016 [66]	pallet recycler/repairer	LCA (Carbon Footprint)	environmental
Tornese et al., 2018 [33]	pallet provider	Simulation model	environmental + economic
Tornese et al., 2019 [52]	pallet provider	Optimization model	environmental + economic
Vargas et al., 2019 [22]	pallet manufacturer	Field study	environmental + economic
von Lanzenauer and Wright, 1978 [11]	pallet provider	Optimization model	economic
Wattanasiriseth and Krairit, 2019 [18]	pallet manufacturer	Optimization model	environmental + economic
White and Hamner, 2005 [70]	supply chain	N/A	environmental + economic
White and Wallin, 1987 [12]	pallet manufacturer	Statistical analysis	efficiency/technical performance
Won et al., 2006 [57]	user	Test case	efficiency/technical performance
Wu et al., 2016 [39]	pallet provider	Optimization model	economic
Zhang et al., 2010 [31]	pallet provider	Field study	N/A
Zhang et al., 2012 [30]	pallet provider	conceptual model	n/A
Zhang et al., 2014 [32]	pallet provider	Optimization model	economic
Zhang and Feng, 2012 [51]	pallet provider	Optimization model	economic
Zhao, 2011 [49]	pallet provider	conceptual model	efficiency/technical performance
Zhou and Song, 2019 [37]	pallet provider	Optimization model	economic
Zhou et al., 2018 [41]	pallet provider	Optimization model	economic

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