Article

Case Study of Municipal Waste and Its Reliance on Reverse Logistics in European Countries

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Abstract: The authors have examined municipal waste, its components and their integration with reverse logistics processes. Background: The theoretical part begins with a definition of municipal waste. Later, the integration between municipal waste and reverse logistics is provided, including presentation of the hierarchy of qualitative methods and models. Methods: The authors constructed a correlation matrix and applied a dynamic regression model to identify that the level of municipal waste impacts recycling of biowaste which demands reverse logistics. Results: The authors provided a dynamic regression model which could be applied for forecasting the size of recycled municipal waste into biowaste indicated in European Union countries. Conclusions: The variety of components in municipal waste prevents the increase of the recycling rates and has to be changed to ones that have higher recycling rates.

Keywords: municipal waste; packaging; recycling; logistics processes; reverse logistics

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1. Introduction

Package design is paramount to grabbing buyers' attention. In direct relation to the creation of the packaging, the demand for the product grows [1]. Product packaging design, like branding, is critical to product positioning in the industry and can either drive sales or block sales entirely [2].

The globalisation of modern goods and transactions has presented a new perspective in the return management process [3]. Unfortunately, most companies emphasise getting the product out the door and overlook the need for returns and business management acts as if not expecting the potential return of the shipped product. This gap is often attributed to a deficiency of system automation required to manage the returned product. Indeed, they focus more on immediate reverse logistics customer issues but concentrate less on returns [4].

According to Gartner, Inc., the net profit loss due to improper handling of returns results in loss of control and loss of income and inventory can be estimated to be 35%. Therefore, it is economically prudent and makes good business sense to create an efficient and reliable reverse logistics process [5].

The reverse logistics activities occur during recycling, where packing material is used as a component of municipal waste [6]. The report “*The Future of World Packaging to 2022*” indicates that the need and demand for packaging will gradually grow by 2.9% to reach \$980 billion in 2022. Global packaging sales will increase by 3% at an annual rate of 4% from 2018. In Western Europe, packaging sales accounted for 22%, in North America 23%, and in Asia even 36% of total sales [1,2].

The management of municipal waste demands reverse logistics. The physical return triggers reverse logistics processes. The authors investigate the connection points between reverse logistics and municipal waste management.

An analysis of literature (i.e., review of books published by Oxford University Press, Cambridge University Press, Harvard University Press, Springer, M.E. Sharpe, Routledge,

other publishers was performed and identified that the theme of municipal waste is rarely discussed in the literature on reverse logistics. The analysis presented in Table 1 shows that only 0.49 per cent of the above publications describe investigations in that research area.

Table 1. Review of literature.

Year	Literature of Reverse Logistics	Thematic of Municipal Waste	
		Literature of Municipal Waste	Under the Literature of Reverse Logistics
1994–1998	813	45,600	1
1999–2003	3460	46,300	5
2004–2008	8130	44,100	10
2009–2013	11800	46,600	117
2014–2018	36600	58,200	137
2019–2021	30200	61,700	173
Total	91003	302,500	443
%	100%		0.49%

Source: Constructed by authors, according to publications published by Oxford University Press, Cambridge University Press, Harvard University Press, Springer, M.E. Sharpe, Routledge, and other publishers.

Reverse logistics differs from waste management in that it focuses on the addition of value to a product to be recovered and then the outcomes will be used by forward logistics while waste management involves mainly the collection and treatment of the waste products that have got no new use.

That is why the article aims to identify the trends towards recycling and the size of the flows of municipal waste that are recycled. The recycling of municipal waste without the proper organization of waste flows, which are handled by reverse logistics and proper infrastructure, which is a necessity for reverse logistics, is hardly possible.

The article investigates the links between reverse logistics and municipal solid waste management. The article consists of seven main sections. The study starts with the introduction and the summary of the literature. In the second section, the authors discuss the research of various authors to reveal the essential elements of reverse logistics and municipal solid waste management processes. The third section presents the hierarchy of qualitative methods and models for researching reverse logistics and waste collection aspects. The fourth section analysis the role of reverse logistics; and the fifth part—packing and recycling aspects. The sixth section highlights the relationship between a three-level methodology between reverse logistics and municipal waste and describes a dynamic regression model. The seventh section presents results of the dynamic regression model, i.e., helping to forecast the recycled biowaste amounts.

2. Literature Review

Reverse logistics is the activity that includes the reverse distribution of materials, as well as reducing the number of new materials in the forward system [7–9]. According to De Brito et al., reverse logistics focuses on the recovery of products when they are no longer desired (end-of-life products such as computers or mobile phones) or can no longer be used (end-of-life products, i.e., tires and packaging) to obtain economic returns through reuse, recycling or recycling in new production [10–12].

Other authors note the importance of environmental requirements and the increasing role of the reverse supply chain in the extraction of materials [13–16]. Valenzuela et al. examined recycling models for plastics based on a reverse logistics model and a waste recycling model and also pointed out that the reverse logistics process is a process from consumption to point of origin that includes the planning, execution and effective control of the costs of raw materials, work in progress, finished goods and related information, to recover the primary value of materials or dispose of them properly [17]. Table 2 presents the main elements of reverse logistics described by different authors.

Table 2. Essential elements of reverse logistics.

	Elements	References
Essential elements of reverse logistics	Operation cost	[18–42]
	Recapture value	[18,21,24,26,28,30,35,41]
	Technical feasibility	[24,28,29,35,40,42–44]
	Recycling network	[18,19,22,25,26,28–30,33,36,40–48]
	Return cost	[25,30,32,35,42,43,49]
	Remanufacturing network	[18,21,26,30,36,42,44,48–50]
	Recovery value	[18,25,36,44,49,50]
	Reuse network	[18,20,21,27,28,31,33,41–43,45–47,50]
	Product recovery	[18,19,21,23–26,28,30–34,39,42,49,51,52]
	Environmental impacts	[18,20,21,23,24,27–31,33,35,36,38,40–43,45–47,49–53]
	Service management	[18,20,34,37,40,44,49–51,53]
	Market demand	[18,19,30,32,34,37,44,50,53]
	Sustainable development	[22,23,27–31,35–37,40,44–46,51,53,54]
	Green effect	[20,22–27,34–37,39,40,44–46,49,51,52,54]
	Product return	[18,21,23–25,30–32,34–36,39,41,42,45,48,49,54,55]
	Closed loop supply chain	[24–26,29,30,32,35,40,42,50–52,55]
	End-of-life product	[18,19,21–26,35,39,42,43,50,55]

Table 2 shows that in recent years the publications describing the processes of reverse logistics, necessarily emphasize the impact of such processes on the environment and sustainable development, green effect and others, which are disclosed in more detail in the table.

Municipal solid waste (MSW, as specified in Appendix B) includes refuse from households, non-hazardous solid waste from agriculture areas, commercial and institutional establishments (including hospitals), market waste, yard waste, and street sweepings [56]. MSW, which is defined as waste that is collected and treated by the municipality. MSW is the term applied to domestic waste and domestic-type industrial waste (paper, plastic, electronic appliance waste).

MSW includes everyday items used and then thrown away, called rubbish or trash in everyday life. According to Vergara et al. MSW is all solid or semi-solid materials disposed of by residents and businesses, excluding hazardous wastes and wastewater [57]. MSW includes food packaging, bottles, clothing, furniture, lawn clippings, scraps of foods, newspapers, household appliances, paints, and batteries [14,47]. The primary producers of solid waste are in residential areas such as apartments, houses, companies, schools, hospitals and others.

According to Ogwueleka, MSW management is the management of waste in urban areas in terms of its collection, transfer, treatment, recycling, reuse and disposal [56]. The main goals of MSW management are related to the promotion of the quality of the urban environment, the creation of jobs and income, the protection of environmental health and the maintenance of economic efficiency and productivity [56,58]. The definition of MSW does not include building rubble, waste from the demolition of buildings and structures, and wastewater from municipal sewage treatment plants and sewer networks.

Table 3 shows the trends that many authors in their scientific papers emphasize waste management, waste minimization and reduction, green images in the above-mentioned processes.

Table 3. Essential elements of MSW.

Essential elements of MSW	Elements	References
	Waste reusing	[18,26,31]
	Waste incineration	[21,23,28,32,42,47]
	Air emission	[22,31,40,47]
	Carbon footprint	[18,20,21,26,30,36,39,46,47,49]
	Waste recycling	[19,21,32,35,37,39,51]
	Waste disposal	[20–26,31,39,41,43,47,51]
	Zero Waste	[21,32,47,51]
	Responsible use	[24,26,31,35,40,41,45,46,51]
	Waste treatment	[22,26,28,29,39,46,52]
	Waste use for energy	[21,26,45,51,53]
	Green image	[18–20,22,24–26,30,34,35,40,42,43,45,46,50,52,54]
	Waste generation	[18–20,22,28,29,31,40,42,43,47,50,55]
	Waste minimization (reduction) & recovery	[20–22,25–27,29,32,35,40,43,45,47,50–52,55]
	Waste landfilling	[21,23,24,28,30,32,35,42,47,55]

The similarity of household waste shows how household waste can be classified according to the European classification. It is the European classification possibility proposed by Eurostat for the scope of municipal waste. Waste organisation is based on the principle that municipal waste includes household waste and waste from non-household sources, regardless of the division of responsibility for municipal waste collection that rests with the municipality or individuals [59]. Typical household and commercial solid waste include clothing, disposable utensils, garden waste, cans, disposable office tables, paper and boxes. In contrast, institutional and industrial solid waste includes restaurant waste, paper, school waste, wooden pallets, plastics, corrugated boxes, etc. and office documents [60,61].

3. Municipal Waste Recovery and Disposal Categories vs. Reverse Logistics

The authors identify the interface between reverse logistics and MSW. Some directions are identified in previous studies. The authors focus on such directions: (1) the comparison of urban solid waste and municipal governance practices in several European countries to identify the characteristics and main aspects of waste management and physical reverse logistics by modelling logistics for urban solid waste; (2) the improvement of decisions at the operational reverse logistics level for electronic equipment waste; (3) the design of reverse logistics network for electrical and electronic waste in Turkey; (4) the construction of routes used for the management for urban solid waste in Brazil; (5) creation of optimal reverse logistics network for determining the carbon footprint; (6) the production planning for products repair and recycling based on reverse logistics network management and other studies cited in Table 4.

Table 4. Hierarchy of qualitative methods and models for researching reverse logistics and waste collection aspects.

Model Type	Model Technique	Solution Method	References Discussing Reverse Logistics and Waste Collection
Mathematical programming method	Single objective	Linear programming	[62–66]
	Multiple objectives	Mixed-integer linear programming	[67–72]
		Mixed-integer programming	[73,74]

Table 4. Cont.

Model Type	Model Technique	Solution Method	References Discussing Reverse Logistics and Waste Collection
		Multiple regression	[75,76]
		Analysis of hierarchical regression	[77]
		Fuzzy-goal programming	[78]
		Stochastic dynamic programming	[79]
		Non-linear programming	[80,81]
	Time series	Dynamic regression analysis	<i>this study</i>
Causal models	Causality identification methods	Causal effect modelling	[82]
		Diagram of causal systems	[83]
Heuristic methods	Simple heuristic	Simulated annealing heuristics	[84]
	Artificial intelligence techniques	Markov chain	[85]
		Object-oriented Petri nets	[86]
		Bayesian network modelling	[87]
		Fuzzy logic	[88]
		Rough sets	[89]
		Neighbourhood rough sets	[90]
		Metaheuristic	Genetic Algorithm Multi-objective evolutionary Algorithm Multi-objective differential evolution algorithm Particle swarm optimisation Ant Colony Optimization
Analytical models	Multi-criteria decision making	Analytical hierarchy process	[97]
		DEMATEL	[98]
Analytical models	Systematic models	Delphi method	[55,99]
		Network model	[100]
References Discussng Reverse Logistics and Waste Collection		Description of Study	
[62]	Linear model is constructed for co-collecting separated waste streams and for integrating reverse logistics delivery and collection activities.		
[63]	Linear model is presented production-recycling-reuse of plastic beverage bottles in the context of reverse logistics and waste management.		
[64]	A manufacturing/remanufacturing inventory model is formed with waste disposal and developed reverse logistics process for energy used.		
[65]	Linear programming model presents the impact of waste pickers activities result on the reverse MSW logistics network.		
[66]	Model is suggested for integrated forward-reverse logistics with carbon footprint considerations.		
[67]	MILP model includes reverse logistics networks for returned medical waste seeking to improve medical waste management.		
[68]	Reverse logistics network is constructed that sources end-of-life products.		
[69]	Model is developed for the planning and management of the electronic waste collection system in the city of Genoa.		
[70]	MILP model is formed for determining the best WEEE recycling offer price by determining reverse logistics operation planning strategies.		
[71]	Optimization reverse logistics activities are described with MILP model of end-of-life vehicle recycling.		
[72]	Model is developed to determine which recycling strategy is should be selected for commercial waste.		
[73]	Heuristics is suggested for the configuration of reverse logisticsnetworks serving the recycling of electronic appliances and computers.		
[74]	Regression method is used to investigate the relationship between food firm competitiveness and reverse logistics attributes important for waste management.		

Table 4. Cont.

Model Type	Model Technique	Solution Method	References Discussing Reverse Logistics and Waste Collection
[75]	Major factors are examined that may influence industries to implement reverse logistics, among which is the regulation of the waste amount.		
[76]	Four-step hierarchical regression analysis is used seeking to motivate firms to implement reverse logistics to handle e-waste.		
[77]	Fuzzy goal programming is presented for a lead/acid battery reverse logistics network design.		
[78]	Model of stochastic dynamic programming is presented for reverse logistics interaction with production planning of the re-manufacturing system, determining the amount of recycled waste.		
[79]	Non-linear model of multifunctional reverse logistics is constructed for planning and design of an optimal computer waste management system.		
[81]	Causal effect model is proposed to describe the need for the collection of agricultural waste (i.e., pesticide packaging).		
[82]	Diagram of the causal system is used to create a new WEEE handling system based on two flows a forward and reverse logistics flows.		
[83]	Simulated annealing algorithm is tailored to generate a solution using the output of an e-recycling reverse logistics network.		
[84]	Markov chain approach is used for presenting retailer reverse logistics which deals with waste handling.		
[85]	Petri net forecasting model is suggested for household waste and model reverse logistics network.		
[86]	Bayesian network is constructed for the reverse logistics that are used for product recovery and waste reduction.		
[87]	Simulation model is presented for reverse logistics network collecting end-of-life appliances.		
[88]	Rough set theory is applied to reduce the complexity of the RL for the company involved in waste management.		
[89]	Neighborhood rough set conceptual application is developed for management decisions within the context of reverse logistics and defective products.		
[90]	Genetic algorithm is presented to model the reverse logistics network for medical waste management.		
[91]	Model is constructed for the selection of solid waste transfer stations under a reverse logistics network.		
[92]	Optimization of the flow distribution of e-waste reverse logistics network is researched to obtain Pareto optimum solution with an evolutionary algorithm.		
[93]	Differential evolution algorithm is used to design product return network to balance costs and loads.		
[94]	Reverse logistics network optimization model is proposed which fully considered environment effect and the waste recycling factors.		
[95]	Model of multi-objective ant colony optimization (MACO) algorithm is suggested for reducing reverse logistics cost considering environmental factors was verified through a simulation on waste textile product reverse logistics.		
[96]	AHP technique is proposed for the decision-making process to evaluate strategies for obtaining optimal strategies in reverse logistics that collects used products as a waste.		
[97]	DEMATEL technique is suggested as a decision-making tool used to design reverse logistics for collecting textile waste.		
[55]	Delphi method is used to develop a model to select the most appropriate firms for the treatment of infectious waste objectively and efficiently.		
[98]	Solution is proposed for assessing the green practices including reverse logistics and use of waste.		
[99]	Network model is presented to rank the alternatives for implementing the process of reverse logistics, which include three major stages: waste collecting, sorting and reprocessing.		

In Table 4, the authors examined the type of qualitative methods and models dedicated to reverse logistics and waste collection are used by other authors for their research. Among the methods, the most popular is the mixed-integer linear programming method in studies dedicated to the above-mentioned topic [100]. The authors identified that the dynamic regression model is not mentioned among above listed quantitative methods. Time series analysis could help to identify the capacity that is required to handle reverse logistics at different periods to perform waste collection and recycling.

Reverse logistics principle, evaluation and recycling of organic waste is relevant for both developing and economically developed countries from the point of view of solving current problems in waste management. Reverse logistics focuses on adding value to the product to be disposed of.

The implementation of life cycle processes (LCA) is an essential tool in reverse logistics. The life cycle assessment includes alternative material concepts and various components from the extraction of raw materials through the use phase to recycling; alternative ideas are implemented over the entire product life cycle, starting with the development process [101,102].

In Table 5, the authors briefly summarize the main sources and types of waste, with a description next to each.

Table 5. Municipal waste by source and types, modified by authors following [103].

MSW Source	Types of Solid Waste	Description
Agriculture	Solid waste, which includes waste from the food and meat processing industries, industrial, agricultural, yard, garden and plant debris, and medical solid waste, as well as hazardous solid and chemical waste	Agricultural activities associated with the preparation, production, storage, processing, and consumption of agricultural products, livestock, and processed products generally generate solid agrarian waste.
Commercial	Food wastes, metals, glass, special wastes, plastics, paper, cardboard, wood, hazardous wastes	Commercial Waste or MSW is produced in businesses and includes general waste, mixed dry recyclables and organic waste.
Household	Textiles, food wastes, metals, glass, special wastes (batteries, consumer electronics, oil, tires, bulky items), plastics, paper, cardboard, wood, ashes, household hazardous wastes	Household Waste or MSW is produced in our homes and includes general waste, mixed dry recyclables and organic waste.
Institutional	Food wastes, metals, glass, special wastes, plastics, paper, cardboard, wood, hazardous wastes	Actions address waste materials originating in institutional facilities, such as government offices, schools, hospitals, nursing homes, correctional facilities, research institutions and public buildings.
Municipal service	Street-cleaning residues, trimmings landscape and trees, collecting general wastes from recreational areas (such as parks, beaches, etc.)	Household waste and waste of a similar type and composition are taken into account by municipal waste.

Commercial household waste has similar properties and composition to household waste. Such waste can be collected separately from household waste in removable containers [104–106]. The waste management pyramid defines levels of waste prevention and management. Under the waste management pyramid there are stated waste management steps, which should be named [107–109]:

1. reduced,
2. reused,
3. repaired,
4. recycled,
5. recovered,
6. composted,
7. incinerated,
8. landfilled.

Reverse logistics are the processes of planning, implementation and control of the return flow of raw materials, production stocks, packaging and finished goods from the original production, distribution or use location to the final disposal. The flow goes from the customer, more precisely from the point of consumption to the manufacturer, more precisely to the place of origin, to dispose of them properly or to return the value.

This activity is due to some aspects of environmental protection. However, most of them relate to issues respecting the correct distribution of waste. From this, we can conclude that reverse logistics is associated with garbage, especially those that are suitable for processes that restore their useful functions and for processes that are safe distance [17,110].

Based on reverse logistics, the ultimate goal of a company must be resources reduction, that is, waste and energy savings producing greener products reduction [20,21,26]. In such cases, the company should reuse the materials and make an effort to maximise waste recycling. In this case, reverse logistics at the end of the chain would focus on waste disposal [52,86]. Any predictable returns or pattern that recurs or repeats over one year is said to be a seasonal return.

Reusing waste management, proper handling and recycling, that is, activities in the return channel indicates the connection between waste management and take-back logistics [14,15,17,110]. Remove items—any waste management element that needs to be removed.

When it comes to waste management, reverse logistics plays a vital role [6,7]. As we can see in Figure in Appendix A, reverse logistics is a process that allows organisations to reuse, reduce, use energy, landfill and recycle waste generated at various points in their value chain [18,34].

The links between the supply chain, return logistics and waste management processes are also evident in the diagram [16,35]. Returning goods will always be part of the business, but it is not worth considering only an operating expense. Properly implemented reverse logistics processes can improve a company's performance [3,15]. In addition, better management of returned goods will help reduce waste and generate higher profits, as the same goods can be reused [103,104].

Reverse logistics differs from traditional waste management in that it adds value back into the chain by recovering and repurposing products, while waste management mainly focuses on disposal [109]. Fundamental to reverse logistics is offering efficient, potentially profit-generating methods of disposing of end-of-life products and waste [17,110]. A well-integrated waste management system encompasses government, business and society [10,61,107].

What is considered a waste to someone today may be a resource in the future, asserted by the authors [111,112]. They further point out that waste in one industry may be a raw material in another industry in recent industrial development.

Municipal waste and waste, in general, can be treated as redundant objects, which have lost their initial functionality, but that present value in terms of their secondary function [113,114].

Table 6 shows that the municipal waste is distributed according to recycling, landfill, incineration, composting by million tones and by kilograms per capita in the years from 2010 to 2019, when the numbers are presented as the European Union average [115]. The numbers of recycling and composting are growing. However, the volume of landfills is decreasing, and waste incineration is increasing. The environmental impact of incinerated waste is highly dependent on the nature of the trash that is disposed of.

Table 6. Municipal waste by waste management operations, EU-27, 2010–2019 [116].

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	million tones									
Recycling	55	56	58	56	59	63	65	66	67	68
Composting	29	29	30	31	33	33	36	38	38	39
Incineration	53	55	54	56	57	57	58	59	59	60
Landfill	79	74	67	63	59	57	54	53	52	53
Other	6	6	6	5	4	4	5	6	6	4

Table 6. Cont.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	kg per capita									
Recycling	125	128	130	128	134	141	146	148	149	152
Composting	66	66	69	71	73	75	82	85	84	87
Incineration	121	125	122	127	128	128	131	132	132	134
Landfill	178	167	153	142	134	127	121	118	116	119
Other	13	13	14	10	9	9	10	13	13	10

During recycling, waste is recycled into products or materials. Waste is sorted from the general waste stream [117]. In such cases, on-site processing in industrial plants is excluded. Other categories of waste are composition or decomposition. The processing of organic substances by aerobic or anaerobic processes and the processing into substances that can be used as fuels and for energy generation do not belong to the waste treatment category. In the case of household waste, they are recycled directly or after their pre-treatment.

Both composting and decomposition are biological processes in which biodegradable waste is decomposed aerobically or anaerobically. The products of these processes are composted or gestate. After any further processing, agriculture benefits or in the hope of using it wisely, the ecology is used as a recycled product or as a material for tillage [118]. Municipal waste can be composted directly or after pre-treatment [119]. If the product after treatment is subsequently disposed of in a landfill, incinerated or otherwise not used for the above purpose, in which case the biological treatment of the waste MBT (mechanical-biological treatment) cannot be considered as composting [118]. Wastes from composting/fermentation and incineration of debris from another recovery/disposal operation to be recycled materials as metals [115,120].

Incineration is the thermal treatment of waste in an incineration plant. Incinerate immediately or after pre-treatment, possibly municipal waste. Incineration of municipal waste makes it possible to obtain as secondary fuel [107,121,122].

The landfill is defined as waste discharge into the ground and temporary storage in permanent places for more than one year [120]. Landfills with internal (waste generator itself eliminates waste generation) and external sites are defined. Municipal waste is disposed of in landfills either directly or after pre-treatment. If a sorting step is performed in the landfill area, the sorting results are assigned to the proper recovery/disposal operations [103,110].

4. The Role of Reverse Logistics

Reverse logistics processes offer companies the opportunity to become more environmentally friendly through reuse, recycling and recovery [5,15]. A material reduction in a direct system based on minimum return quantities, possible material reuse, and simplified recycling create a more comprehensive picture of reverse logistics [109].

The traditional supply chain uses resources from the environment. Such resources are converted into valuable products, and the cycle is considered complete when the product arrives and is distributed among consumers [121–124]. It is noteworthy that secondary raw materials follow “reverse sales channels”, which are more associated with a reverse logistics strategy than with a method of using traditional sales and logistics channels [125]. Reverse logistics is defined as “... the role of logistics in product returns, serving activities such as reduction, recycling, material replacement, material reuse, waste disposal and recycling, repair and recovery ...” [126]. In reverse logistics, an integrated approach is used to be successful. By definition, reverse logistic activities take many forms. Rogers and Tib-ben-Lembke [124] classify the list of possible reverse logistics actions. The activities are classified according to the materials used in products and packages in which products are delivered (see Table 7).

Table 7. Reverse Logistics serving Activities, constructed by the authors following [123].

Materials in	Reverse Logistics Serves such Activities
Package & Products	Reduce
	Reuse
	Repair
	Recycle
	Recover
	Compost
	Incinerate
	Landfill

In Table 7, the authors highlight the main activities served by reverse logistics.

Reduce is an activity that minimises the quantity and use of materials that cannot be recycled.

Reuse—an activity to clean, repair products and materials in products for reuse without any pre-processing steps.

Repair—the fixing of broken items in products and materials.

Recycling is the removal of material from a recycled product or package. These are carried out to recycle a product or packaging as raw material for a new product or packaging [127,128]. During waste collection, the driver should know that will be the further step. If the waste will be recycled the driver should not mix different waste streams by putting them into the truck.

Recover activity uses technologies and methods allowing to recover materials from mixed wastes.

Composting—activity, which separately collected waste converts into biowaste.

Incineration is an activity, which helps to transform waste into energy, plastics to fuels, and other resources.

The landfill is a site for the disposal of waste materials, also known as a tip, dump, rubbish dump, garbage dump, or dumping ground.

The main problem is that all products and/or packaging are sent to landfill when recycling is not involved [129].

When forward logistics end, reverse logistics begins. In the beginning, consumers buy the product they need, such as a newspaper or a soft drink. After reading a newspaper or drinking a soft drink, the product usually runs out, or the newspaper read becomes irrelevant, the product's useful life ends [130]. And then, consumers have to decide how to dispose of waste properly. It depends on consumers decision to dispose of leftover packaging or unwanted newspapers. Their choices are potentially substantial long-term effects on the environment [131]. Several factors must be considered, such as the activities that encourage a particular disposal method or financial incentives.

The reason for this is that in many cases, the price of the container, such as an empty soda bottle or a used newspaper, is not apparent to consumers or manufacturers, so there may be an incentive to recycle used raw materials be pretty low. The value of such a secondary or residual product will only increase as a potential raw material for a new product [129]. Therefore, the supply and demand for secondary raw materials must be developed to have value from new raw materials. The focus here is on reverse logistics.

5. Packing and Recycling

The packaging protects products that are placed on the market for sale, storage, use, etc. The packing generally relates to the design, evaluation and manufacture of packaging. Packing is critical for the movement of products that are distributed in large quantities. Improper packing could cause handling problems during reverse logistics activities. Common packaging materials are boxes, cardboard boxes, cans, bottles, pouches, envelopes, packages, and containers [132].

The increased demand for packaging has led many companies to look for methods and ways to improve packaging design to increase sales of their products [133]. Attractive, durable packaging design not only protects goods from damage and/or breakage but also helps to attract the end user's attention.

Packaging types and methods are presented in Table 8.

In Table 8 the authors briefly summarize the main packaging types and methods, with a description next to each.

Decisions about the choice of primary, secondary and tertiary packaging are of great strategic importance. In this article, we describe the key concepts for choosing product packaging from a logistics perspective and the difference between primary, secondary, and tertiary packaging [134–137].

Primary packaging is designed to contain, store and protect products. It is in direct contact with the product and is designed to keep it in optimal conditions. This packaging is the least used, so it does not complicate a single sale of goods. Primary packaging forms are jars, cans, bags, bottles, sacks, etc., [138].

Secondary packaging consists of an aggregate of primary packaging. This type of packing further protects the product and makes it easier to market on a larger scale. These are mainly cardboard boxes, although they can also be plastic. For example, in the case of milk, a single carton would be the primary packaging, and the carton containing the carton would account for the secondary packaging [138,139].

We need tertiary packaging to create larger units of loads, which includes primary and secondary. The most common forms of tertiary packaging are pallets, containers, and the modular cartons they contain. A distinction is made between three packaging types, which depend on the function and purpose: individual packaging, inner packaging and outer packaging [138,140].

Individual packaging is used for packaging each particular product. The unique packaging aims to protect the product from various climatic influences such as cold, heat, moisture, light, and wind [141].

The inner packaging is a unit that is sold in retail stores. It is used to bundle or group individually packaged products into a unit, such as lollipops in pouches. Each individually packaged candy is additionally grouped by weight in a single pack. Attractive packaging design is essential to arouse the consumer's desire to buy and thus to stimulate sales. It is, therefore, necessary to pay attention to the interior design of the packaging [142].

The most extensive packaging in which products are packaged in outer packaging is the outer packaging, such as cardboard boxes or wooden boxes. The primary purpose of the outer packaging is to protect products from breakage, dirt and elements [143].

Following the pyramid of plastic waste management, it is vital to prevent plastic use, reduce unnecessary plastics, and use reusable plastics designed for long life. It is suggested to recycle low-value plastics and produce recyclable high-value materials.

Recycling is understood to mean the flow of valuable materials [7,124]. For example, the bottle-from-bottle recycling method leads the industry and results in 100% recycled plastic used in bottles for cleaning and handwashing. Thus, recycling achieves a good green triple effect: less waste is sent to landfills, 70% less energy (as primary energy) is used for resin production and beautiful bottles are made from recycled plastic [144].

- For hand washing detergents, dishwashing detergents and sprays made from 100% PCR (post-consumer recycled), 100% recycled plastic is used, i.e., all plastic bottles made from 1-PET. Compared to using pure plastic, PCR has about 70% less carbon footprint.
- 50% recycled plastic is used in 2-HDPE bottles, ranging from 25% PCR in our toilet cleaners to 50% PCR in our detergent with 8× magnification.

Recyclable design is a closed packaging solution. With this in mind, recycling systems have been carefully researched to determine which plastics and packaging materials are suitable for recycling. Bottles are designed to be compatible with this purpose whenever

possible. With this method, all packaging is developed to maximise recycled content, materials, efficiency and recyclability [145].

Table 8. Packaging types and methods.

Packaging Types	Packaging Methods	Description
Anti-corrosive Packaging	<ul style="list-style-type: none"> Papers and films with volatile corrosion protection (VCI) Moisture-absorbing barrier aluminium foil Oil or liquid coating methods 	Corrosion protection packaging should protect products from corrosion and avoid lengthy operations. Various materials are used to protect goods from the effects of different climatic conditions, such as paper, oil, bubble wrap with VCI, chips and bags, which are used as part of the anti-corrosion package.
Packaging of Pharma [50]	<ul style="list-style-type: none"> Primary Package Secondary Package Tertiary package 	During packaging of drugs or pharmaceuticals, the package goes through processes from production plants via distributing companies to end consumers. The package of pharmaceutical products is designed to ensure drug safety, ease of use and product safety upon delivery. The primary purpose of pharma packaging is to equip vital medicines for surgical devices, blood and blood products, liquid and bulk dosage forms, and solid and semi-solid dosage forms while maintaining their original condition and properties. The packaging described is used for delivery, etc.
Plastics Packaging [51]	<ul style="list-style-type: none"> Bottle made from bottle Design for recyclability Refills method 	Plastic packaging is mainly used for packaging various items such as fragile or non-perishable products. In addition, plastic packaging materials are used for coating materials or plastic-related products. For reuse in their factories, most plastic packaging companies recycle waste or plastic waste and offer alternatives.
Flexible Packaging [52]	<p>Recycling of such types *:</p> <ul style="list-style-type: none"> PET or PETE HDPE LDPE PV PP PS Other plastic 	Flexible packaging can be easily reshaped and defined as any packaging. If you choose flexible packaging, it has some benefits: <ul style="list-style-type: none"> Provides safety for food products and shelf life indications through heat seal tightness, clogging prevention, ease use solutions and high print quality. This packaging type generally reduces landfill waste as it creates little waste in printing processes. Improvement of the production processes, reducing greenhouse gas emissions and volatile organic compounds, energy consumption, and water. By using lighter and more flexible bags, more respect for nature, a lower environmental impact and lower consumption of energy and fossil fuel during transport are achieved.

* PET or PETE—Polyethylene Terephthalate, HDPE—High-Density Polyethylene, LDPE—Low-Density Polyethylene, PV—Polyvinyl, PP—Polypropylene, PS—Polystyrene.

The refuelling method ensures that only the required amount of plastic and other materials are used. Most of the plastic waste consists of containers and packaging. Almost

13% of all solid household waste is made up of various plastics. When looking for ways to make packaging as green as possible, researchers always emphasise the need to find additional ways to reduce environmental impact. For example, easy-to-use bags for replenishing supplies for manual, automatic, and dishwashing detergent save around 80% of plastic, water, and energy compared to a disposable bottle [146].

Different possibilities of recycling flexible packaging and plastic materials [136,147]:

- Polyethene terephthalate is the easiest to recycle. It is widely used in beverage bottles and food packaging (PET or PETE).
- High-density polyethene usually is used recycled into plastic bottles and bags, also used for thicker bottles for motor oil, bleach, and hair products (HDPE).
- A thinner, low-density polyethene is used to make plastic freezer bags and grocery bags. It can be recycled back into plastic bags (LDPE).
- Polyvinyl chloride is difficult to recycle and is environmentally hazardous, but it is used to manufacture furniture and pipes (PVC).
- Fibre plastic—polypropylene can be recycled into fibre materials for further use in clothing, roper, and other ways (PP).
- Polystyrene is used to make packaging materials, foam cups and other lightweight products. Because of its low density, it is difficult to recycle, but it can be reused (PS).
- Other plastics include polymer fibres, acrylic, polycarbonate, nylon, and fibreglass.

In industry, it's a good idea to assess the optimisation level of the packaging in terms of the material it is made of, transportation, handling and storage, waste management, and cost. Only with the overview of the process will you be able to choose the logistics packaging best suited to the company's application [148,149].

To raise awareness among customers, help them increase sales, and make them aware of the latest trends, many companies use the packaging methods listed in Table 9.

Table 9. Types of plastics and the examples of their applications in packing.

Plastics Types	Examples of Applications
Polyethene terephthalate (PET or PETE)	Fizzy bottles, bleach, cleaners and most shampoo bottles
High-density polyethene (HDPE)	Most shampoo and cleaner bottles, bleach, milk bottles
Polyvinyl chloride (PVC)	Thermal insulation (PVC foam) and auto parts, fittings, pipes, door and window frames (hard PVC)
A thinner, low-density polyethene (LDPE)	Bin liners, packaging films, carrier bags
Fibre plastic—polypropylene (PP)	Microwave-safe food bowls, margarine barrels, carpet fibres and threads, wall coverings and upholstery for automobiles
Polystyrene (PS)	The insulating material in construction, foam boxes for eggs and hamburgers, plastic cutlery and plastic cups for yoghurt, protective packaging for electronic items and toys
Other plastics	Plastics that do not fall into any of the categories listed above, such as B. Polycarbonate, which is widely used in the aerospace industry for glazing

In Table 9, the authors provide examples of how individual types of plastics can be used in packaging.

By choosing these methods, the packing of products delivers ideal results. Using these packaging methods, the shelf life of the products is extended, and competitive advantage is created. In addition, innovative packaging design maximises product profitability [138–149].

6. Materials and Methods

The collection of municipal waste involves operations of reverse logistics, including sorting, storing, and transportation. This study aims to figure out the effective actions important for decision-making helping to achieve sustainable development.

Various stakeholders make decisions:

- Producers, which decide which materials have to be used in products and in which volume, what should be their packing materials and what should be production methods;
- Retailers, which select and provide packing materials to consumers;
- Consumers, which apply to sort and products reuse practices;
- Logistics service providers implement a reverse logistics service management system.

The authors divided the methodology into three layers which present the connections of municipal waste and reverse logistics (see Table 10).

Table 10. Three-level methodology highlighting the connection between municipal waste and reverse logistics.

Level	Relationship to Reverse Logistics	Description of Municipal Waste Generation Minimisation by Stages	The Application of Methods	Links with Sustainability
1st level Use of environmentally friendly materials	The physical system supports the production and the reduction of the use of material.	<ul style="list-style-type: none"> • Selection of recycling supporting products and packing materials during production and selling stage. 	<ul style="list-style-type: none"> • Review of literature; Statistical analysis; • Statistical analysis. 	<ul style="list-style-type: none"> • The decision helps to minimise the negative impact on the environment.
2nd level Collection of municipal waste	The physical system is used for the collection of municipal waste from end-users.	<ul style="list-style-type: none"> • Sorting during the collection of municipal waste. 	<ul style="list-style-type: none"> • Panel data analysis; • Regression analysis. 	<ul style="list-style-type: none"> • Waste reduction and long-term sustainability supporting system.
3rd level Transformation of collected municipal waste	The physical system that supports recycling.	<ul style="list-style-type: none"> • Selection of methods that allows prolonging the life of materials. 	<ul style="list-style-type: none"> • Comparison; • Investigations. 	<ul style="list-style-type: none"> • Decision helping to save natural resources.

Table 10 provides a summary highlighting the link between municipal waste and reverse logistics with the help of a three-level methodology, providing descriptions, relationships and methods specific to each level.

For the research, the authors used such indicators, such as

- (1) Recycling of biowaste;
- (2) The recycling rate of e-waste;
- (3) The recycling rate of municipal waste;
- (4) The recycling rate of packaging waste by type of packaging.

The yearly data was retrieved from Eurostat for 30 European countries (27 European Union countries, Island, Norway and United Kingdom) for the period 2000–2019 [120]. In total it was 4359 data sets with the values.

The authors revised the data, constructed a correlation matrix and selected for the regression model only elements that have a probability lower than 0.1 (Table 11). The novelty of the study is that the authors constructed a dynamic regression model, by analysing the impact in year t and year $t-n$. The authors of this work use the dynamic regression model first applied by Petris et al. [150]. The first step in the modelling procedure was the transformation of time series to help identify the dependent variable and its relationships to the regressors. The developed model meets the requirements important for the construction of a simple regression model but provides dynamic interrelationships.

Table 11. Correlation matrix of variables transformed into dlog.

Covariance Analysis: Ordinary					
Sample: 56 577					
Included observations: 40					
		Recycling of biowaste	Recycling rate of e-waste	Recycling rate of municipal waste	Recycling rate of packaging waste by type of packaging
Recycling of biowaste	Correlation coefficient Probability	1.0 -			
Recycling rate of e-waste	Correlation coefficient Probability	−0.08 0.59	1.0 -		
Recycling rate of e-waste (−1)	Correlation coefficient Probability	0.10 0.52	0.10 0.53		
Recycling rate of municipal waste	Correlation coefficient Probability	0.86 0.0	−0.17 0.26	1.0 -	
Recycling rate of municipal waste (−1)	Correlation coefficient Probability	0.26 0.09	0.31 0.04	0.38 0.01	
Recycling rate of packaging waste by type of packaging	Correlation coefficient Probability	0.36 0.02	−0.07 0.65	0.54 0.00	1.0 -
Recycling rate of packaging waste by type of packaging (−1)	Correlation coefficient Probability	−0.15 0.35	0.17 0.29	−0.06 0.70	−0.24 0.12

Table 11 summarizes the correlation analysis performed for this study, noting the level of correlation between the elements listed in the table. The constructed Table 11 shows the link between the recycled rate of packing waste and the recycled rate of municipal waste, as packing waste is part of municipal waste. Table 11 indicates that for the recycling of biowaste the recycling rate of municipal waste (with probability 0) the same year strongly correlates.

The authors constructed a dynamic regression model helping to identify the amount of biowaste that is recycled. The completed equation is presented below (1).

The authors use the regressors in constructing mathematical equation:

$$rec_biow_t = \beta_0 + \beta_1 rec_biow_{(t-n)} + \beta_2 rec_mu_{(t-n)} + u_t \quad (1)$$

where: rec_biow_t —dlog of recycling of biowaste in year t , which is expressed in kg per capita; β_0 —intercept in the equation; $rec_biow_{(t-n)}$ —dlog of recycling of biowaste, in year $t - n$, which is expressed in kg per capita; $rec_mu_{(t-n)}$ —dlog of recycling rate of municipal waste, in year $t - n$, which is expressed in kg per capita; u_t —random error of regression model and $\beta_{1,2}$ —the influence of regressors on biowaste processing reflected coefficients of elasticity.

7. Results

The results show that residuals of the equation spread following normal distribution (Figure 1).

Figure 1. Normal distribution formed from equation residuals.

Figure 1 shows that the average of residuals approximates to zero. The forecasting of volumes of the recycled biowaste are presented in Figure 2.

Figure 2. Forecasting the recycled biowaste level by the European Union countries.

The formed equation of the dynamic regression model is specified below (2) by defining coefficients and standard error:

$$rec_biow_t = -1.1 + 0.091 rec_biow_{(t-1)} + 0.23 rec_mu_{(t)} \quad (2)$$

(0.75) (0.012) → (0.036)

Seeking to identify concrete values for dynamic regression model (2), the authors used the Panel least squares method and presented the results of method application in Figure 3. Where Durbin-Watson statistics is 2.20.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.104664	0.752624	-1.467750	0.1428
REC_BIOW(-1)	0.916663	0.012444	73.66330	0.0000
REC_MU	0.238563	0.036551	6.526858	0.0000
Root MSE	8.526593	R-squared		0.972816
Mean dependent var	53.36563	Adjusted R-squared		0.972716
S.D. dependent var	51.76258	S.E. of regression		8.550072
Akaike info criterion	7.135226	Sum squared resid		39768.43
Schwarz criterion	7.158833	Log likelihood		-1948.484
Hannan-Quinn criter.	7.144453	F-statistic		9733.870
Durbin-Watson stat	2.206447	Prob(F-statistic)		0.000000

Figure 3. Formation of equation (2): panel least squares revision method.

The application of the method shows that the adjusted R squared is 0.97. The statistical validity is revised by applying the Lagrange multiplier tests. The tests show the correct statistical validity. The probability for the Breusch-Pagan test is lower than 0.05. The detailed presentation of tests is presented in Appendix C.

8. Discussion

The returns management process deals with product returns from customers. These activities should be fast, controllable, visible and straightforward. Repeated returns can

also occur when the seller rejects the return and returns it to the buyer without a refund. A type of reverse logistics for packaging management aims to reuse packaging materials to reduce waste and recycle. In the article, the returns management process is considered as relating primarily to the avoidance of returns and the return of products from customers. Redemption actions should be quick, simple, visible and easy to use. It is also possible that custom-made items will be returned if the seller refuses to accept the buyer's return and sends the item back to the buyer. Another type of reverse logistics discussed in the article aims to reuse packaging materials to reduce waste and recycle. Also described other types of reverse logistics management for product repair, refurbishment, and rework, including refurbishment, remanufacturing, and reconditioning activities. Repairs include the disassembly, cleaning, and reassembly of products.

To achieve sustainable development, the authors point out the need to build and expand a sustainable network in all supply chain processes, i.e., production, logistics and reverse logistics. Furthermore, particularly sustainable development aims to draw attention to an integrated approach to ecological, social and economic aspects, which leads to long term, sustainable profit growth.

The development of sustainable reverse logistics and sustainable waste management is essential for environmental protection. By reducing the overall negative impact of logistics on the environment, sustainable return logistics aims to solve environmental problems while considering the costs of recycling and disposing of waste, especially municipal waste. Therefore, the article discusses sustainable practices such as recycling, reuse, waste reduction, product return management, etc., to achieve process efficiency.

The study has some limitations: the authors do not revise the process efficiency; they identify the options for how to increase recycling rates and provide the dynamic regression model, which proves that.

9. Conclusions

The links and interdependencies between municipal waste and reverse logistics are a new topic that other authors have not explored so far. This article reveals that municipal waste is strongly and directly related to reverse logistics processes. The paper also discusses essential elements of reverse logistics and municipal solid waste. The authors constructed the hierarchy of qualitative methods and models for researching reverse logistics and waste collection aspects and figure out that most often authors apply mixed-integer linear programming method.

The authors identified aspects of materials and their recyclability opportunities. Also, highlighted reverse logistics, which is playing an important role in seeking sustainable development. The authors provided a methodology that identifies connection points between municipal waste and reverse logistics. Reverse logistics appear as supporting production processes and the collection of municipal waste from end-users. The authors identified three levels of connection points. The second level of methodology was researched in a mathematical way seeking to identify interconnections between recycling and municipal waste generation. The authors determined that the link among the above-identified components is positive.

Further research directions could evaluate the impact of specific materials and production methods on improving recycling rates. The study could be also extended to other countries and the recycling of other waste streams could be added. Also, the authors could compare the flows of reverse logistics with forwarding logistics.

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Appendix A

Figure A1. Reliance on reverse logistics and waste management.

Appendix B

Table A1. The abbreviations and definitions of key terms in the paper.

Full name	Abbreviation	Definition
Reverse logistics	RL	<ul style="list-style-type: none"> Reverse logistics (RL) is the process of planning, implementing, and controlling the efficient and cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin to recapture value or proper disposal [9].
Municipal solid waste	MSW	<ul style="list-style-type: none"> MSW is defined to include refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste, and street sweepings [56].

Appendix C

The authors performed Residual Cross-sectional dependence test:

Residual Cross-Section Dependence Test

Null hypothesis: No cross-section dependence (correlation) in residuals

Equation: EQ01_2VAR

Periods included: 19

Cross-sections included: 30

Total panel (unbalanced) observations: 547

Test employs centered correlations computed from pairwise samples

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	615.87	435	0
Pesaran scaled LM	6.13		0
Bias-corrected scaled LM	5.29		0
Pesaran CD	-1.31		0.18

Figure A2. Residual Cross-sectional dependence test.

Figure A2 shows that Probability of Pesaran CD test is higher than 0.1. Also, the authors performed Redundant Fixed Effects tests:

Redundant Fixed Effects Tests

Equation: EQ01_2VAR

Test cross-section and period fixed effects

Effects Test	Statistic	d.f.	Prob.
Cross-section F	4.03	-29497	0
Cross-section Chi-square	115.64	29	0
Period F	1.40	-18497	0.12
Period Chi-square	27.16	18	0.07
Cross-Section/Period F	3.09	-47497	0
Cross-Section/Period Chi-square	140.34	47	0

Figure A3. Redundant Fixed Effects tests.

Figure A3 shows that Probability of Chow test is lower 0.05. Fix evaluation method is chosen properly.

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