

Review

A Systematic Literature Review on Environmental Sustainability Issues of Flexible Packaging: Potential Pathways for Academic Research and Managerial Practice

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Abstract: The purpose of this review is to investigate environmental sustainability issues of the flexible packaging (FP) segment of the packaging industry. Increasingly, waste and pollution caused by FP have become a significant challenge for global sustainable development. Prior research studies have examined a diverse set of environmental challenges associated with FP, albeit, in a fragmented way. There is a paucity of research exploring and synthesizing the environmental burden of FP in an integrated fashion. To bridge this knowledge gap, we conducted a systematic literature review (SLR) to identify, synthesize, and analyze the environmental sustainability issues of FP utilizing the SCOPUS database. Based on an in-depth critical analysis of selected articles, this paper provides novel insights to scholars, practitioners, and policymakers for developing an improved understanding of environmental issues of the FP sector. This paper promotes academic scholarship and strengthens managerial practice in addressing the environmental sustainability challenges of FP.

Keywords: environmental issues; sustainable development; flexible packaging; plastic waste; recycling



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1. Introduction

Flexible packaging (FP) is an emerging sector in the manufacturing industry that provides efficient ways of processing various materials including plastic, paper, and aluminium foil that fulfil the requirements of packaging different products [1,2]. The packaging criteria comprise shelf-life, cost, safety, and flexibility throughout its life cycle [3]. Due to its characteristics of lightweight, low cost of production and transportation, and increasing shelf-life, FP has gained a major market share as compared to rigid packaging (e.g., bottles, jars, and soda cans) [4].

Environmental sustainability refers to “a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity” [5] (p. 5). It addresses the environmental issues related to emissions, waste, pollution, and natural resource depletion to maintain and preserve the environment on a long-term basis [6,7]. Among the different manufacturing sectors in the processing industry (such as paper and pulp, dairy, rubber, and cement), FP is recognized as a significant contributor to environmental waste due to the use of packaging materials such as plastic, inks, solvents, and adhesives. The packaging industry consumes 37% of the total plastic and its demand is continuously increasing [8,9]. Both developed and developing countries are facing environmental sustainability problems originating from FP operations [10,11]. Some of the key environmental issues associated with FP materials include toxic chemicals production, resource depletion, and solid waste generation due to a lack of recycling and sustainable packaging materials

availability [1,3,12]. The spread of FP material waste leads to issues such as blockage in the drainage systems, ingestion by animals, and soil depletion. The presence of macro, micro, and nano plastics causes air pollution, water pollution, and soil infertility, affecting plants, animals, and humans. In essence, FP is responsible for environmental issues including acidification, climate change, marine pollution, eutrophication, ozone depletion, and freshwater toxicity [3]. These issues get escalated due to a lack of waste treatment facilities in manufacturing plants and municipal corporations [8]. In 2015, around 4.1 megatons (Mt) of macro plastics entered the environment from the mismanaged municipal solid waste in developing countries [13]. Further, in the United States (US), plastic packaging waste accounts for 41% of total municipal waste, of which only 8% is recycled, 76% is sent to landfill, 14% is combusted, and 2% is leaked into the natural environment [14,15]. While the FP materials have the potential of recyclability, only a small quantity (14%) is recycled worldwide [16] due to the several challenges faced by this industry such as material structure; lack of technological advancements; and material recovery, collection, and sorting issues [3,10]. Moreover, a large quantum of plastic ranging from 55 to 158, 155 to 413, and 29 to 78 kilotons (Kt), entered the Caspian Sea, Persian Gulf, and the Gulf of Oman, respectively, from the surrounding lands and is projected to increase by 15, 29, and 38% by 2030, respectively [14,17].

FP is effectively fulfilling the consumer requirements of product safety and long shelf-life. Nevertheless, the environmental sustainability aspects must be considered along with the economic performance to achieve lower costs in production and ease of transportation due to lightweight and low volume [13,18,19]. While several recent studies have investigated emerging environmental sustainability issues concerning FP and have emphasized mitigation strategies for overcoming environmental challenges [20–22], the academic scholarship and managerial practice remain fragmented and isolated in this particular research domain. For example, Ahamed et al. [3] examined environmental sustainability issues of the mismanaged post-consumer FP waste such as marine pollution, air pollution, and soil infertility, and demonstrated different waste management techniques including incineration, landfill, and recycling. Kliopova-Galickaja and Kliaugaitė [1] investigated the environmental sustainability issues including volatile organic compounds (VOCs) (e.g., ethanol, ethyl acetate, and isopropyl alcohol) emissions, energy use (e.g., electrical and thermal energy), and greenhouse gas (GHG) emissions (e.g., carbon monoxide (CO) and nitrogen oxides (NO_x)) linked with the manufacturing processes of FP. However, there is a dearth of research that has examined the greening of FP holistically and explored the environmental impact of this segment of the packaging industry. To the best of our knowledge, there is no other such research work available that investigates the environmental burden of FP. There is a dearth of literature that examines potential solutions to address these issues through a comprehensive literature review and develop holistic insights on environmental sustainability aspects of this industry. To bridge this knowledge gap, the primary objective of this review article is to identify, synthesize, and critically examine the key environmental issues associated with FP and propose potential solutions for reducing environmental problems. Therefore, this paper addresses the following research question (RQ).

RQ. *What are the critical environmental sustainability issues arising from manufacturing and use of flexible packaging products and how could these be mitigated?*

The remainder of the paper is structured as follows. Section 2 presents an overview of FP and its manufacturing processes. Section 3 explains the research methodology of the paper, which is the systematic literature review (SLR). Section 4 presents the descriptive analysis of the selected articles followed by emerging environmental sustainability issues of FP and potential pathways for effectively addressing these issues. Section 5 considers a discussion on the SLR results and research gaps, which is followed by a conclusion section.

2. An Overview of the Flexible Packaging

FP is widely used in the storage and packaging of consumer goods including food, chemicals, medicines, beverages, and electronics. Various types of bags, pouches, films, sachets, and squeezable containers are the different pack categories of FP [21]. The objective of FP is to maintain product quality during the process of distribution, storage, sales, and consumption [23,24]. Among different materials, plastic is much used (about 76.8%) in the manufacturing of FP as compared to paper (11.4%) and aluminium (9.8%) [25]. A variety of plastic substrates can include LDPE (low-density polyethylene), BOPP (biaxially oriented polypropylene), OPP (oriented polypropylene), PET (polyethylene terephthalate), and HDPE (high-density polyethylene).

FP may comprise a single-layer film that uses only one film or a multi-layer structure in which two or more films are laminated with the use of adhesives. The selection of using a single-layer or multi-layer film depends on the attributes of the consumer products related to their protection and shelf-life requirements. For example, to extend the shelf-life, a high barrier film is laminated between the printing layer and sealing layer, enhancing protection [2]. In multi-layer film structures, different polymer layers are laminated to improve the package functionality with lamination of 2–17 layer films using these structures [22,26,27]. The multi-layer films provide satisfactory results and protect the product from moisture, light, and oxygen [21]. Further, the low cost of production, ease of transportation, and increased product life are the benefits of this structure [10]. The structure used in multi-layer packaging can be a variety of materials including polymeric (thermoplastics) and non-polymeric (paper or aluminium foils) [22]. Multi-layer packaging currently uses 17% of global film production and is mainly employed in electrical appliances, food packaging (such as meat, vegetables, and cheese), fabrics, and snack foods (such as pasta, biscuits, and chips) [10,23].

The manufacturing processes of FP generally include extrusion, printing, lamination, and slitting [24]. In the extrusion process, the granules are melted and transformed into film layers [28]. The printing process, also known as flexography printing, applies various colours of inks to the films [24]. In the lamination process, adhesives, glue, and hardener are applied to bond various substrates such as plastic film, aluminium foil, and paper [29]. Finally, the slitting process involves cutting large rolls into several smaller finished rolls according to customers' requirements [24].

3. Research Methodology

The paper followed the SLR methodology for conducting a comprehensive literature review recommended by Tranfield et al. [30] comprising the planning, conducting, and reporting stages of the review. The underlying reason for using the SLR methodology is to generate robust research findings based on a more systematic approach [31] as compared to ad hoc literature reviews [32]. The ad hoc literature reviews lack knowledge regarding a collection of studies in a specific field [31]. On the other hand, SLR facilitates synthesizing the results from a collection of articles in an exhaustive manner to respond to a particular research question. It is also recognized as a “gold standard” [31] (p. 334), which helps in integrating the results in a translucent and reproducible manner. Since the SLR produces reliable results by applying the pre-defined inclusion criteria and searching the articles in a systematic approach, hence, it reduces the chances of biasedness [33].

Within the different stages of SLR, the planning stage identifies the need for the review and develops a literature review protocol. A search strategy is developed to identify the relevant studies aligned with the research question and overall aim of the review [31]. In this stage, inclusion and exclusion criteria are developed including keywords, databases, time period, and search fields. Accordingly, a review protocol for this paper is given in Table 1.

Table 1. Review protocol.

Unit of analysis	Peer-reviewed journal articles in the English language were selected
Search limitations	The search was limited to journal articles on the environmental sustainability issues of FP
Type of analysis	Qualitative
Time period of analysis	Not specified
Boolean operators used	AND and OR
Search fields	Title, abstract, keywords
Databases	Keywords were searched in different combinations from the popular database SCOPUS
Keywords used	Flexible packaging, environmental waste, flexible plastic, flexible plastic packaging, emissions, waste, environmental sustainability, environmental issues, sustainability, environmental impact

The conducting stage requires the collection and analysis of the relevant studies extracted from the databases according to a predefined inclusion criterion. From this perspective, the inclusion criteria for this review comprise the journal articles in the English language. The start date of the review was not specified to obtain the maximum number of articles [34]. Different keywords (Table 1) were used to explore the relevant articles from the popular database SCOPUS. It is recognized as a reliable database and is suggested by various researchers [35–38]. The keywords were searched in the title, abstract, and keywords list. As a result, 80 articles were identified in the first stage after applying the inclusion criteria where the first article was published in 1994. After removing the duplicates, 44 articles were selected. Additionally, six articles were excluded due to the unavailability of the full text. After evaluating the content of the articles, a further six articles were excluded. Finally, 32 articles were selected that were relevant to the study requirements. Figure 1 presents the filtering procedure of the articles using the methodology for reporting systematic reviews PRISMA (preferred reporting items for systematic reviews and meta-analysis).

In the first stage, the articles were descriptively analyzed. In the second stage, an in-depth analysis was conducted to investigate the environmental sustainability issues of FP and the solutions to address these problems by following the content analysis technique suggested by White and Marsh [39] as a systematic and rigorous method to analyze the articles. Based on the content analysis, two categories emerged under the environmental sustainability issues of FP namely environmental sustainability issues of FP manufacturing processes and environmental sustainability issues of post-consumer use. Under these categories, several environmental challenges were observed. On the other hand, two categories emerged under the potential solutions to address the environmental problems of FP including (i) technical and methodological aspects and (ii) strategic and collaboration aspects.

The reporting stage requires careful analysis and synthesis of the review results, which can be presented in different ways [31]. After critically analyzing the SLR findings, the results are presented in terms of journal name, yearly publications, research methodologies, keywords used in the articles, countries where research was undertaken, environmental sustainability issues of FP, and the potential solutions. The following sections present the reporting stage of the review.

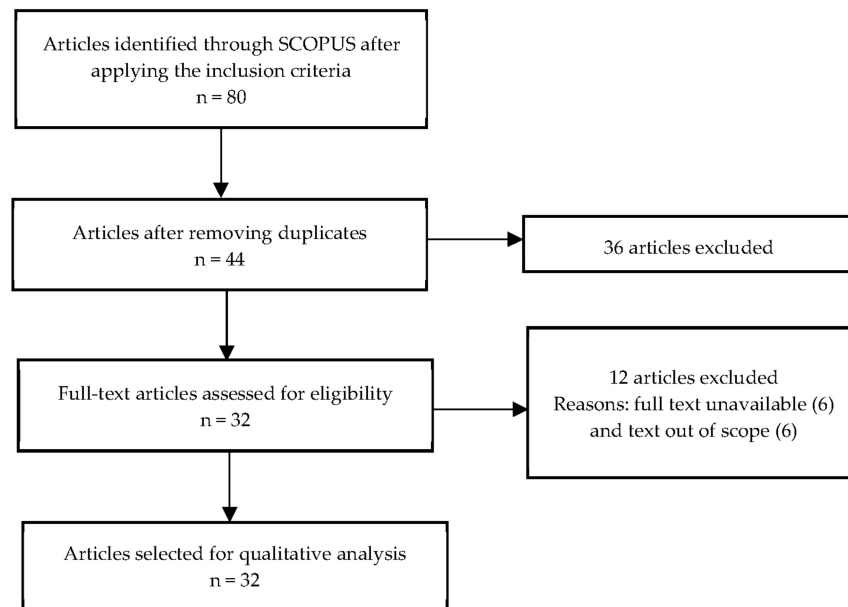


Figure 1. Filtering procedure of article selection.

4. Descriptive Analysis

4.1. Articles Distribution by Journal Name

Figure 2 exhibits the number of articles published in peer-reviewed journals. The chart highlights that the Journal of Cleaner Production, Journal of Hazardous Materials, International Journal of Life Cycle Assessment, Polymers, Journal of Print and Media Technology, and Waste Management contributed two articles each (37.50%). The “Others” category in the chart indicates the journals with a single publication, which is 62.50% of the total published articles.

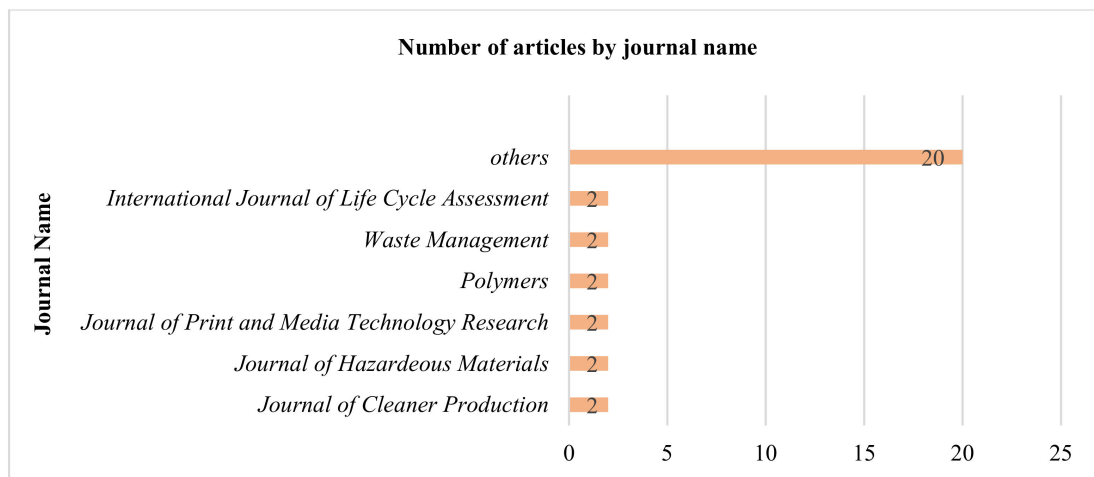


Figure 2. Distribution of the articles by journal name.

4.2. Articles Distribution by Methodology

Figure 3 presents the articles distribution according to the research methodology adopted in the selected studies, which included the experimental research, case study, review, survey, and interview. The analysis reveals that the experimental research is primarily used as a research methodology in 22 articles followed by the literature review methodology used in 7 articles. Further, case studies, interviews, and surveys were used in only a few studies e.g., [10,40].

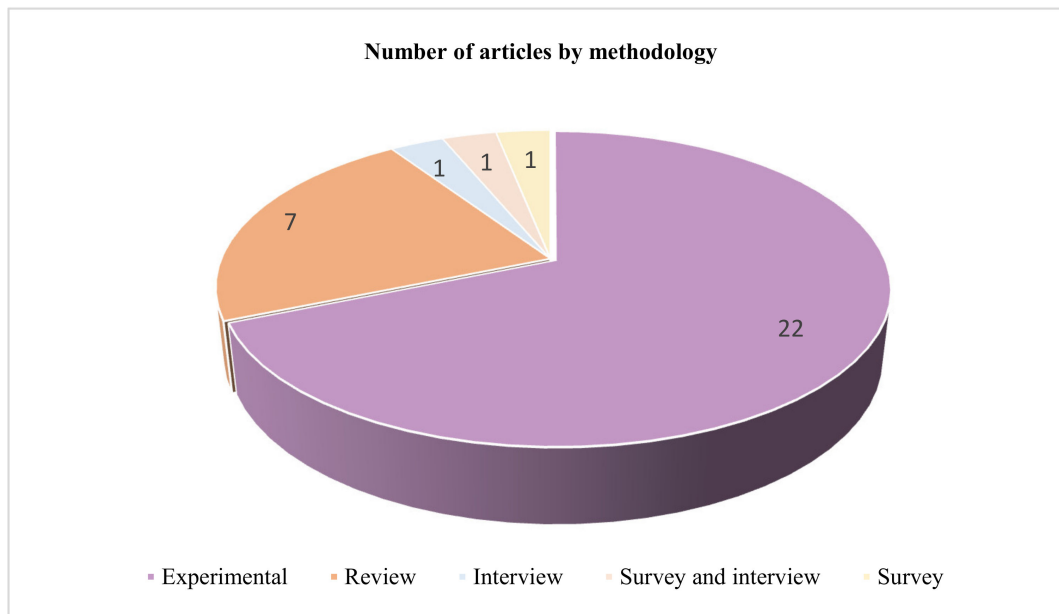


Figure 3. Distribution of the articles by methodology.

4.3. Articles Distribution by Year of Publication

Figure 4 highlights the number of articles published by year. The analysis reveals that the first article was published in 1994 and only a few articles were published until 2013. After 2013, there was an increasing trend in the number of publications, which indicates the research interest was developed in this area due to the increasing environmental sustainability issues of FP.

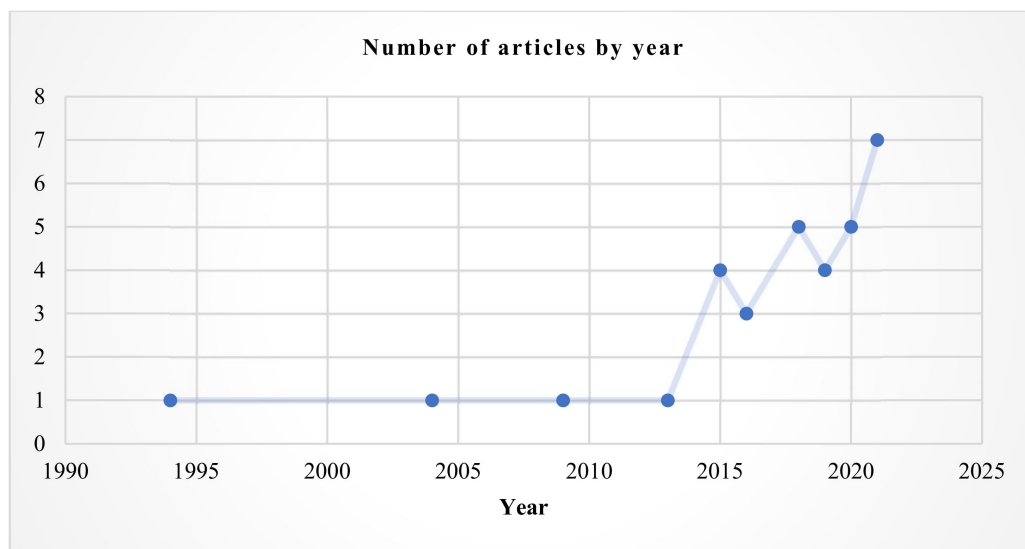


Figure 4. Distribution of the articles by year.

4.4. Articles Distribution by Country

Figure 5 presents the distribution of the articles by country classification. The SLR results indicate that most of the research is undertaken in developed countries with 22 articles (68.80%). Further, within the developed countries, 14 articles (63.60%) are published from the European countries, which shows the increasing environmental awareness in these countries. Among the European countries, most research is conducted in Italy with six

publications, followed by Spain, Switzerland, and Lithuania with two articles each. On the other hand, only 10 articles are published from developing countries.

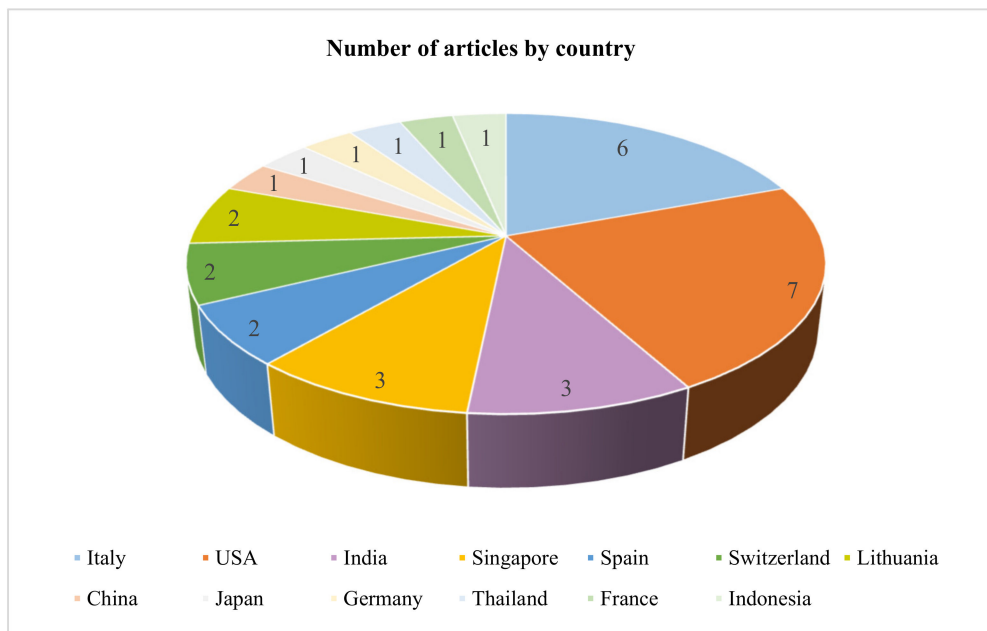


Figure 5. Distribution of the articles by country.

4.5. Keywords Used in Articles

Table 2 presents the main keywords used in the articles. The analysis of keywords is recognized as a common practice that can facilitate identifying the research focus in a specific domain [41].

Table 2. Main keywords used in articles.

Keywords Used in Articles	Occurrence
Flexible packaging	10
Recycling	5
Plastic waste	4
Life cycle assessment	4
Environmental impact	3
Volatile organic compounds	2
Sustainability	2
Emissions	1

In addition, Figure 6 presents the word cloud for highlighting keywords used in the 32 articles, which show the most frequently used words such as “flexible packaging”, “plastic”, “waste”, “recycling”, and “environmental” whereas keywords including “volatile organic compounds”, “health”, and “emissions”, are less frequently used. The keywords analysis highlights plastic waste (solid waste) as a major concern in prior studies as compared to other environmental sustainability issues such as VOCs emissions, soil pollution, and health and safety risks.

liquid waste is produced during the printing process, which is gathered in tanks and handed over to waste management organizations [1].

FP has an energy footprint in the form of energy consumption (e.g., electrical energy) where a mix of energy resources such as natural gas, coal, and petroleum is used in the manufacturing processes and generating a combination of electrical and thermal energy losses [1,46]. For instance, the extrusion process primarily consumes extensive electrical energy that generates electrical and thermal energy losses [23,47]. Furthermore, there are heat energy losses in the printing process when energy is produced for the drying chamber through water-heating boilers to dry the inks [1]. Since FP deals with a variety of materials and includes long run times, the excessive setup time in the printing process [45] also leads to electrical and thermal energy losses during this idle time.

5.1.2. Post-Consumer Use

Due to the use of multi-layer film structures and decomposition challenges, FP waste is considered an uneconomic material for collection and recycling [12]. Since there is a lack of technological advancements for separating multi-layer films such as food packaging comprising a combination of PE and PP structures, a large quantity of post-industrial and post-consumer waste is being sent to landfills [43]. It is estimated that the FP segment accounts for nearly 30–35% of the municipal solid waste in developed countries [11,12]. For example, in the US (2015), 238 million metric tons of plastic waste from containers and packages are sent to landfills, comprising 30% of the municipal solid waste [43]. Nearly 59% of the plastic waste in Europe was found to be linked with FP materials [48].

The analysis also revealed that soil pollution is an environmental sustainability issue resulting from the FP waste of post-consumer use. A lack of collection and mismanaged municipal solid waste of plastic packaging from industrial and urban areas causes soil infertility [3]. Moreover, the presence of nanoparticles of plastics in the crops and plants [49,50] poses risks to human health by impacting the food chain through agricultural produce. The quantities of micro and nano plastic are also found in urban dust, which could be inhaled by animals and humans, leading to health hazards [3]. Due to recycling issues with FP waste, an increase in the illegal burning of this waste in developing countries has been observed, which leads to air pollution and an increase in respiratory illness [10].

Another significant environmental sustainability issue of FP waste of post-consumer use is marine pollution, which is entering the oceans at increasing rates and threatening sea life [51]. It is estimated that approximately 8 million tonnes of plastics are leaked into the world's oceans per year, equivalent to disposing of one garbage truck into the ocean every minute [52], and is expected to double by 2030 [20]. The recovery of these plastics from seas and rivers and management of the recovered plastic waste are significant challenges [53]. The most alarming impacts of marine pollution are the ingestion and suffocation through plastic debris by hundreds of marine wildlife such as turtles, whales, seabirds, and fishes, limiting their ability to swim and increasing internal injuries and infections [3,54]. These packaging materials are fragmented into micro-plastics and nano plastics, posing a life-threatening risk to marine wildlife. Furthermore, these plastics are also disrupting ecosystems due to the spread of marine bacteria and organisms [3].

Packaging plays an important role in household food products and one of the key concerns in FP is the size of the package. Bayus et al. [2] examined the material consumption of family-sized packages versus individual sizes. The study concluded that a family-sized package consumes less material (about half per serving), which results in material conservation, energy savings, and low carbon emissions. However, large-sized packaging may lead to food waste at the consumers' end, which is another environmental sustainability challenge [2,55]. From this perspective, a study highlighted that 20–25% of household food waste is associated with packaging characteristics [2], negatively affecting the recyclability of FP waste due to contaminated content [55].

Table 3 presents an overview of environmental sustainability issues related to FP manufacturing processes and post-consumer use addressed in prior studies.

Table 3. Environmental sustainability issues addressed in the literature.

Authors	Environmental Sustainability Issues of Flexible Packaging												
	FP Manufacturing Processes						FP Post-Consumer Use						
	VOCs Emissions	Energy Footprint	GHG Emissions	Health Hazards	Resource Depletion	Liquid Waste	Solid Waste	Air Pollution	Marine Pollution	Soil Pollution	Health Hazards	Solid Waste	Food Waste
Büsser and Jungbluth [18]		X	X										X
Lopez et al. [56]								X				X	
Bayus et al. [2]					X								X
Horodytska et al. [22]							X					X	
Kliopova-Galickaja and Kliaugaitė [1]	X	X	X	X	X	X							
Koshti et al. [57]									X	X		X	
Mumladze et al. [58]								X				X	
Borman et al. [59]								X	X		X	X	
Ahamed et al. [12]					X			X	X	X	X	X	
Anchawale et al. [60]		X											
Anchawale et al. [61]	X												
Barron and Sparks [51]									X				
Pongpimol et al. [10]								X				X	
Veksha et al. [21]												X	
Ahamed et al. [3]					X		X	X	X	X	X	X	
Bening et al. [40]												X	X
He et al. [29]	X	X	X										
Kozake et al. [62]	X		X	X									
Schmidtchen et al. [48]		X			X				X			X	

5.2. Potential Solutions to Environmental Sustainability Issues of Flexible Packaging

The analysis highlights that research studies are focusing on mitigating environmental sustainability issues of FP through technological and methodological methods including waste management and treatment techniques, less use of materials, use of environmentally friendly materials, and use of environmental and statistical tools. Additionally, strategic and collaboration aspects comprising government policies and strategies, circular economy business models, stakeholder collaborations, and consumer awareness also address environmental problems of FP.

5.2.1. Technological and Methodological Methods

The SLR results revealed different recycling methods and technologies for reducing FP waste including mechanical, chemical, and biological recycling [3,22,57]. Mechanical recycling is emphasized by several authors as a salvaging technique for FP waste in which the re-extrusion process is executed to reuse the clear mono-layer post-industrial waste. This is considered as a closed-loop recycling method [3,22]. The resulting material quality is similar to the virgin materials, hence, it is suitable for the manufacturing of high value-added products. In addition, open-loop mechanical recycling is also conducted for single and multi-layer FP structures due to contamination (e.g., inks) and low quality of the FP waste. In this method, waste is shredded, washed, dried, and re-granulated. However, the resulting material is used in the manufacturing of low value-added products such as trash bags, plastic lumber, and pipes [22].

For the multi-layer FP waste, delamination, compatibilization, and dissolution techniques are emphasized as recycling methods, however, these are in the early stages of development [22,53]. In one study, the recycling of post-consumer FP waste was investigated through compatibilization methods where low amounts of nanofillers with different morphologies (lamellar and needle-like) were added [63]. Similarly, Ferraioli et al. [53] evaluated the effectiveness of compatibilizers and mineral fillers (Dellite 67G and Zeolite 4A) to upgrade the recycling of post-consumer waste retrieved from the seas and rivers to analyze the after-life application of plastic waste. The findings demonstrated that the thermal consistency of recycled materials slightly increased with the addition of the two mineral fillers in these methods. However, additional benefits such as an improvement of both elastic modulus and elongation at break values, in the range of 20–30%, were observed in the compatibilized recycled blends through the combined use of compatibilizer and fillers.

In another study, switchable hydrophilicity solvents (SHSs) as green and sustainable chemicals were successfully used with the aim of achieving a recycling rate of more than 99% by recovering the layers of a multi-layer FP waste as a delamination technique [58]. Although mechanical recycling is viewed as an effective technique for recycling FP waste, there are some challenges including the low quality of the FP waste due to contamination and the associated high cost of sorting and drying [3,22]. Moreover, the high cost of compatibilizers is a major concern for recyclers [64]. Due to these challenges, a large quantity of FP waste is disposed of in landfills [22].

Chemical recycling, also referred to as tertiary or feedstock recycling, is a process of depolymerization of synthetic materials into value-added components such as monomers. It includes the chemical modification of the polymer structure in which liquids and gases are produced to be used as feedstock to produce new plastics [22,65–67]. This technique is useful in material recovery, facilitating the circular economy objective of resource circularity as compared to incineration and mechanical recycling [3]. Two major chemical recycling techniques include gasification and pyrolysis [3,22]. In a recent study, the conversion of the FP waste into high-value carbon nanomaterials and oil through pyrolysis/catalytic upgrading was investigated [21]. Nonetheless, this technique is also in the initial stages of development (laboratory scale) and requires exploration at the industrial level while addressing economic feasibilities [3]. Along with the mechanical and chemical recycling techniques, biological recycling is emphasized as an environmentally friendly and economically sound method of reducing the environmental burden of FP [68]. This technique

follows an enzymatic approach for biodegradation of polymers (e.g., PET), which not only helps in minimizing the FP waste but also produces useful gas such as methane [57].

Researchers have also highlighted landfill as a waste management technique due to the lack of mechanical recycling technologies (e.g., delamination, compatibilization, and selective dissolution-precipitation), contamination, and dirtiness of FP waste, which results in rejection from recycling plants [22]. Nevertheless, landfilling poses environmental risks such as soil pollution, GHG emissions, and leakage of microplastics into the oceans, and hence is regarded as the least environmentally friendly technique [3,22].

Further, some research studies have emphasized incineration as an energy recovery method to manage FP waste [56,57]. Through incineration, not only electricity is produced but 90–99% of waste is also reduced. While incineration helps in natural environmental protection, approximately 96 Mt of GHG emissions are reported through incineration compared to landfill, which generates around 16 Mt [3]. Incineration is also considered as a downcycling practice that is contrary to the CE objectives of managing resources in a closed-loop cycle [22]. However, it is regarded as a benign waste management option in the case of less space for landfill such as in Japan [22,53], and treating the contaminated FP solid waste (after sorting), which is unsuitable for recycling [22].

With respect to the management of post-consumer FP waste, kerbside collection programmes are executed in places such as in the European Union. Waste collection programmes for recycling FP waste also include door-to-door collection, civic amenities, bring points, retail return, and a deposit and return system [22]. Additionally, sorting and separating the collected FP waste is an important step in increasing the efficiency of the recycling process, which is generally undertaken in materials recovery facilities (MRFs). Manual sorting is mostly undertaken in MRFs; however, there are mechanical equipment available such as vacuum systems for collecting and conveying hand-picked materials and bag-splitters to open and empty the plastic bags [22].

The SLR results also revealed several studies using different environmental and statistical tools such as life cycle analysis (LCA), design of experiment (DOE), design for recycling [69], correlation analysis and regression analysis for selecting FP materials, recycling post-industrial and post-consumer waste, and experimenting with the biopolymers [2,4,12]. A study in Brazil used the DOE methodology as a useful tool that assisted in recycling multi-layer (a combination of PET and PE) post-industrial FP waste by using polymer compatibilizers [64]. Furthermore, the analysis revealed that LCA is the most frequently used approach to analyze the environmental sustainability impacts at different stages of the product [2,18]. The results also indicated less use of virgin materials and hazardous chemicals by reducing the thickness of the films and the number of layers in the manufacturing of FP products to reduce the environmental burden of this sector [2,18].

The development of alternative and environmentally friendly materials such as water-based inks, solventless laminates, and bio-based and biodegradable materials to address the environmental issues of FP have also been highlighted in the SLR [1,22]. One study highlighted the use of a recently developed aqueous ink—'Lunajet' as an environmentally friendly water-based ink for FP printing [62], which can minimize the environmental impact of solvent-based inks. Kliopova-Galickaja and Kliaugaitė [1] also emphasized the use of water-based inks in the flexible packaging printing process and highlighted several advantages that include less VOC emissions due to minimal use of solvents (i.e., only 5%), less use of inks (i.e., 20–60%), a decrease in energy consumption (i.e., 10–35%), and elimination of worker's health and safety risks [1]. While water-based inks have been successfully applied on the paper-based packaging, more research is required in the application of these inks on plastic films, which are much used in FP [61]. Moreover, there are some other challenges associated with these inks such as a high cost of manufacturing, low productivity, and high energy requirements [62].

One study compared the environmental impacts of three laminates—aluminium foil, metallized oriented polypropylene (MOPP), and metallized polyethylene terephthalate (MPET)—through LCA of these laminates from raw material extraction to the end-of-life

stages [2]. The study results highlighted that the MPET and MOPP have lesser environmental impacts as compared to the aluminium foil (i.e., global warming of MPET and MOPP is half of the aluminium foil). Similarly, another study used LCA to evaluate the environmental impacts of solventless and traditional solvent-based dry lamination [29]. The study concluded that solventless lamination has environmental benefits such as reduced VOCs and air pollutants. Although the study identified the environmental advantages of solventless lamination, the attributes and consistency of such type of lamination can have performance issues with high temperatures in food packaging.

Additionally, the use of biobased and biodegradable polyester polymers such as polylactic acid (PLA) derived from renewable sources such as sugarcane and corn starch are viewed as a potential environmentally sustainable alternative for traditional plastics [70]. Similarly, biodegradable polymers based on chitosan are also considered as an alternative material to reduce the environmental impact of oil-based polymers [71,72]. Schmidtchen et al. [48] conducted experiments on macroalgae (seaweed) as a promising renewable packaging substrate to be used in FP through a novel approach of semi-dry extrusion for its production. The benefits of this approach are deemed as low cost of production, water and energy conservation, and a wider range of product variety. The cost of biodegradable and bio-based materials is higher, nonetheless, the use of these materials can facilitate improving environmental sustainability performance [10].

5.2.2. Strategic and Collaboration Aspects

The SLR results revealed strategic and collaboration aspects for addressing the environmental sustainability issues of FP including the support from the stakeholders (such as recyclers), circular economy business models, government policies, and consumer awareness. Governments need to play a significant role in the environmental sustainability of FP through stringent environmental policies, regulations, and strategies focusing on minimizing the use of plastic and hazardous materials, controlling air emissions, recycling FP waste, and promoting the use of biodegradable FP products [3]. For example, governments in developed countries such as North America, the United Kingdom, Australia, New Zealand, and several European countries have either banned the single-use of plastic or introduced levies on plastic bag consumption [3,73–75]. On the other hand, developing countries have also initiated strategies for handling FP waste. In China, the government is giving subsidies to farmers to encourage the use of biodegradable plastic films such as plastic biodegradable mulches (BDMs) in agricultural applications [20]. Kenya has also banned plastic bags, which considerably reduced plastic consumption [13]. Some regions in India have also initiated environmental regulations against the manufacturing and consumption of single-use plastic [20].

The execution of extended producer responsibility as an environmental protection strategy can also aid in managing environmental sustainability issues of FP by ensuring the manufacturers take responsibility for their packaging products during the whole life cycle [40]. Improved stakeholder collaboration including customers, suppliers, manufacturers, retailers, recyclers, and collectors [3,76,77] is vital to address the environmental sustainability challenges of FP. Furthermore, both the public and private sectors should work together in managing FP waste [10].

The researchers also emphasized a circular economy approach as a potential business model [3,40] that focuses on reducing waste and environmental emissions, conserving resources and materials, and achieving long-term environmental sustainability [78,79]. From this perspective, the 9R (R0: refuse, R1: rethink, R2: reduce, R3: reuse, R4: repair, R5: refurbish, R6: remanufacture, R7: repurpose, R8: recycle, and R9: recover) framework [80,81] can be implemented for improving the environmental performance of FP [20] and achieving the objective of the CE approach.

Consumer education and awareness regarding the selection, consumption, and disposal of FP products can also address the environmental sustainability issues of this segment since the consumers are the “key players” in the execution of a circular economy

for FP [82] (p.1). Consumers must be educated about the environmental consequences of plastic pollution and the potential ecological and social benefits of selecting products with environmentally friendly packaging [82,83]. Their awareness of minimizing the use of plastic packaging by choosing products with alternate options such as paper-based packaging and biodegradable packaging must be enhanced. Moreover, the consumers' selection of family-size bags in food products can also minimize the environmental burden [2].

Table 4 presents potential solutions addressed in SLR studies to mitigate the environmental sustainability issues of flexible packaging.

Table 4. Potential solutions to address environmental sustainability issues in flexible packaging.

Potential Solutions to Address Environmental Sustainability Issues in FP		References
<i>Technical and methodological aspects</i>	Use of environmentally friendly materials	Kliopova-Galickaja and Kliaugaitė [1], Kozake et al. [62], He et al. [29], Ahamed et al. [3], Rocca-Smith et al. [70]
	Waste management and treatment	Ahamed et al. [3], Koshti et al. [57], Horodytska et al. [22]
	Less use of virgin materials and toxic chemicals	Ahamed et al. [12], Bayus et al. [2]
	Use of environmental and statistical tools	Bayus et al. [2], Ahamed et al. [12], Garofalo et al. [63]
<i>Strategic and collaboration aspects</i>	Government policies and support	Ahamed et al. [3]
	Extended producer responsibility	Bening et al. [40]
	Stakeholders' collaboration	Ahamed et al. [3]
	Circular economy business models	Ahamed et al. [3], Bening, et al. [40]
	Consumer awareness	Bayus et al. [2]

6. Discussion

While FP is an efficient packaging method for protecting products from damage and spoilage, the increasing environmental burden of this sector has become a global challenge. This paper provides an integrated analysis of the key environmental issues arising from both manufacturing and post-consumer use of FP products and their mitigation.

Based on the SLR results and analysis of the selected studies, Figure 7 presents a holistic integrated framework of the environmental problems and their technical and methodological, as well as strategic and collaboration-related solutions for addressing the environmental sustainability issues of FP. The framework includes several environmental issues related to the manufacturing processes (e.g., resource depletion, health and safety risks, energy footprint, VOC emissions, liquid and solid waste, and air emissions) and post-consumer use (e.g., solid waste, soil pollution, food waste, health hazards, marine pollution, and air pollution). To address these problems, several potential solutions are classified into two categories—technical and methodological aspects and strategic and collaboration aspects. Under the technical and methodological aspects, waste management and treatment, less use of virgin materials and hazardous chemicals, use of environmentally friendly materials, and use of environmental and statistical tools are some approaches discussed in prior studies. In the strategic and collaboration aspects category, government support and policies, stakeholders' collaboration, extended producer responsibility, consumer awareness, and circular economy business models are proposed.

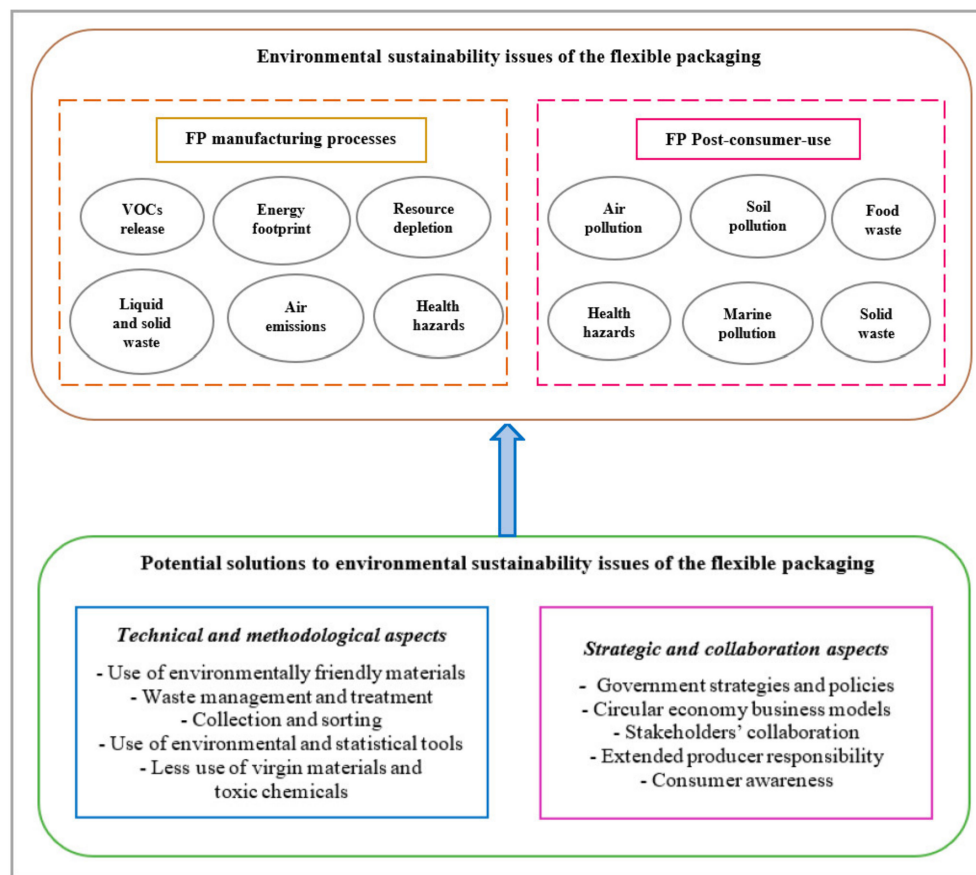


Figure 7. A framework for the environmental sustainability issues of flexible packaging and potential solutions.

The review results reveal that most of the articles are published after 2013, which indicates that the research interest (Figure 4) in the environmental sustainability of FP has been developed due to the increasing environmental burden of this industry. Further, our analysis also highlights some research gaps in the current literature. Although both developed and developing countries are struggling to minimize environmental issues of FP, most of the research is conducted in the developed countries—predominantly in the European countries—which shows a higher level of increasing environmental awareness. Additionally, developed countries are implementing upcycling/closed-loop practices that are more aligned with the objectives of a circular economy approach, while downcycling and open-loop practices are mostly followed in developing countries, not aligned to this approach.

The results further illustrate that quantitative experimental research has been adopted as a frequently used methodology in the reviewed articles. This can be attributed to a more focused research approach with material-based evaluations at industrial and laboratory levels e.g., [58,61,70]. This finding also highlights that the focus of current research is less on organizational and manufacturing strategies, theoretical frameworks, and policies (e.g., [10]). While case studies, interviews, and surveys provide comprehensive insights to investigate a research phenomenon [84,85], the analysis reveals that only a few studies have utilized these methodologies e.g., [10,40]. Although experimental research methodology helps in developing technical solutions, interviews with practitioners and experts can provide an in-depth understanding of the environmental challenges of FP, which can be useful in developing strategies and policies for managing environmental sustainability issues [10,40,86]. The analysis further points out that a literature review has been adopted as a research methodology in some studies [3,22,57], however, a holistic analysis of envi-

ronmental sustainability issues of FP through rigorous review methodologies such as SLR and integrative literature review is largely missing.

The analysis highlights that the environmental issues such as solid waste related to FP post-consumer use (Table 3) are more addressed in research studies specifically in developed nations e.g., [4,43], which can be associated with the stringent regulations and increased awareness regarding solid waste management issues in these countries [67]. However, some other environmental sustainability issues of FP post-consumer waste such as food waste are only addressed in a few studies e.g., [2,18]; the focus of current literature being more on reducing plastic pollution [87]. The reason can be associated with the challenges faced by the FP industry to simultaneously achieve the objectives of minimizing food waste, increasing supply chain efficiency, and reducing packaging waste [88]. Generally, these objectives create paradoxes, for example, more packaging increases product protection, which results in reducing food waste, however, it also increases packaging waste [86].

On the other hand, resource depletion issues related to the FP manufacturing processes are more addressed in articles e.g., [1,2,12,48] due to the growing concerns about sustainable production and consumption of natural resources used in this industry [20]. However, there is a lack of studies emphasizing the employees' health and workplace safety hazards associated with the FP manufacturing processes e.g., [1,62]. This can be attributed to a lack of knowledge and awareness of the significance of occupational health and safety aspects in manufacturing organizations specifically in the process industry using hazardous chemicals and materials [89,90].

Though the research studies illustrated various recycling technologies for FP waste treatment, high investment requirements, collection and sorting issues, and contamination are the challenges associated with these technologies [3,22]. Similarly, the use of biopolymers (e.g., polyhydroxyalkanoates (PHA) [46] and polycaprolactone (PCL) [23]) seems to be a promising solution to environmental problems of FP, nonetheless, most of the developments are in the preliminary stages and require industrial and economic feasibility assessments [46,57].

7. Conclusions, Implications, and Future Research Directions

This paper examines the environmental sustainability challenges faced by the FP industry through an SLR including the descriptive and content analysis of the selected articles. The descriptive analysis highlights the following: (a) Journal of Cleaner Production, Journal of Hazardous Materials, International Journal of Life Cycle Assessment, Polymers, Journal of Print and Media Technology, and Waste Management have contributed two articles each (37.50%); (b) most research was performed in the developed countries, especially in the European countries, and (c) a research interest was developed after 2013 due to the increasing environmental problems of FP. The content analysis classifies the environmental sustainability issues of FP and the potential solutions into different categories (Tables 3 and 4). To conclude, this paper provides a holistic understanding of the environmental aspects of this industry through a comprehensive literature review, which is missing in the current body of knowledge.

7.1. Implications

7.1.1. Theoretical Implications

This study has significant theoretical, managerial, and policy implications. From a theoretical perspective, this review paper has synthesized, critically examined, and documented the current literature on environmental sustainability issues of FP and the potential solutions into different categories. Drawing on the SLR results, the key environmental issues are classified under the FP manufacturing processes and post-consumer use. On the other hand, the key solutions addressed in the studies are categorized under the technical and methodological aspects and strategic and collaboration aspects. In addition, this SLR contributes to the literature by presenting a holistic framework of the environmental sustainability issues of flexible packaging and solutions to address these challenges (Figure 7).

This framework can guide the researchers in understanding the environmental concerns, developing sustainability models, and extending research in this domain.

7.1.2. Managerial Implications

From a managerial perspective, this paper provides the practitioners and managers with useful insights regarding the environmental aspects of the FP industry. The practitioners and industrial managers can use the study results in recognizing the environmental issues related to the FP manufacturing processes and adopting adequate solutions to reduce the energy footprint, natural resource depletion, and health hazards. For example, industrial managers can develop guidelines for the storage, usage, collection, and recovery of hazardous materials and ensure the use of personal protective equipment while handling these materials according to occupational health and safety guidelines. In addition, the findings can also facilitate the practitioners in developing sustainable packaging solutions that can help in minimizing the environmental problems related to post-consumer use.

7.1.3. Policy Implications

Similarly, the policymakers can benefit from the study results in developing legislative frameworks and adequate policies to reduce the environmental impact of both the manufacturing processes (such as VOCs release and GHG emissions) and post-consumer use (such as solid waste, soil pollution, and marine pollution). In addition, the policymakers can use the findings for implementing the circular economy principles in the FP industry through waste management techniques, stakeholders' integration, and support for using sustainable packaging materials.

This review has some limitations such as the current research was conducted through reviews of journal articles selected from SCOPUS, therefore, articles other than the SCOPUS database are not included in this review. Further, only peer-reviewed journal articles are considered to ensure the quality of publications. Another limitation is the selection of keywords and search strings, therefore, future SLR studies can use different search strings to expand the scope of this study.

7.2. Future Research Directions

Building on the analysis of the results, this review presents some important research gaps and future research directions, which could provide fresh insights for academic scholars, practitioners, and policymakers. The researchers can explore the role of stakeholders including consumers, government, suppliers, retailers, collectors, and non-governmental organizations [76,77] through a qualitative study to address the environmental challenges of FP. Additionally, more research is required in developing countries due to the increasing environmental burden of FP. Similarly, researchers need to investigate the less-focused environmental areas related to FP manufacturing processes and post-consumer use such as VOCs release, workplace safety, soil pollution, and food waste.

Future research studies can explore the impact of other tools and practices such as material flow analysis (MFA), design for environment (DFE), environmental management system (e.g., ISO 14001), value stream mapping, energy management system (e.g., ISO 50001), statistical process control, 5S (seiri, seiton, seiso, seiketsu, and shitsuke), and DMAIC (define, measure, analyze, improve, and control) [8,91–94] to overcome environmental issues in FP manufacturing. Similarly, integrated operational and environmental strategies such as total quality environmental management (TQEM) and green-lean-six sigma (GLSS) could also be investigated in achieving environmental sustainability objectives while maintaining the operational performance [95–98] of the FP industry.

While the theoretical framework plays a significant role in knowledge creation [99], none of the prior studies integrated any organizational theory with the environmental performance of the FP industry. Based on this finding, we argue that scholars need to focus on the theoretical aspects to promote academic scholarship and develop a more rigorous theory concerning the environmental sustainability of FP. In this regard, the applied research

can use relevant organizational and sustainability theories such as the natural resource-based view [100], stakeholder theory [101], and paradox theory [102] to effectively address the sustainable production and consumption of natural resources, environmental protection, stakeholders' aspects, and packaging paradoxes in the FP industry.

While several studies separately evaluated the environmental issues of FP e.g., [1,3,10], studies suggested frameworks for minimizing the environmental burden of FP including air emissions, energy footprints, health hazards, resource depletion, workplace safety risks, and soil and marine pollution are lacking. The need for holistic framework development in this area for addressing the environmental sustainability challenges is also stressed [13,103]. Such holistic frameworks integrating organizational theories, manufacturing strategies, stakeholder collaboration, and sustainability dimensions can also bring valuable insights into this domain.

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