

Maintenance policies and models: A bibliometric and literature review of strategies for reuse and remanufacturing

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ABSTRACT

Reuse and remanufacturing have been widely studied in the maintenance related literature due to the imperative of preserving resources and protecting the environment. To provide researchers with a holistic view of the existing research, there is a need to check how relevant methods have been developed. This paper undertakes a bibliometric analysis and a comprehensive literature review of maintenance policies and models that deal with reuse or remanufacturing as sustainable strategies. A total of 581 papers collected from Web of Science, Scopus, and IEEE Xplore databases were analysed. 53 of them were chosen for further investigation after four selection criteria were applied. The bibliometric analysis provided a general understanding of the publication trends while the literature review built a taxonomy that organises the related literature under the dimensions of models, businesses, and sustainable strategies, which creates novelty in the maintenance-sustainability related literature. The main contribution is the classification of related papers and identification of the main knowledge gaps, including the neglect of the environmental and social aspects of sustainability vis-à-vis the prioritisation of an economic perspective.

1. Introduction

This paper presents a bibliometric analysis and a comprehensive literature review of maintenance policies and models applied to the context of reuse and remanufacturing. Currently, maintenance models are widely applied in industries to promote better and cheaper maintenance, reliability, quality, and safety in the operating process. More recently, due to the advent of environmental concerns and the demand for sustainable operations, sustainable issues such as reusing or remanufacturing products or industrial items have been considered in maintenance modelling. In the literature, however, recent sustainable maintenance models focus their investigation on end-user products such as automobiles, rather than on the equipment used in industrial plants. As such, this paper aims to gain a clear understanding of how maintenance models and policies have been developed in the context of reuse and remanufacturing and to identify the trends and gaps in knowledge development in relevant literature.

The importance of this paper arises from three distinct facts. First, sustainability is a thematic topic, on which more studies are needed [1]. Second, maintenance models can be used to generate economic, environmental, and social benefits [2,3]. Franciosi et al. [3], for instance,

provide a Preventive Maintenance (PM) policy that minimises conventional, environmental, and social costs generated by maintenance interventions. The environmental cost is associated with the greenhouse gas emissions attributable to maintenance activities and the social cost is linked to accidents due to failures. However, maintenance models are not generally considered and designed to deal with issues from environmental and social perspectives. Third, comprehensively investigating reuse-related strategies in the context of maintenance policies and models is lacking: as described in the two following paragraphs, reuse and remanufacturing have not been widely addressed in the maintenance model related literature, which presents a significant gap since these strategies are two of the most important ways to link maintenance with sustainability.

Before delving deeply into the topic of reuse and remanufacturing, we need to recall that maintenance and sustainability have been investigated in a wider manufacturing context. Holgado et al. [4], for instance, conducted exploratory research on the impacts and contributions of maintenance models for sustainable manufacturing. The authors analysed the strategic importance of maintenance in manufacturing and discussed the economic and environmental dimensions of maintenance in a case study. Franciosi et al. [5] studied the impacts of maintenance

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on the sustainability of the manufacturing industry, provided a systematic literature review to analyse the relationship between maintenance and sustainability, and proposed a conceptual framework for measuring maintenance impacts on sustainability. Other interesting papers on measuring such impacts include [6,7]. Jasiulewicz-Kaczmarek et al. [6] proposed a multiple criteria approach to helping decision-makers (DMs) in improving economic, social, and environmental results of a system under maintenance and provided a case study to show the benefit of analysing sustainability in maintenance modelling. Their proposed method allows for assessing the level of maintenance sustainability by considering a maintenance indicator. Sari et al. [7] suggested an integrated and hierarchical framework to assist DMs to capture important perspectives when assessing the contributions of "sustainable cleaner maintenance" and aligning them with the objectives of a company. Maintenance management in terms of the economic, environmental, and social challenges of sustainable development is approached by Jasiulewicz-Kaczmarek et al. [8]. The authors indicated the latest trends in this area and described potential opportunities of data-driven maintenance technology.

More specifically, some papers have reviewed topics relating either to maintenance models and policies or to reuse and remanufacturing but none have considered both areas jointly. Maintenance models and policies in warranty management were reviewed by [9,10] provided a systematic literature review on how maintenance tasks and maintenance management strategies are changing in the context of Industry 4.0. Kerin and Pham [11] presented a literature review of the emerging digital technologies of Industry 4.0 in the context of remanufacturing, on which little research can be reported in maintenance models or policies. Diallo et al. [12] provided a review of quality, reliability, and maintenance issues in closed-loop supply chains relating to remanufacturing and focused on how these topics have been studied in the context of remanufactured or second-hand products, but they did not investigate maintenance models or policies. Additionally, other important papers that in some way relate maintenance to sustainability are as follows.

Saihi et al. [13] proposed a systematic review of modelling-based literature regarding maintenance and sustainability, organised relevant literature based on application areas and modelling assumptions and considered the combination of maintenance models with "sustainability", "energy", "Triple Bottom Line", "environment", "ecological", "green", "carbon", "emission" or "social". Karuppiah et al. [14] presented a literature review regarding the exploration of key barriers to sustainable predictive maintenance and analyse environmental, financial, organisational, and social barriers. Vrignat et al. [15] presented a literature review focused on sustainable manufacturing, maintenance policies, and prognostics and health management from a perspective of maintenance management policies.

The above brief umbrella review (i.e., a review of reviews) surveys prior related literature. It is found that there is no paper specifically reviewing maintenance policies and models for the reuse and remanufacturing of product items, which provides the motivation of us to writing this current paper and filling this gap also creates its novelty. Reuse and remanufacturing are two of the topical themes that will have to be focused on by researchers from the reliability and maintenance community in future, mainly due to the increasing need to protect the environment and to address global warming. They can also improve resource efficiency and reduce manufacturing emissions, which are the greenhouse gas emissions generated during the period that a product is being manufactured. As the European Commission stated¹: maintenance extends product's lifetime and has a higher potential to reduce the environmental impact of manufacturing. As such, providing researchers and practitioners in the reliability and maintenance community with a holistic and comprehensive review of existing research on reuse and

remanufacturing in the reliability and maintenance literature is imperative for the development of further studies.

This paper therefore presents a bibliometric and network analysis, and a literature review. The former shows publication trends, the most influential sources of publication, the most cited authors, etc. The latter emphasises the classification of the existing work in terms of the focus on product items, in terms of the model strategy, business strategy and sustainability strategy. From this discussion, further investigations are suggested based on the identified knowledge gaps.

The remainder of this paper is structured as follows. Section 2 introduces the methodology used in the paper. Section 3 presents bibliometric and network analyses. Section 4 provides the literature review. Section 5 answers the research questions and discusses the main gap in the literature. Finally, Section 6 draws conclusions and proposes future research topics.

2. Research methodologies

The research methodologies used in this paper consist of developing the bibliometric analysis and the literature review. The former is a useful instrument to analyse current trends in the literature in a particular area [16]. The latter provides a search and screening of publications and their subject [13]. The steps for developing this paper can be divided into four important points: search strategy, document selection, relevant topics for bibliometric analysis, and research questions for the literature review, as set out in the following sections.

2.1. Search strategy

The brief umbrella review presented in the introduction section identified the topics to be reviewed in this paper. In the search strategy, the keywords "maintenance model", "maintenance policy", "reuse", "remanufacturing" and "second-hand" were selected for investigation based on the following considerations.

Regarding maintenance-related terms, a "maintenance model" is the use of quantitative methods to analyse and evaluate the performance of maintenance and refers to the mathematical formulae that can be used to optimise maintenance policies [17]. A "maintenance policy" is a type of approach adopted based on the model, such as, the type and frequency of actions to be considered in maintenance [18]. Similarly, the term "maintenance strategy" is generally considered as a synonym of "maintenance policy". The terms "maintenance policy" and "maintenance strategy" are used interchangeably in the literature. As such, we only consider the terms "maintenance model" and "maintenance policy" in both the bibliometric analysis and in the literature review.

The main difference between the terms "reuse" and "remanufacturing" is that the latter guarantees the remanufactured item/product being restored as-good-as-new [19,20], whereas the former is commonly used for second-hand products [21]. Both terms are reuse-related terms and are more susceptibly associated with actions guided by maintenance models, which is the reason why they were considered in both the bibliometric analysis and in the literature review. On the other hand, "recycle" and "recover", from their definitions, are more related to processes not necessarily guided by maintenance models [22–24]. The term "repair" is not necessarily associated with a reuse action but is used in maintenance in a general approach [19].

The Boolean operators "AND" and "OR" were used to establish the link between keywords, which forms the search string: [("maintenance model" OR "maintenance policy") AND ("reuse" OR "remanufacturing" OR "second-hand"))]. This search string was adapted according to the search mechanism of the three databases used: Scopus, Web of Science, and IEEE Xplore. These three databases were selected to increase the possibilities of finding more related papers. For the same reason, the search field was defined as "all", considering all available content of the documents from these databases. Finally, articles are included in the analysis while review papers are used for double-checking whether

¹ <https://www.sciencedirect.com/science/article/pii/S0959652621006405#bib21>

other similar reviews have been previously documented. No time interval was defined to vary all possible data independently of the years of publications. Conference papers were not included in the analysis because many of them were extended and published in journals, which generally show more attractive results. For example, journal papers [25–30] had prior developments in conference papers. Some considerations on these prior developments are addressed in Section 4.3.

2.2. Document selection

The mentioned search string resulted in 581 initial articles distributed in Scopus (567 articles) and Web of Science (14 articles) databases. IEEE Xplore did not return any result, given the search strategy that was adopted and described in the last section. After acquiring the data from the two databases, we removed duplicated papers: 14 articles found in the Web of Science database were also presented in the Scopus database. As a result, the articles from the Scopus database were considered for the analysis as they represent the entire dataset of articles from the search strategy adopted. The information about the articles listed in the .csv file contains authors, title, year, source title, abstract, author keywords, etc.

The first filter of the data removed 13 review papers that were collected for a re-analysis of the studies that focused on literature reviews. Thereafter, the 554 original papers, 485 non-related articles were discarded based on the title and the abstract, which left 69 articles to be reviewed. Amongst the 69 remaining articles, 4 were not available for access and 12 were classified as not related articles. The articles discarded were on themes that are not within the scope of this literature review. Some examples are: sustainable operation, friendly production, carbon emissions, smart manufacturing, renewable energy, perishable

inventory, energy consumption, non-conforming products, production remanufacturing strategy, quality assessment of used-products, etc. As a result of the selection process, 53 papers were investigated in detail. Fig. 1 illustrates the process for selecting documents.

2.3. Relevant topics for the bibliometric analysis

The topics chosen for examination in the bibliometric analysis were as follows:

- i Publication trends: to verify the number of papers published per year over the years.
- ii Occurrence and co-occurrence of keywords: to quantify the most common keywords and check the relationships amongst them.
- iii Main and most influential sources of publication: to classify the popularity of the sources.
- iv Most influential papers: to emphasise the main papers.
- v Author influence and co-authorship: to present the influence of the main authors.

The examination of topics i, iii and iv was executed using *Microsoft Excel* due to its simplicity of organising and filtering the information from the data on the spreadsheet obtained in the Scopus database. Topics ii and v were investigated using *VOSviewer*, which is a software tool for constructing and visualizing bibliometric networks, due to the convenience in the process to obtain and analyse the required information from the Scopus file output with extension csv and due to the excellent visualisation features of this software.

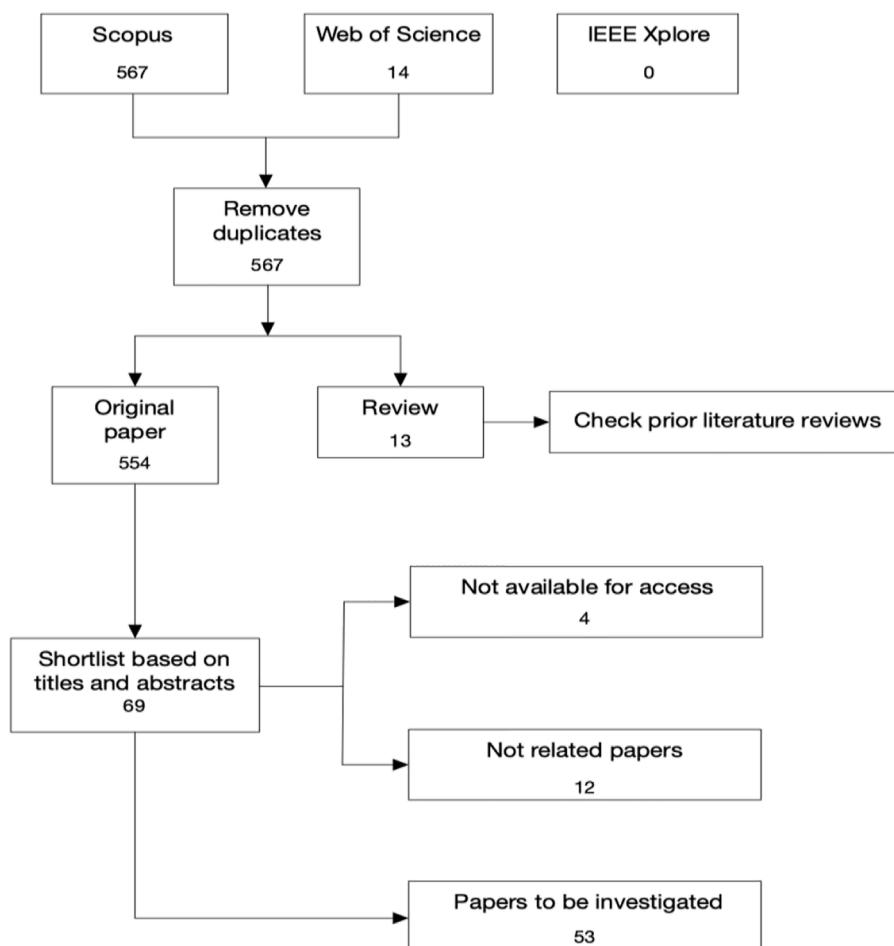


Fig. 1. Document selection process.

2.4. Research questions for the literature review

The following research questions (RQ) were formulated to guide the literature review by addressing some important topics for investigation.

RQ1: How have maintenance models and policies evolved historically in terms of consideration of reuse and remanufacturing?

RQ2: What type of model strategies have been considered over time to address reuse and remanufacturing?

RQ3: Which business strategy has been predominantly adopted in maintenance models or policies: Second-Hand Market (SHM), in-house maintenance, or leasing?

RQ4: Which sustainable strategy has been predominantly adopted in maintenance models or policies: reuse or remanufacturing?

RQ5: What has been proposed in terms of reuse?

RQ6: What has been proposed in terms of remanufacturing?

3. Bibliometric analysis

According to the research methodologies defined in [Section 2](#), the bibliometric analysis focuses on the 53 articles that deal with maintenance policies or models in the context of reuse or remanufacturing. Unlike the literature review presented in [Section 4](#), the emphasis of the bibliometric analysis is placed on the publication trends, sources of publication and influential authors. The objective is to show an overview of how many maintenance policies and models in the context of reuse and remanufacturing have been published, and their publication sources and authors.

3.1. Publication trends

The number of articles that study maintenance policies or models with a focus on reuse or remanufacturing has been increasing considerably over the last ten years. [Fig. 2](#) shows the bar chart of the numbers of original articles published. Three different phases can be considered: low, moderate, and high development. The first phase is represented by the period prior to 2010, during which a very small number of papers were published, suggesting that the context of reuse was not generally investigated in maintenance policies. The second phase is represented by the following 6 years, from 2011 to 2016, during which a moderate scientific production on this theme is observed, compared to the entire period analysed. Finally, the third phase starts with the first peak of publications with this theme in 2017 and continues until the present moment. Possible causes for this relevant growth may be associated with the advent of concerns about the impact of industries on the environment and the higher academic interest in developing strategies to improve the relationship between society and the environment.

3.2. Occurrence and co-occurrence of keywords

The frequencies of the keywords in papers can be used to easily

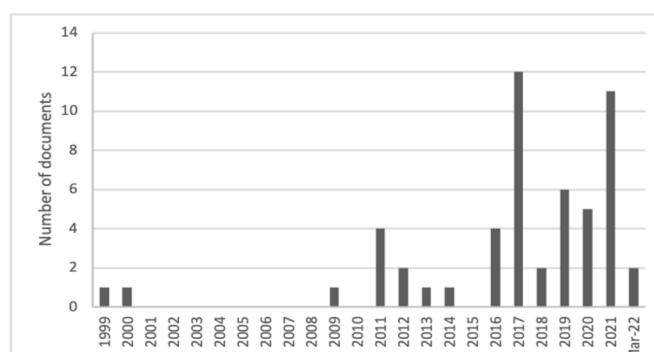


Fig. 2. Number of articles published over the years.

detect the most used terms that synthesise the articles published in a specific area. The analysis in the VOSviewer shows that, within the scope of this paper, the most recurrent keywords are: *Preventive Maintenance (PM)*, *remanufacturing*, *second-hand product*, *reverse supply chain*, *sensor embedded products*, and *warranty*. These keywords can be organised in three different clusters based on their co-occurrences, as shown in [Fig. 3](#). The first cluster (green) mainly relates to PM, remanufacturing, and reverse supply chain. The second cluster (red) relates to second-hand products with upgrade actions. The third cluster (blue) specifically relates to “mission success probability”.

3.3. Main and most influential sources of publication

The main and most influential sources of publication can serve as good indicators of journals that have been published on the theme. The first is based on the number of papers published and the second is based on the number of citations those papers had received. [Table 1](#) organises the main and most influential sources of publication and orders them by the number of papers and then by the number of citations. From the table, the main and most influential source on the theme approached in this paper is journal *Reliability Engineering and System Safety*, which contains the largest number of papers and is the source of the most cited articles, compared to other sources. Other important sources of publications can also be checked in [Table 1](#).

3.4. Most influential papers

The most influential papers, classified in terms of citations, are described in [Table 2](#). They use distinct approaches to dealing with the theme considered in this paper. From [Table 2](#), maintenance policies and warranty policies for second-hand products are seen to be a specific topic that had been extensively studied. In addition, most citations encompass papers in which the maintenance model or policy focuses on products rather than industrial items. This seems to be a trend in this area and will be further investigated in the literature review.

3.5. Author influence and co-authorship

[Fig. 4](#) shows the influence of authors considering the five most cited on the theme analysed in this paper. The analysis of influence was based on the number of citations and the number of papers. This information was collected from the Scopus.csv file using the software VOSviewer. It is important to mention that before collecting an author's data from the Scopus database, all authors' names were manually checked to avoid inconsistencies due to the name of the same author being cited in a different way in distinct articles. In total, 6 inconsistencies were found and corrected before the analysis.

Altogether, 32 authors with at least 2 papers published on this theme were identified and considered in the analysis. The most cited authors in this area are Shafiee, M., Alqahtani, A. Y., and Gupta, S. M., with the two last mentioned having the highest number of articles published: 9 articles. The set of authors with at least two published papers can be organised in terms of co-authorship in 12 clusters described in [Fig. 5](#). From this figure, it is also possible to have an idea about authors that have published on this topic more recently.

4. Literature review

This section presents the details about the relevant literature regarding maintenance policies and models in the context of reuse and remanufacturing. Two distinct assumptions are easily observed in this context. The first one refers to models that deal with the reuse or remanufacturing of product items (sold by companies in SHM or leased). This set of papers represents 68% of the papers analysed in the literature review. The other assumption, which represents 32% of the papers, refers to the product items that are used in the industrial process and can

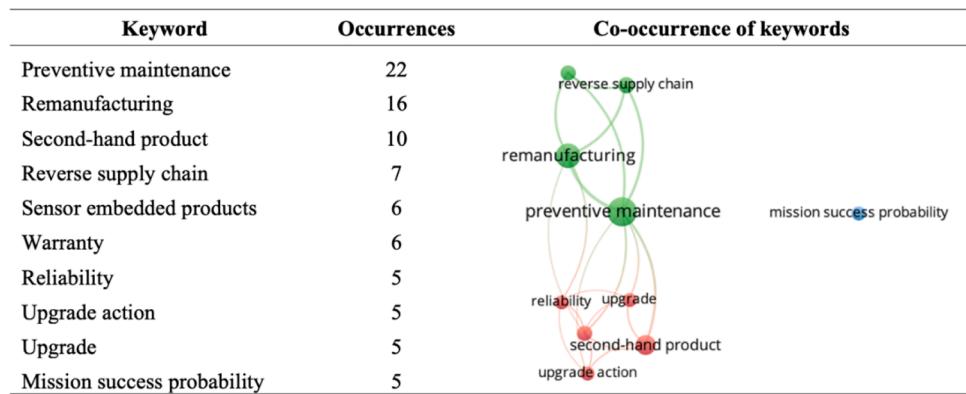


Fig. 3. Occurrence and co-occurrence of keywords.

Table 1
main and most influential sources of publication.

Journal	Number of papers	Number of citations
Reliability Engineering and System Safety	14	144
International Journal of Production Research	3	45
Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability	3	40
Computers and Industrial Engineering	2	99
International Journal of Production Economics	2	72
Journal of Manufacturing Systems	2	32
Applied Stochastic Models in Business and Industry	2	24
Open Cybernetics and Systemics Journal	2	2
Mathematical and Computer Modelling	1	74
Journal of Cleaner Production	1	44
IIE Transactions (Institute of Industrial Engineers)	1	42
International Journal of Advanced Manufacturing Technology	1	41
Quality and Reliability Engineering International	1	24
Journal of Mechanical Design, Transactions of the ASME	1	11
Journal of Intelligent Manufacturing	1	10
Others	16	62

Table 2
most cited papers.

Paper	Citations	Year of publication
Warranty cost analysis for second-hand products [31]	74	2000
A bivariate optimal imperfect preventive maintenance policy for a used system with two-type shocks [32]	53	2012
Warranty and maintenance analysis of sensor embedded products using internet of things in industry 4.0 [33]	49	2019
On optimal upgrade level for used products under given cost structures [34]	48	2011
A study of maintenance policies for second-hand products [30]	46	2011
Warranty as a marketing strategy for remanufactured products [35]	44	2017
On the investment in a reliability improvement program for warranted second-hand items [36]	42	2011
Joint determination of price and upgrade level for a warranted second-hand product [37]	41	2011
Investigating reliability improvement of second-hand production equipment considering warranty and preventive maintenance strategies [38]	28	2017
A study of quality management strategy for reused products [39]	28	2013

be reused or remanufactured to decrease maintenance costs.

In both assumptions, the papers were analysed and organised according to the following categories of analysis: “model strategy”, “business strategy”, “sustainability strategy” and “sustainability impact”. The categories “model strategy” and “business strategy” were created based on the type of strategies commonly used in the selected papers. In terms of “model strategy”, for instance, it was found that most papers consider one or a combination of the following strategies/activities getContexts: Preventive Maintenance (PM), Condition-Based Maintenance (CBM), warranty, upgrade, reliability model, and sensor-embedded products. Therefore, to provide a good classification and representation of the main strategies adopted in the models, all these important terms were considered in the two proposed taxonomies. Similarly, in terms of “business strategy”, three distinct actions were identified in the review. The first one refers to the action of repairing items “in-house” for reuse in the same facility. The second one refers to the action of repairing items for sale in a “SHM” and the repair can be performed within or outside the company. The importance in this specific classification is the objective of the repairing action, which is to prepare the item to be sold again. The third type of action relates to the “leasing” of reused/remanufactured items. In this case, the interaction between the companies during the leasing contract is generally investigated in the studies. The categories “sustainability strategy” and “sustainability impact” were defined according to the prior definition of the scope of the paper (models for reuse and remanufacturing), and according to the triple bottom line of sustainability (economic, environmental, and social perspective) [40].

Two distinct taxonomies were created to classify the current existing literature on this theme. The first directly categorises the papers from their sustainability strategy of reuse or remanufacturing (Fig. 6). This is helpful for those readers who wish to consult the models and papers relating to reuse or remanufacturing.

The second taxonomy categorises the papers based on reuse or remanufacturing of product items sold by companies or used in the industrial process and, on the categories, “model strategy”, “business strategy” and “sustainability strategy”. The category “sustainability impact” was not considered in the taxonomy since papers only focus on the economic perspective of sustainability, except for papers [2,41]. Fig. 7 shows the second taxonomy and the section in which each of its parts is analysed in this paper.

4.1. Maintenance models focused on products

Most of the papers assume the systems under maintenance are end-products when dealing with the concept of reuse or remanufacturing in maintenance models or policies. In total, 36 papers were studied. In this section, the model strategy was sub-divided into PM, CBM, warranty policies, and upgrade actions. The business strategy was sub-divided into SHM, lease, and in-house maintenance. The sustainability strategy was

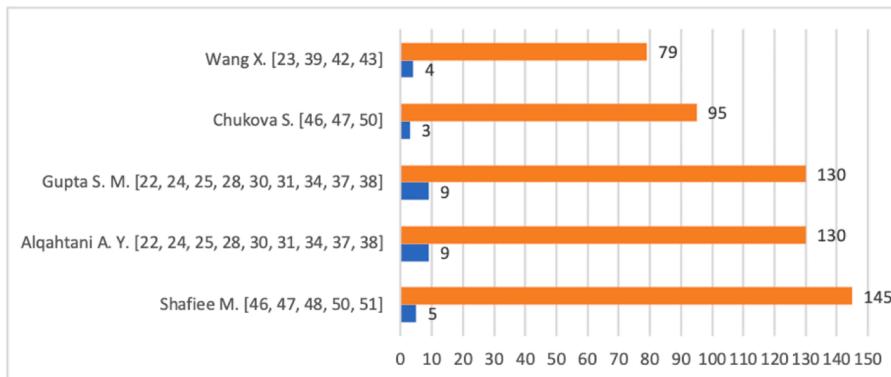


Fig. 4. top five numbers of citations per author (orange) and number of articles per author (blue).

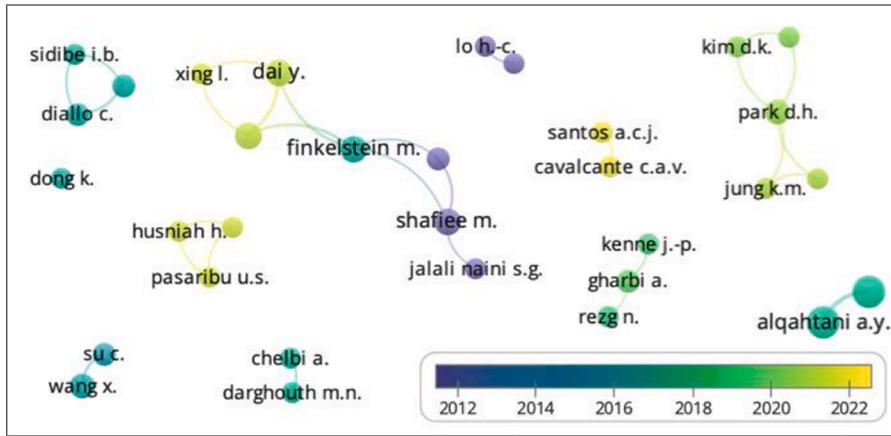


Fig. 5. co-authorship representation.

sub-divided into reuse and remanufacturing (reman). Finally, the sustainability impact was observed in terms of economic (eco), environmental (env) and social (soc) perspectives. Table 3 shows the classification of each paper in each category analysed.

As can be seen in Table 3, 83% of the papers analyse warranty policies as a model strategy for dealing with reuse or remanufacturing. 89% of them are focused on a business strategy related to the SHM. 86% consider the concept of reuse, but none of them deals with an analysis regarding the environmental or social perspectives of sustainability. A discussion on each paper is presented according to the taxonomy presented in Fig. 7.

4.1.1. Preventive maintenance (PM) and condition-based maintenance (CBM)

In this subsection, those papers that use PM or CBM in the context of reuse or remanufacturing are addressed.

Sibide et al. [28] considered a replacement policy for second-hand products that started their second life cycle in a more severe environment. Their objective was to determine the optimal replacement age by minimising the expected total maintenance cost rate in the second operating environment. Similarly, Yeh et al. [30] proposed two periodical PM policies aiming at decreasing the high failure rate of second-hand product items. Their expected maintenance cost was minimised by determining the optimal number of PM actions and the corresponding maintenance effectiveness to be achieved.

In [50,51,57], PMs were applied in the context of using the leasing strategy. In [57], PM on used equipment for lease was investigated and its associated policy was optimised by using an enumeration algorithm. The authors considered a maintenance policy based on the method for reducing the fixed failure rate. As in [28, 30], reuse was adopted as a

sustainability strategy in [57], while the following papers [49–51] considered leasing as a business strategy and adopted remanufacturing as a sustainability strategy. [50] assumed that PMs improved the reliability of the remanufactured products in the form of reducing the failure rate and that the improved reliability was still less than the reliability of a new one. In the proposed multi-period lease contract for remanufactured products, the lessor can decide the maintenance policy and the price for the lease contract; and the rate of its usage and the periods suitable to its business are available for the lessee. In [51], the case of returned-used product items in the lease contract with or without a PM monitoring option was investigated. The influence of the degradation on the failure and emission rates was used to determine the optimal PM strategy that minimised the total cost of production, maintenance, and carbon emission. A CBM policy was considered in [49] for leased remanufactured products that operate in various environmental conditions.

As can be seen, regarding the business strategy, most of the papers that used only PM or CBM policies in the context of second-hand products dealt with the leasing strategy, followed by the SHM. In terms of the sustainability strategy, reuse and remanufacturing are being undertaken with a similar frequency. Finally, sustainability impact is approached only by means of an economic perspective. This is an assumption made by all maintenance related papers on second-hand products.

4.1.2. PM, warranty policies and upgrade actions

The above-mentioned papers considered PM actions as the main maintenance strategy (CBM in [49]) in the context of reuse or remanufacturing of products. However, various papers considered PM actions in warranty policies and upgrade actions [25,26,35,38,42,43,46–48].

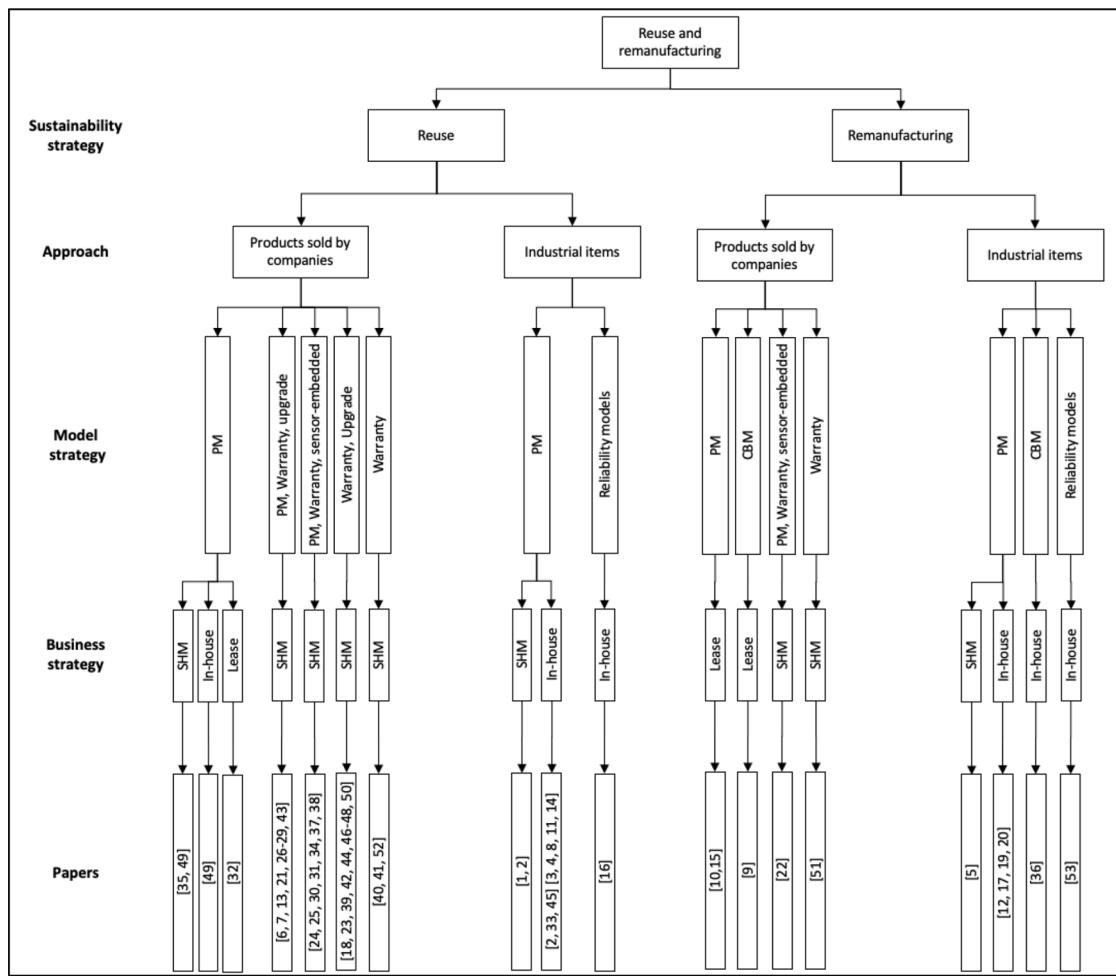


Fig. 6. Taxonomy 1 of maintenance policies and models for reuse or remanufacturing (reman).

Dai et al. [42] investigated PM strategies for second-hand products covered by a 2D warranty (which considers both the age and the usage of the product) from the perspectives of dealers and customers. Three types of PM options were considered: PM under warranty, PM during the post-warranty period, and PM over the lifespan of the product. It was also considered that free upgrade actions can be performed by the dealer before the re-sale of the product. A 2-dimensional (2D) warranty policy was also used in [47], in a product that could have a distinct degradation process due to the variation in the intensity of customer usage. Additionally, different PM strategies were considered in [38], periodic PM actions having the same efficiency level of maintenance and periodic multi-phase PM actions having a varied maintenance efficiency level. In [25], an optimal non-renewing warranty policy for second-hand products incorporated a periodic PM strategy to reduce the deterioration of the product. The optimal length of the warranty period was based on the optimizing the expected cost rate during the maintenance cycle. In [25], the concept of a full refund was considered instead of the replacement of the failed second-hand product. In [43], an optimal post-warranty maintenance policy for a second-hand product with a fixed-length warranty period was considered. During the warranty period, the product is assumed to be preventively maintained by the user. After the warranty expires, the product items are maintained by the users themselves for a fixed-length maintenance period. In [46], the sales volume was incorporated into a decision model for second-hand products subject to upgrade level, warranty, and PM policies. In [26], a post-warranty strategy with a variable self-maintenance period for the second-hand product was proposed. It was assumed that the product was replaced by another one on the first failure following a fixed length

period of post-warranty self-maintenance. In [48] an optimization model for second-hand products sold with the non-renewing free repair warranty policy was proposed. The optimal upgrade level and PM policy were jointly derived to maximise the dealer's expected profit. The upgrade action occurs at the end of the product's past life and during the warranty period whereas the PM actions occurred when the age of the product reaches a pre-specified threshold value. In [35], warranty was considered as a marketing strategy for remanufactured products. All these papers considered the SHM as the business strategy and reuse as the sustainability strategy. Additionally, the sustainability impact was considered only in economic terms.

4.1.3. PM and warranty policies in sensor-embedded products

Another classification well described in the taxonomy refers to the papers that jointly consider PM and warranty policies in the context of sensor embedded products [33,44,45,52–56].

One-dimensional warranty policies with an upgrade level were considered in [44,45] and without an upgrade level, in [33,53,54]. Two-dimensional warranty policies were considered in [52,55,56]. In [33], warranty and maintenance analysis of sensor embedded products were performed considering the concept of the internet of things. In [44], a simulation model for sensor-embedded remanufactured products was proposed considering the remanufacturer's perspective. The product is subjected to upgrade actions at the end of its life. [45] presented a similar proposal, focuses on the remanufacturer's perspective on sensor-embedded remanufactured products with an upgrade action at the end of product's past life, and adopted a combined money-back guarantee warranty policy with the PM strategy. In [53], a

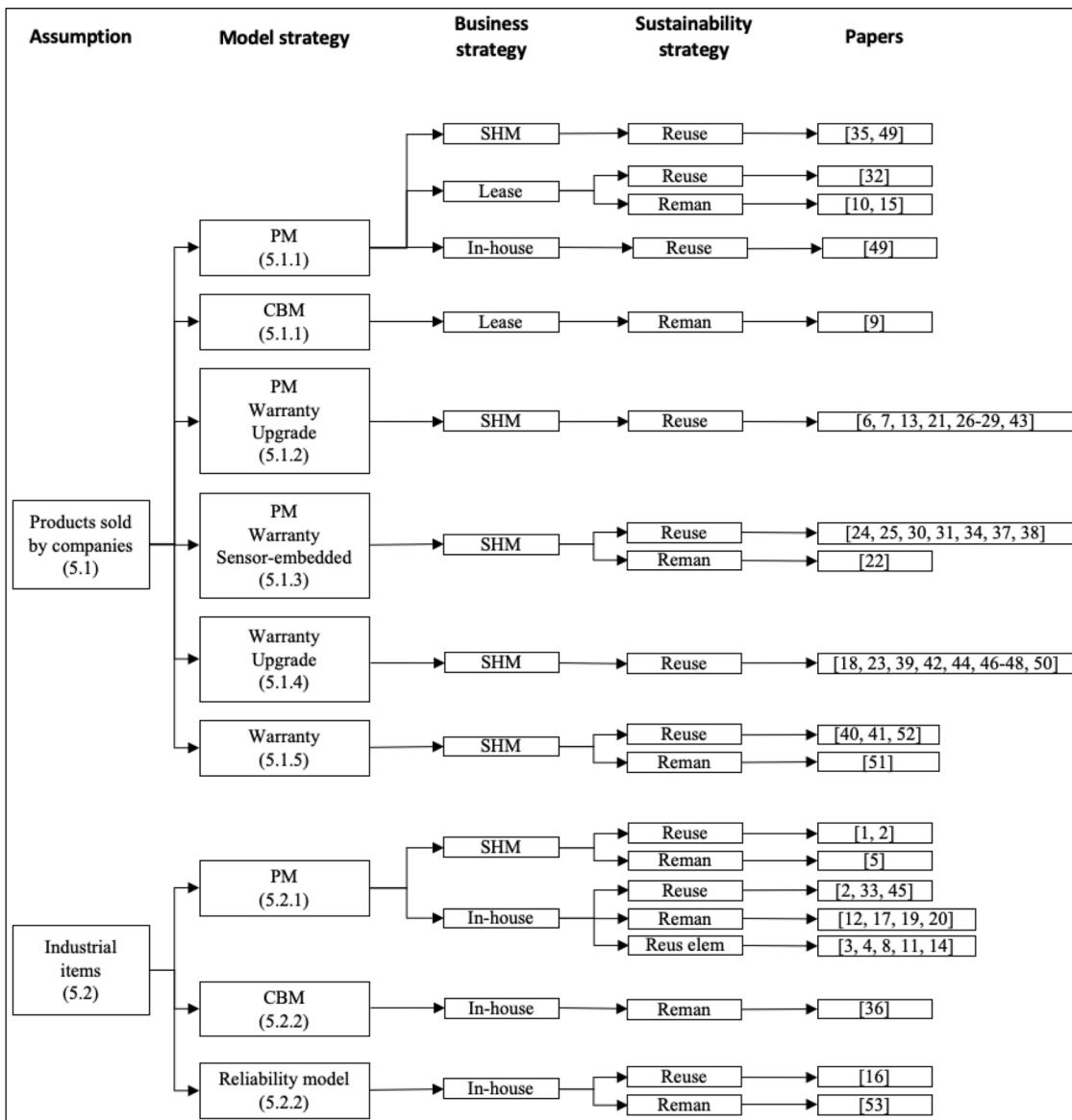


Fig. 7. Taxonomy 2 of maintenance policies and models for reuse or remanufacturing (reman).

Table 3

Papers with focus on the reuse or remanufacturing of products.

Paper	Model strategy				Business strategy			Sustainability strategy	
	PM	CBM	Warranty	Upgrade	SHM	Lease	In-house	Reuse	Reman
[25,26,38,42-48]	X		X	X	X			X	
[49]		X				X			X
[50,51]	X					X			X
[33]	X		X		X				X
[35,52-56]	X		X		X				X
[57]	X					X			X
[28]	X				X				X
[27,34,36,37,39,58-61]			X	X	X				X
[62,63,31]			X		X				X
[30]	X				X		X		X
[64]			X		X				X
Total	20	1	30	19	32	4	1	31	5
Perc	56%	3%	83%	53%	89%	11%	3%	86%	14%

combination of various warranty policies was investigated. In [54], a methodology was suggested to simultaneously minimise the cost incurred by the remanufacturers and maximise consumer confidence toward buying remanufactured products. The same authors proposed a

similar methodology in the context of two-dimensional warranty policies in [56] and investigated the impact of offering renewing warranties on remanufactured products in [52,55]. All these papers considered the SHM as the business strategy and reuse as the sustainability strategy,

except [33] that considered remanufacturing as the sustainability strategy.

4.1.4. Warranty policies and upgrade actions

A set of different papers dealt with warranty and upgrade without necessarily considering or emphasising PM actions [27,34,36,37,39, 58–61].

An optimal warranty policy for second-hand products was considered to determine an optimal length of warranty period from the dealer's point of view in [27]. The policy was based on a two-stage repair-or-full-refund maintenance strategy. In this strategy, if the failures of a product cannot be repaired during the warranty period, the user receives a full refund, and the maintenance cycle ends. In [58], an upgrade model was developed for complex second-hand systems that were sold with a non-renewing free repair/replacement warranty. The authors considered two types of components: repairable (may be imperfectly upgraded with various degrees) and non-repairable (can be upgraded only by replacement, if necessary). In [59], a pre-sale upgrade model was proposed for used repairable products sold with two-dimensional warranty policies. In [37], the authors also dealt with the dealer's point of view and proposed a decision model to determine the optimal price and upgrade strategy of a warranted second-hand product to maximise the dealer's expected profit. Similarly, the optimal expected upgrade level to maximise the dealer's expected profit per product was investigated in [34], in which the authors considered the concept of reliability improvement, also used in [60,36]. In [60], a two-dimensional free repair warranty policy was proposed to minimise the total expected servicing cost per unit sale from the dealer's perspective. In [36], the authors presented reliability improvement programs for second-hand products sold with a failure-free warranty. Both stochastic analysis and reliability improvement and an investment cost–benefit model were integrated to deal with the optimal improvement decision problem. In [39], a profit model that takes into consideration upgrade actions and minimal repair costs during the warranty period was proposed. The expected profit per used product item for the manufacturer is maximised by determining the optimal upgrade level and the length of warranty. In [61], a model to determine the optimal upgrade action that considers the trade-off between the cost of an upgrade action and the reduction of the expected warranty cost was presented. All these papers considered the SHM as the business strategy and reuse as the sustainability strategy and the sustainability impact was considered only in economic terms.

4.1.5. Warranty policies

Some papers considered warranty, without necessarily considering PMs or upgrade actions [31,62–64].

In [62], a warranty policy for second-hand products from the user's perspective was proposed. The authors introduced two types of warranties, which were the non-renewing, free replacement-repair warranty and the non-renewing, pro rata replacement-repair warranty and compared them via numerical examples. In [63], the authors proposed a warranty policy that considered a mixture of new and reconditioned components in the replacements upon failure of products under warranty. In [64], the warranty and sustainable improvement of used products through remanufacturing was analysed for used products sold with a failure free warranty. The model can be used by the dealers for deciding whether and how much to invest in remanufacturing projects. In [31], probabilistic models were developed to compute the expected cost of the warranty to the manufacturer when the items are sold with free replacement or pro rata warranties. All these papers considered the SHM as the business strategy and reuse as the sustainability strategy, except [64] which considered remanufacturing as the sustainability strategy.

4.2. Maintenance models focused on industrial items

A small number of papers deal with the concept of reuse or remanufacturing in maintenance models or policies. In total, 17 papers were found and examined. In this section, the model strategy is sub-divided into PM, CBM, reliability model, missions, and shocks. The business strategy was sub-divided into SHM and in-house maintenance. The sustainability strategy was sub-divided into reuse, remanufacturing (reman) and reusable elements. Finally, the sustainability impact was observed in terms of economic (eco), environmental (env) and social (soc) perspectives. Table 4 shows the classification of each paper in each category analysed.

As can be seen in Table 4, 82% of the papers optimise PM policies as a model strategy for dealing with reuse or remanufacturing. 88% of them are focused on a strategy associated with in-house maintenance. 41% consider the concept of remanufacturing, 29% reusable elements, and 29% reuse. Only 12% discuss the environmental perspective of sustainability. A discussion on each paper is presented as follows. First, models that consider PMs [2,32,41,65–71,73–76] are discussed in Section 4.2.1. Then, CBM model [29] and reliability models [72, 77] are reviewed in Section 4.2.2.

4.2.1. Preventive maintenance (PM)

PM is the main model strategy used in the context of reuse or remanufacturing of industrial items. Papers [65,2,76,32] considered reuse as a sustainability strategy. Papers [41,68,73–75] considered remanufacturing, and papers [66,67,69–71] considered reusable elements.

Regarding the papers that considered reuse, in [65], a maintenance policy for k -out-of- n : F systems was proposed. It included both age replacement and minor repairs as PM activities. The paper considered that some components were still usable after the replacement of the multi-component system so that they could be sold as second-hand items. In [2], a structured model to assess the viability of considering different percentages of reused items in an inventory was considered. The authors analysed the effects of the different reliability of a new item and that of a reused item in the system and discussed up to which level of reliability the reused item might differ from a new one and still be economically and environmentally viable. In [76], a model for the joint determination of the optimal acquisition age, upgrade level, and imperfect PM strategy was developed. The system could be upgraded before being put into operation. Also, it is preventively maintained at each point when its reliability reaches a minimum required reliability threshold. In [32], the authors proposed an optimal imperfect PM policy based on a cumulative damage model for a used system with initial variable damage. The used system is subject to shocks that can yield a random damage to the system or cause the system's failure. The PM policy is then based on both planned time and the number of shocks.

In terms of remanufacturing, the authors in [68] developed an integrated methodology to optimise maintenance, remanufacturing, and multiple spare part strategies (new and remanufactured exchange) in a multi-component system with dependencies. [41] modelled the possibility of reuse of an item, considering its defective condition, based on the delay time concept. The model may be applied to any item that wears out over time and that may be replaced by a new one or by a refurbished item. As in [2], the environmental perspective of sustainability was also taken into consideration in [41] as the authors reinforced the importance of reusing items to the environment, instead of just demonstrating their economic benefits. In [73], a simulation-based experimental methodology was used to determine the optimal PM frequency and buffer allocation in a remanufacturing line. In [74], the authors dealt with the control of a hybrid manufacturing-/remanufacturing system subject to failures. The model considered the heterogeneity of returned products in the deterioration of the remanufacturing machine. Imperfect repair and replacements were also considered in the policy. Similarly, the variation of type and quality of

Table 4
Papers with focus on the reuse or remanufacturing of industrial items.

Paper	Model strategy PM	CBM	Reliability model	Mission	Shocks	Business strategy SHM	In-house	Sustainability strategy Reuse	Reman	Reusable elements	Sustainability impact Env
[65]	X					X	X	X			X
[2]	X					X	X			X	X
[66,67]	X					X	X			X	X
[68]	X					X		X		X	X
[69–71]	X					X		X		X	X
[41]	X					X		X		X	X
[72]						X		X		X	X
[27,73–75]	X					X		X		X	X
[76]	X					X		X		X	X
[29]						X		X		X	X
[32]	X					X		X		X	X
[77]						X		X		X	X
Total	14	1	2	5	29%	4	2	15	5	7	17
Perc	82%	6%	12%	29%	24%	12%	88%	29%	41%	29%	100%
											2
											12%

returned products was considered in [75]. In this paper, a combined optimisation of manufacturing, remanufacturing and maintenance policies was considered, and PM was used to recover the machine availability of the remanufacturing system.

Regarding the papers that consider reusable elements, [66] modelled the probability of mission success of a standby system with reusable elements and an imperfect storage unit. Similarly, [67] modelled a dual-unit standby system with non-identical, reusable units that performed the mission task alternatively according to a schedule of replacements and maintenance. In this system, when one unit is operating online, the other unit undergoes maintenance. [70] and [69] considered, respectively, homogeneous, and heterogeneous warm-standby systems that perform missions of a fixed duration. In both papers, the system operated in a random environment subject to shocks while preventive replacement was used to reduce the probability of an operation failure. After replacement, elements can be reused as standby elements. In [71], the same idea was considered for a homogeneous cold standby system.

As can be seen, most papers that used PM as the main model strategy also considered in-house as the business strategy, which means that reuse or remanufacturing is seen as an activity that can be developed within the process without the need to sell or acquire reused items. Additionally, the main sustainability strategy was remanufacturing, followed by reuse and reusable elements. Finally, it is important to mention that from all papers analysed in this literature review, only [2, 41] reinforced the importance of reuse in terms of the environmental perspective.

4.2.2. CBM or reliability model

Only a few papers used CBM or reliability models as the model strategy for reuse or remanufacturing. Hence, those different model categories were examined together in this section.

Regarding the CBM model, a condition-based replacement policy was considered in [29] to maintain a system subject to stochastic degradation. In the model, spare parts can be either new or used. In terms of reliability models, [72] proposed a model considering the failure probability of a used component in a new piece of equipment. The model was analysed using historical data and the authors showed that the reuse of components could make an improvement to the reliability of the equipment. [77] suggested a reliability model that facilitates design for reuse of items. This model can be used to estimate life-cycle replacement requirements for remanufactured systems, thus facilitating decisions during the stage of system design and use. All these papers considered in-house maintenance as the business strategy and just focused on the economic perspective of the sustainability impact.

4.3. Research in conference papers

It is important to notice that some conference papers represent an early stage of development towards more robust journal papers. For instance, [30] was previously presented in [78,25,27] and [28] was previously developed in [79,80] while [28] arose from [81,29] from [82–84] and [26] from [85]. The developments related to these conference papers are briefly mentioned in this section, as are two other important papers due to their direct consideration of environmental and/or social aspects in maintenance models [3,86].

Concisely, warranty policies were investigated in [79,80,85] and upgrade levels were investigated in [81]. The problem of spare parts returns was addressed in [82–84]. Regarding the consideration of environmental and social aspects in maintenance models, Santos et al. [86] proposed a delay time model that comprises two defective states in which the item can be reused if the minor defective state is detected, and the item cannot be reused if the major defective state is detected. Furthermore, Franciosi et al. [3] provided a periodic PM model that minimised conventional, environmental and social costs generated by maintenance interventions. These papers emphasised that maintenance policies and models have also been discussed in relevant conferences

and events, which suggested important directions for future investigations. Some of the discussions presented have already been upgraded and converted into published papers, which have already been considered in the literature review of the present paper.

4.4. Characterising and comparing the most cited policies

This section provides an important characterisation of the five most cited maintenance policies/models in the reuse/remanufacturing field. A general view on each policy is succinctly presented along with their main assumptions and objectives. Finally, some considerations in terms of applicability are provided. The reader is referred to the original papers for more details.

Table 5 provides succinct yet very informative information on the following important aspects of the models/policies: general idea, main assumptions, main objective, and applicability.

From **Table 5**, it is noted that the most cited papers have proposed PM and/or warranty policies for second-hand items that are to be sold again in the market. In terms of applicability, the policies can be applied to systems that companies consider it is important to reuse. Depending on the context, a specific policy may be more appropriated. For instance, in the case of a system subject to variable damages, one alternative is to apply the method adopted in [32]; and in the case of a system that needs upgrading before resale, an alternative is to consider the method suggested in [34]. A similar analysis can be easily performed for the other papers that were reviewed. The reader can take advantage of **Figs. 6** and **7** or **Tables 3** and **4**, to select the set of papers that are more relevant for each individual's particular case.

5. Research questions and gaps to be investigated

In this section, the research questions set out in **Section 2.4** are answered based on the insights obtained from the bibliometric analysis and from the literature review. The main gaps also identified which future research should investigate.

5.1. Response to the research questions

In **Section 2.4**, six research questions were formulated to guide the literature review and address important topics to be investigated. The answers to all of them can be concisely and directly observed as follows based on the prior analysis presented in **Sections 3** and **4**.

RQ1: How have maintenance models and policies evolved historically in terms of consideration of reuse and remanufacturing?

This question aims to give a more general view in terms of all aspects analysed in this paper. This ranges from the assumption used by authors to the model strategy, business strategy and sustainability strategy. Analysing the papers according to the date of publication in **Fig. 8**, we can easily see that both assumptions focused on product items sold by companies and on product items that are used in the industrial process and were traditionally used over the years. Similarly, the model strategy of adopting warranty and upgrade action was generally adopted over the years. PM policies were beginning to be focused on their application in 2012 in the context of reuse and remanufacturing. Regarding the sustainability strategy, both reuse and remanufacturing were widely undertaken over the years. This demonstrates that the different strategies adopted by the authors are more related to the context of the problem analysed than to a tendency of applying one or other strategy. Traditional strategies, such as PM, warranty policies and upgrade actions, which have been studied for a long time are still being applied in the most varied applications. An analysis on the model strategy, business strategy and sustainability strategy over the years is presented in a more detailed way in the next three research questions.

RQ2: What types of model strategies have been considered over time to address reuse and remanufacturing?

Most of the model strategies considered in the analysis of the papers

Table 5
Characterising and comparing the most cited policies.

Paper	[31]	[32]	[33]	[34]	[30]
Policy Main idea	Warranty policy Probabilistic models are developed to compute the expected warranty cost to the manufacturer when the items are sold with free replacement or pro rata warranties	PM policy To investigate an optimal imperfect PM based on a cumulative damage model for a used system with initial variable damage.	PM and Warranty To investigate warranty and maintenance of sensor embedded products using the internet of things.	Warranty/upgrade To analyse how the dealers can carry out overhaul and upgrade actions in used products before their release.	2 PM policies To provide two alternatives of maintenance policies to be applied to second-hand products.
Main assumptions	<ul style="list-style-type: none"> The system is subject to shocks (minor or catastrophic); Every failure results in a warranty claim; All warranty claims are valid; The time needed to carry out the rectification is negligible; Dealer sells each item as (without any upgrade action). 	<ul style="list-style-type: none"> The system undergoes PM at a planned time T. 	<ul style="list-style-type: none"> Internet of Things is a facilitator of planning for both warranty and maintenance products; End-of-life product is subjected to PM when the product's remaining life reaches a pre-determined value. 	<ul style="list-style-type: none"> Two types of upgrade action: minimal repair and complete repair; The upgrade action improves the reliability of the item; The cost of the upgrade action depends on the age and the upgrade level; All failures in the warranty policy are rectified by the dealer at no cost to the buyer. 	<ul style="list-style-type: none"> Model 1: Degree of PM is assumed to be equal in each PM action; Model 2: at each considered epoch, the age of the product is evaluated and, if it exceeds a threshold value, a PM action is carried out.
Main objectives	To determine the optimal warranty cost.	To obtain the optimal PM schedule that minimises the expected cost rate.	To maximise the expected profit for the remanufacturer.	To obtain the optimal number of PM actions and the corresponding degree of maintenance to minimise the expected maintenance cost.	To determine the optimal number of PM actions and the corresponding degree of maintenance to minimise the expected maintenance cost.
Applicability	Manufacturers that sell second-hand items associated with a specific type of warranty.	Used systems subject to variable damages.	Remanufactured products sold with one-dimensional warranty.	Used systems to be upgraded before resale.	Second-hand products to be used for a pre-specified period.

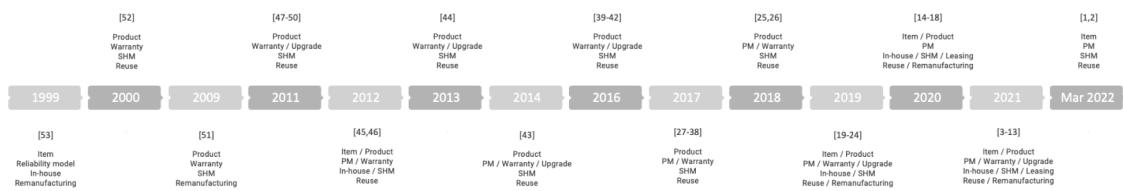


Fig. 8. Timeline of reviewed papers and their most common strategies.

have been extensively used over time. However, three of them have a considerable importance due to their recurrence in many different papers. Fig. 9 shows the number of papers that consider each model strategy over the years. The most common model strategies are PM, warranty and upgrade. As shown in the last section, they can be used together or separately according to the context analysed. Generally, they are used together in the context of second-hand products to be sold in

SHM. Alternatively, they can also be considered separately, for example, applying PM policies in the maintenance of second-hand industrial items.

RQ3: Which business strategy has been predominantly adopted in maintenance models or policies: SHM, in-house maintenance, or leasing?

Regarding the business strategies considered, the SHM and in-house

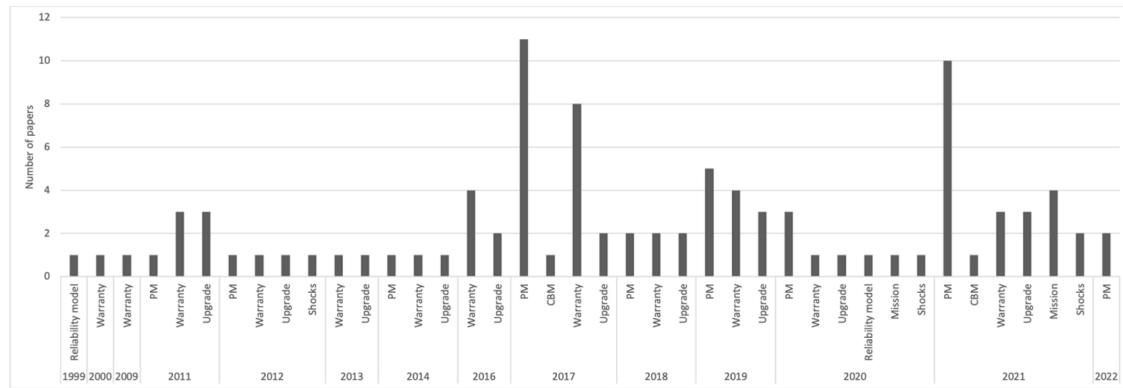


Fig. 9. Application of model strategies since 1999.

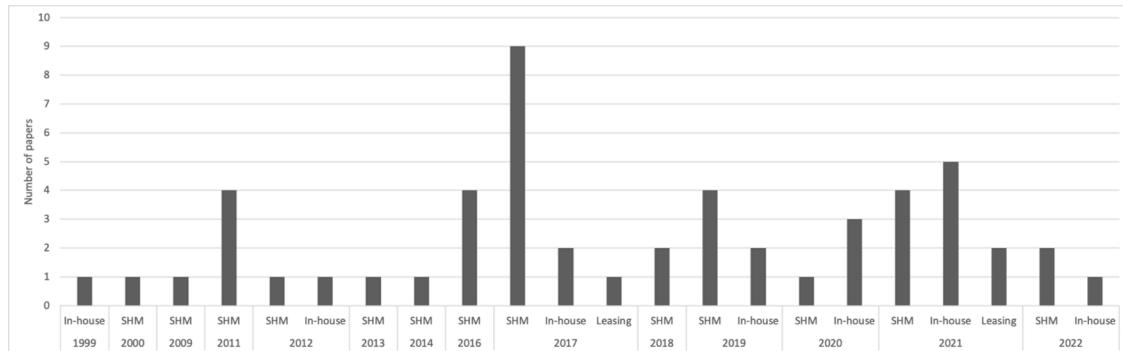


Fig. 10. Application of business strategies since 1999.

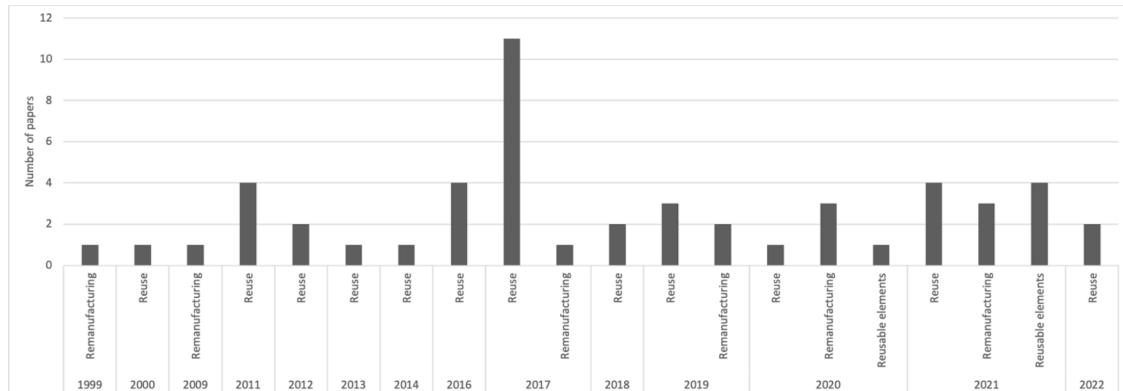


Fig. 11. Application of sustainability strategies since 1999.

maintenance are the ones predominantly adopted over the years (Fig. 10). It was also verified that adopting the business strategy is related to the type of assumptions considered in the model. For models that consider the assumption focused on products sold by companies, the SHM strategy has been extensively applied (89% of the papers). On the other hand, models that consider the assumption focused on the reuse of industrial items generally adopt the in-house maintenance strategy to gain economic advantages.

RQ4: Which sustainable strategy has been predominantly adopted in maintenance models or policies: reuse or remanufacturing?

Both strategies, reuse, and remanufacturing, have been considerably used over the years (Fig. 11). However, the reuse strategy has been studied in more papers. In total, 86% of the papers considered the reuse as the sustainable strategy when the assumption focused on products sold by companies is considered. Considering the papers focused on industrial items, almost 60% of them adopt the reuse strategy (reuse or reusable elements in Table 4).

RQ5: What has been proposed in terms of reuse?

As can be seen in Table 3, the concept of reuse has been predominantly applied as a sustainability strategy in PM, warranty and upgrade models for products sold in SHMs. Also, it has been applied in PM models developed to consider the possibility of in-house maintenance of industrial items that can be repaired so as to be reused again (Table 4). Both types of applications were described in Section 4. For reference, papers that deal with reuse can be easily identified in Tables 3 and 4.

RQ6: What has been proposed in terms of remanufacturing?

In terms of remanufacturing, the concept has been predominantly applied as a sustainability strategy in PM models for used products sold in SHMs or for industrial items. Those papers that consider remanufacturing as the sustainability strategy are also identified in Tables 3 and 4. Each of them was described in Section 4, according to the taxonomy previously proposed.

5.2. Main gaps to be investigated

The main knowledge gap identified in the literature is the neglect of environmental and social perspectives of sustainability, regardless of the sustainability strategy adopted (reuse or remanufacturing). As observed in Tables 3 and 4, only two journal papers consider the environmental aspect of sustainability [2,41] and none of them considers the social aspect. Environmental and social aspects were mentioned in [3], which is an important source that illustrates how environmental and social costs can be linked to maintenance models. This result points to an interesting finding: although sustainable strategies have been considered in maintenance models (the mathematical formulation that aids in the definition of the optimal action to be performed) and policies (the type and frequency of action adopted based on models), especially more recently, the motivation for using these strategies has purely had an economic view. Even those papers that support environmental questions [2,41] develop them based on a conjecture from an economic analysis. Therefore, the consideration of the triple bottom line of sustainability [40] that encompasses not only economic but also environmental and social perspectives is the main theme to be investigated in future studies.

The impact of dedicating more attention to the currently neglected social and environmental dimensions of sustainability has the following relevant implications that are worth emphasising:

- Possibility of complying with new environmental legislations (this topic has been increasingly investigated by governments to reduce the negative environmental impact on the soil, air, etc.);
- Incorporate recent environmental themes that can trigger developments and new contributions to the environmental policy of the companies. For instance, Wu, Wu and Peng [87] consider greenhouse emission in maintenance optimisation and suggest that further developments are needed in this area.

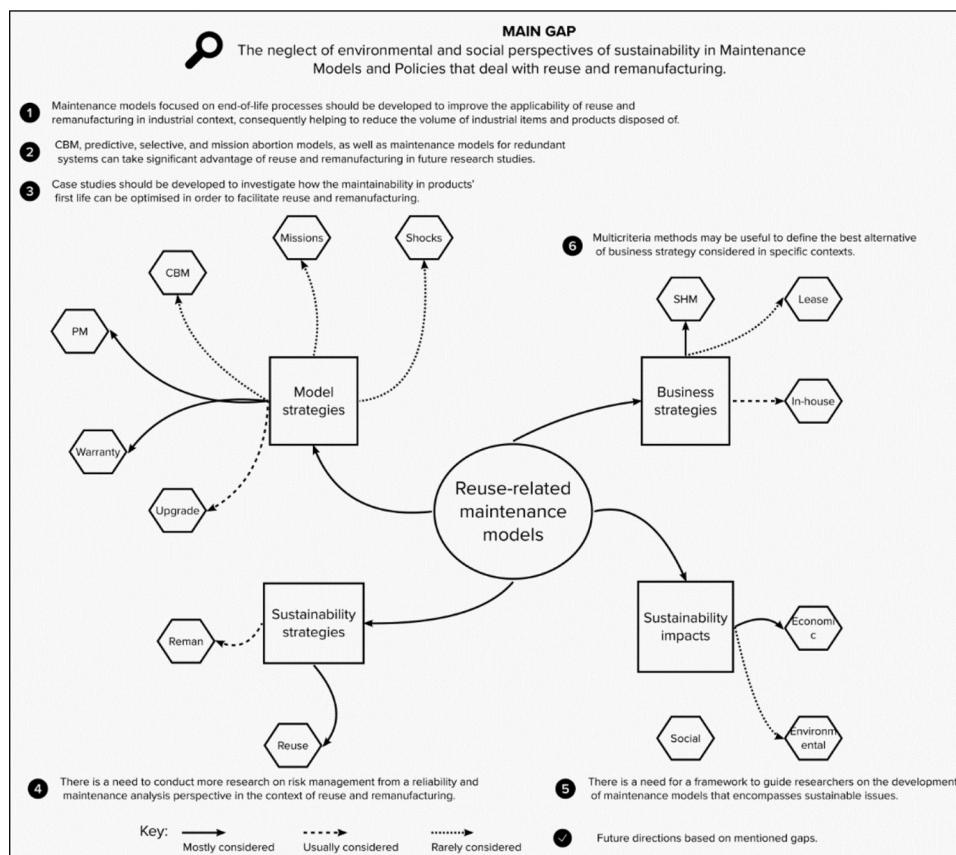


Fig. 12. Mind map with directions for future studies.

- Take advantage of all positive marketing related to the development of environmental and social friendly actions.

More specifically, some relevant gaps inferred from the literature review are now numbered as follows.

Gap 1: One of the main purposes of reuse and remanufacturing is to reduce the disposal of industrial items or products. To this end, more incisive development of mathematical models to deal with the end-of-life processes must be undertaken to.

Gap 2: Despite the increase in investigating maintenance policy optimisation for second-hand products in recent years, there is a need for more development of optimisation maintenance policies.

- Since many systems such as bridges and water networks were built many decades ago and they are approaching the end of their design lives, there is a need to develop approaches that assess their conditions with a view to reuse and repair.
- New investigations may be considered on how new and reused components with distinct reliability affect the lifecycle cost and system availability. Also, new investigations may be considered on maintenance models for redundant systems: measures like “component maintenance priority” [88] can help to establish which components may have redundant second-hand components.
- Selective maintenance models: new investigations may usefully consider the effect of replacement action between missions with new, remanufactured, and reused components.

Gap 3: More case studies on reuse and remanufacturing should be conducted.

Gap 4: There is a need to establish frameworks for characterising general environmental and social costs associated with maintenance for the purpose of reuse and remanufacturing.

Gap 6: Multicriteria decision-making methods may be useful for defining the best alternative of business strategy considered in the context of reuse and remanufacturing.

The mind map in Fig. 12 summarizes and illustrates the future directions based on these numbered gaps.

6. Conclusions

This paper presented a bibliometric analysis and a literature review of maintenance policies and models applied to the context of reuse and remanufacturing. These topics have not been previously investigated holistically with the approach adopted in this work. First, the importance of the paper was commented on in the introduction. Then, the search method was developed and justified to obtain a suitable selection of documents. In total, 581 articles were initially obtained from different databases and 53 were selected for further investigation.

The bibliometric analysis showed that the journal *Reliability Engineering and System Safety* is the main and most influential source of papers. Although the number of studies is still limited, there have been an increasing number of published papers in the last five years, which suggests the importance of the integration of reuse and remanufacturing in maintenance models and policies.

The literature review indicated that these concepts can be investigated by considering a combination of different strategies, depending on the context analysed. In general, two broader perspectives are: to apply reuse or remanufacture to products sold by companies (to SHM) or to industrial items (used within the company's operation). In addition, it is interesting to note that distinct types of maintenance models and policies have successfully incorporated the reuse or remanufacturing concepts to reduce maintenance-related costs.

The main finding of this paper is as follows. Although reuse and remanufacturing are sustainable approaches that can address environmental concerns and improve this dimension of sustainability, they are rarely used to directly promote positive environmental impacts. In fact,

the economic perspective drives the studies and analysis. As a result, the investigated maintenance models and policies have proposed and implemented useful and insightful ideas but have not used the full potential of reuse and remanufacturing approaches.

Consequently, the main gap in the related literature was identified as the neglect of environmental and social aspects of sustainability due to the emphasis on the economic perspective. This result does not mean that the neglected aspects cannot be improved by the application of the models. In contrast, it does suggest that the current advance in these aspects comes marginally from improvements in the economic perspective, the one that has been driving the path of the development of maintenance models in this specific context.

This important gap can be considered as an opportunity for future studies to investigate the economic, environmental, and social dimensions of sustainability in maintenance models and policies. From the academic perspective, a series of interesting new ideas can be generated and implemented, consequently enlarging the current scope of maintenance. Some possible extensions for this purpose were indicated considering different types of maintenance models and policies. From the industrial perspective, companies can make use of environmental benefits to attend new markets and new legislation and to provide a better image of themselves to their clients. Finally, from the social perspective, the entire society can benefit from both economic and environmental improvements promoted by fully incorporating reuse or remanufacturing into maintenance models and policies.

A limitation of the paper is the focus on the types of strategies adopted by maintenance models and policies to incorporate reuse and remanufacturing approaches rather than to study how to apply each one of them. This focus was defined because this paper is the first one in this field. Future investigations can select more models and precisely investigate their possible applications. Finally, this paper did not cover the topic of corrective maintenance, for which the reader is referred to [89] for an example. The authors have endeavoured to ensure that this paper is reasonably complete. However, those papers that are not included were either considered not to bear directly on the topic of the review or were inadvertently overlooked.

CRediT authorship contribution statement

Augusto César de Jesus Santos: Writing – original draft, Formal analysis, Conceptualization. **Cristiano Alexandre Virgílio Cavalcante:** Writing – review & editing, Supervision, Funding acquisition. **Shaomin Wu:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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