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Impact of Management and Reverse Logistics on Recycling in a War Scenario

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Abstract: Nowadays organizations search to maximize their profits, particularly with regard to recyclable materials, making new strategies according to several emerging and changing scenarios. Logistics management is an important tool in achieving these goals, serving as a link between the market and the various areas of an organization. It is responsible for managing physical and organizational flows, both within and between organizations. Reverse logistics management of waste is one of the most complex areas in any organization, due to the financial effort needed in the separation and management of all waste, and due to the human resources allocated to those processes. The supply chain management paradigm, due to the emerging conflicts caused by war inducing extreme changes, shows that supply chains have massive difficulties and costs in obtaining raw materials, namely ferrous and non-ferrous materials. Thus, it is important to study the impact of management and reverse logistics on recycling in a "War" scenario, considering a case study from the Alto Minho region. This article's research has the objective to raise awareness of the possible impacts of improving operations in the context of the recovery and recycling of electrical and electronic equipment through the concept of reverse logistics management. The importance of the recovery of this waste, among others, will necessarily have a great impact on logistics operation and, in particular, reverse logistics. This process includes the collection, separation, storage, reprocessing and reintroduction of electronic waste into the production chains of raw materials and components. With the crisis in production and shortages of semiconductors and raw materials, as is the case with some metals from Russia and Ukraine (exponentially aggravated by the war), this is a credible alternative. This is also relevant to the treatment of waste in landfills, transforming and converting these into biogas, which can be converted into electricity and introduced into the energy network. With this situation we obtain a triple benefit: cheaper electricity, waste treatment, and protection of future generations and the reintroduction of raw materials into production chains; these results are only possible to obtain through reverse logistics management concepts.

Keywords: logistics management; reverse logistics; recycling; valorization; supply chain; war

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1. Introduction

Currently organizations seek to maximize profits, particularly with regard to reusable raw materials, adopting new strategies in the face of constant changes in various emerging scenarios, including the scenario of war in Europe, causing the cost of raw materials and non-essential foodstuffs to be less accessible due to a sharp inflation and thus emerging difficulties throughout the logistics chain. Logistics management is an important tool in obtaining a competitive advantage, serving as a link between the market and the various areas of an organization. In this way, a basic question is posed as to the importance of reverse logistics in supply chain management (SCM). After the industrial revolution in recent decades, we have seen a marked economic evolution, with benefits emerging in the quality of life of the population. This reflects a progressive and exponential appearance of new products on the market and an accompanying development in technological innovations, translating into ever shorter product life cycles. The revolution in production we are witnessing (Industry 4.0 and 5.0) [1], has caused one of the biggest dilemmas of today's society: how to face the dichotomy between mass consumption and environmental sustainability.

The current paradigm leads to an increase in disposable products and consequently to an imbalance between discarded and reused quantities, which will generate huge volumes of materials from post-consumption waste electrical and electronic equipment (WEEE). Strategically, organizations have perceived that reverse logistics should be an integral part of business actions, not only because of the reuse of products (post-consumption), but also because it gives them an appropriate destination [2].

This article aims to analyze the impact of reverse logistics in organizations, namely in the reuse and valuation of assets. The high economic growth seen in recent decades has enabled an improvement in the quality of life of the population.

At the beginning of the 21st century, waste was usually disposed of by landfilling [3]. With undersized landfills, synergies have been created to reintegrate waste into the original production processes in order to minimize the materials to be disposed of in landfills, as well as to reduce the consumption of natural resources. Therefore, this article will study a Portuguese company (Resulima, Apartado 11, 4935-308 Vila Nova de Anha, Portugal) where these processes are already practiced with very favorable benefits for the local and national economy, both in terms of the reuse and reintroduction of raw materials in the production chain and in the production of biogas through the process of anaerobic decomposition of waste and its subsequent use for generating electricity. It must be noted that there are countries where these philosophies and practices are developed, with a very positive result. The reintegration of waste into production processes allows for a more sustainable development, safeguarding future generations. The reintegration of recovered waste [2] into the supply chain (SC) will require an additional flow of materials and information, in the opposite direction to the traditional one, which allows the closing of the circuit.

Thus, the closed loop SC will have to encompass not only the traditional logistics activities which include supply, production, distribution and consumption, but also the activities associated with reverse logistics such as the collection, inspection/separation, reprocessing, disposal and redistribution of recovered waste [4]. It is in this sense that the recovery of waste and in particular WEEE associated with the management of reverse logistics, is an integral part of this whole process in search of continuous improvement in safeguarding our natural resources and our planet.

2. Literature Revision

2.1. The Impact of Reverse Logistics

Reverse logistics has been recognized as the area of business logistics that plans, implements and controls the flow and logistics information corresponding to the return of goods to their original production cycle [5]. Products can be returned in a form close to the original, such as post-sales return, or in the form of waste or refuse, such as post-consumption return. The post-sales return is mainly due to quality problems, such as manufacturing defects or design errors, and commercial problems, such as shipping errors, unrequested consignments, leftover promotions, technological or fashion obsolescence, and loss of shelf life. Post-consumer returns occur mainly due to the inability of the consumer of the good to adequately dispose of the parts resulting from consumption or the waste [2].

In the last decade, several economic, legislative and citizenship factors have contributed to the development of theories, case studies and quantitative modeling concerning SCM in the opposite direction to the traditional that is, reverse logistics [6]. In fact, there are those who invest in the area of reverse logistics because they feel socially motivated to do so, or to try to anticipate the legislations, namely the DL 230/2004 of December 10th, with the changes according to the DL 132/2010 of December 17th, thus respecting the Directives of the EU 2002/96/CE and 2003/108/CE, and taking advantage of the financial opportunities offered by the market or even to obtain a "green" image [7]. Currently in Portugal, there is an increase in environmental legislation that forces organizations to develop new strategies for the recovery of various types of waste and enhancing new investments in reverse logistics, particularly with regards to the establishment of minimum quotas for recycling and recovery [6].

The growing awareness of people and institutions to the problems of an environmental and economic nature, the worrisome shortage of raw materials worldwide made more acute by the issue of war (2022) [8], with an increase in demand for environmentally friendly products [9], the need to manage a logistics flow in reverse to the traditional model (between the final point of consumption and the point of origin), gave rise to the concept of reverse logistics [10].

The mission of reverse logistics is thus to plan, implement and control, in an efficient and effective manner, waste recovery, advocating the reduction of raw material consumption using means such as recycling, substitution and reuse of materials, disposal and the repair and remanufacture of products, closing the circuit of the supply chain. Some authors [3,11] assign the designation of reverse logistics only when the directions of the reverse and traditional flows share the same distribution channel; however, there are other authors who are less restrictive and permit the use of different distribution channels in the waste recovery phase. According to Dias [12], reverse logistics, in the broadest sense, means all operations related to the reuse of products and materials. "Extended responsibility refers to a set of values and principles that drive the organization in the responsible involvement with reverse logistics, thinking the product in its entire life cycle" [10]. Martin Christopher [13], on the other hand, considers that, currently, reverse logistics is a competitiveness factor and occupies a strategic position within organizations, since society is increasingly concerned with the volume of waste and industrial waste and, in this context, reverse logistics through its various channels has gained great usage in SCM [9].

In any reverse flow, one of the crucial objectives is to recover as much value as possible from the products. To achieve this, the following steps should be performed sequentially: collection, inspection/separation, reprocessing, disposal and/or redistribution.

2.2. The Sense of Green Logistics on the Times of War

Nowadays, a lot of equipment is designed to make our daily lives easier, both for the common citizen and for companies, but sometimes they have a very short life span and end up among the urban waste and/or industrial waste [14]. Such products include: appliances, cell phones, computers, televisions, among many others. It should be kept in mind that the vast majority of these products become technologically obsolete in a short period. In certain cases, repairing such equipment is unfeasible due to the high cost or due to the lack of parts. The placement of these products in uncontrolled landfills raises a significant environmental impact (contamination of soil and groundwater) [15]. According to a study report presented to the European Parliament, in 2006, about 6 million tons of EEE waste were produced in European Union (EU) countries, a quantity that has been increasing (more than 8 million tons in 2010), due in part to the development of equipment/machines with more attractive features and shorter life cycles to maintain the level of sales, and by the arrival on the markets of thousands of new consumers from countries with emerging economies such as China, India and Brazil, among others [16].

Worldwide statistics show that waste from EEE continues to grow (about 120 thousand tons of new equipment were placed on the market in 2014). In Portugal, WEEE increased by 6.8% in 2014 compared to 2013, according to data released by the National Association for Registration of Electrical and Electronic Equipment (NAREEE) [17]. According to EU data, by 2022 13 million tons of WEEE will be generated. National and, thus, European goals for the collection, reuse and recycling of these objects have therefore been strengthened. Most of this WEEE [4] contains hazardous substances that can be problematic for the environment [16].

It is possible to find, in one ton of WEEE, a hundred times more precious metals than in the primary source of the raw materials, namely gold, silver, aluminum, platinum and base metals such as copper, among others [18].

On average, recycling allows the recovery of 50% metals, 30% plastic, 10% glass and 10% other materials. Landfills can be considered a gold mine for recycling organizations. According to experts, the amount of aluminum found in North American landfills exceeds the volume of ores on earth [19]. It can therefore be concluded that it is necessary to "move mountains" in order to extract the ore. In this sense, paradigms have to change, since higher quantities of materials can be extracted from a landfill than from the primary source (mine) [20]. The EU (European Union) had an average increase of 50% in raw materials, particularly ferrous materials, a fact that is directly related to the war in Ukraine, creating real chaos in manufacturing industries and throughout the SCM. Recycling will undoubtedly be a process to mitigate these fluctuations in their broadest sense and thus radically mitigate the environmental impacts [15].

2.3. A Description on Waste Recovery

In recent decades, the electronics industry has revolutionized the world with electrical and electronic products that have become ubiquitous in our daily lives. The number of products launched into the market increases year by year both in industrialized countries and in countries undergoing industrialization. Daily life in industrialized countries would no longer be possible without many of these products, which serve such diverse areas as medicine, mobility, education, communication, security, environmental protection, culture, and construction, among others. This includes household appliances such as refrigerators, washing machines, mobile phones, computers, printers, televisions, toys, and others. Such end-of-life equipment is a problem for modern societies. Currently, the available data on e-waste is relatively scarce, and it is necessary to use estimates to reach some conclusions on a regional or global level. Electronic waste or e-waste is one of the fastest growing areas of the international waste stream and is increasing at a much higher rate than all other waste streams. Fast growing electronics industries arising from the demands of information and communication technologies around the world coupled with the rapid product obsolescence and lack of end-of-life management options, have all led to the unsustainable management of the waste stream. this waste stream.

The United Nations University, established in 1973, is the academic and research arm of the United Nations. It is headquartered in Shibuya, Tokyo, Japan, with diplomatic status as a UN institution. Since 2010, the UNU has been authorized by the United Nations General Assembly to grant degrees. Estimates from the United Nations University indicate that electronic waste from the 27 EU members currently stands at 13.4 million tons per year. The amount of e-waste worldwide is estimated to be about 53, 6 million tons per year (2019), and could reach about 74.75 million by 2030 [16].

Although the available information on e-waste treatment capacity in EU member states is very limited, it is estimated that in 2007, with only 15 member states, there was already sufficient capacity to treat this type of waste. E-waste is generally regarded as a problem that can cause damage to the environment if it is not treated properly. However, the resources present in EEE are largely ignored and have a huge impact on SCM [21].

In short, the lack of in-cycle strategies for electronic and electrical devices leads not only to significant environmental problems, but also to a systematic reduction of the available resource base of secondary materials. In modern electronics we can find up to 60 different elements, many of which are valuable, some are hazardous, and some are both valuable and hazardous [22].

Despite all legislative efforts to establish a circular economic flow in developed EU countries [23], most of the valuable resources present in electrical and electronic waste are lost. Several causes can be identified, such as insufficient collection efforts, or recycling technologies are partly inadequate, but mainly because there is a high export flow of e-waste to countries without adequate recycling infrastructure. The latter is also associated with high emission levels of hazardous substances. Unfortunately, these regions with inadequate recycling infrastructure are often located in developing or transition countries. Currently, developing countries are making efforts to implement technologies that enable e-waste recycling and establish a circular flow economy throughout the supply chain.

In addition to the direct impact of effective recycling on the resource base of recycled metals, recycling operations can also contribute considerably to reducing greenhouse gas emissions. Primary production, i.e., mining, smelting and refining, especially of precious metals, has a negative impact on the level of carbon dioxide emissions due to the low concentration of these metals in the ores and the often very difficult extraction conditions.

To "mine" them out of old computers, that is, to recover the metals contained in them, when done in an environmentally sound and correct manner, requires only a fraction of the energy compared to ore mined in nature. A wide range of components that incorporate EEE are made of ferrous and non-ferrous metals [24,25], plastics and other substances that are contained in them.

Glenn Seaborg (1912–1999)was involved in identifying nine transuranium elements and served as chairman of the U.S. Atomic Energy Commission (AEC) from 1961 to 1971. In 1951, he shared the Nobel Prize in chemistry with the physicist Edwin M. McMillan.

Take a mobile phone, for example, it may contain several elements from the periodic table, including base metals such as copper (Cu) and tin (Sn). It also includes very significant metals such as cobalt (Co), indium (In) and antimony (Sb), and precious metals including silver (Ag), gold (Au) and palladium (Pd). Considering the highly dynamic development rates of electronic devices such as liquid crystal displays (LCD)—televisions and monitors, MP3 players, electronic toys, and digital cameras—it is clear that EEE play an important role in the evolution of demand and prices for a large number of metals [26].

The metal resources used in the construction of EEE will be added to the existing metal resources in the devices in use in society. These resources become available again at the end of life of the devices and are redirected through reverse logistics back into the production chains. As mentioned earlier, these represent a potential of about 53.6 million tons of resources per year [16]. Efficient and effective recycling of metals and materials is key to keeping them available for the manufacture of new products, whether electronics, renewable energy applications or new applications [27]. In this way, primary metal energy resources can be safeguarded for generations to come.

2.4. Characterization in Waste Management

The concept of waste logistics management focuses on the operation of collection [28], transport, storage, treatment, recovery and disposal of waste, including the monitoring of disposal sites after the closure of facilities, as well as the planning of these operations. It is preferably aimed at preventing or reducing the production or harmfulness of waste, namely through reuse and changes in production processes, by adopting cleaner technologies, as well as by raising the awareness of economic agents and consumers, thus contributing to the reduction and preservation of natural resources, reflecting the importance of this sector in various aspects, including environmental aspects.

This sector of activity is very relevant to the economy (micro/macro). The challenges faced by those responsible for implementing policies and all the players in the chain management, from public administration to the private sector, from economic operators to citizens in general, as producers of waste and indispensable agents require the continuation of these policies [8].

We must continue to strengthen the prevention of the production of EEE waste and encourage its reuse and recycling, promoting full exploitation for a new waste market, as a way to consolidate its recovery and stimulate the use of specific wastes with high potential [18]. At this time in Portugal, prevention programs are being approved and targets are being set for reuse, recycling and other forms of recovery of WEEE; in 2020, 16,702 tons of WEEE was recycled which increased by 2% in 2021.

It should be noted that the beginning of 2021 saw a worsening of the pandemic situation in Portugal and in Europe [8], with an increase in the number of infected and deaths, which once again led to the closure of countless stores, companies and schools, putting millions on remote work. The administration of vaccines has brought new hope for controlling this pandemic, but the closure of this chapter, unprecedented in our recent history, is uncertain. The impact of this pandemic has left its mark on several fronts, particularly in the widespread increase in prices throughout the value chain, starting with raw materials, which are becoming increasingly scarce, through the price of energy and fuel [29].

Inflation in Portugal is on an upward curve at 10.6% (October) due to the current situation (pandemic plus war), which will certainly translate into a worsening of the financial situation of many companies and families according to the INE [30]. The INE (Instituto Nacional de Estatística) is the official body of Portugal responsible for producing and disseminating quality official statistical information, promoting the coordination, development and dissemination of national statistical activity. Contrary to expectations, despite the definitive closure of many companies, we can see a shortage of labor, and we may be facing a paradigm shift with regards to the future business fabric and operation of companies in Portugal.

ERP Portugal, as the Managing Entity (EG) of electrical and electronic equipment (EEE) once again recorded an increase in the amounts of EEE, as a result of the acquisition of new members exceeding its expectations, in a year where there was a decrease in the availability of products for sale according to the ERP-REEE Annual Activity Report [31].

ERP managed to increase the selective collection of WEEE by about 3.8% as a result of a contractual effort with new collection points, albeit in an unfavorable environment.

The effort was compensated with a significant growth in the network, which at the end of 2021 had 5416 points for the collection of this waste stream, 1337 more points than in 2020 [31]. This activity is an Integrated System for the Management of Waste Electrical and Electronic Equipment, in accordance with Order No. 5258/2018 from May 25, which was extended by Order No. 335/2022 on January 11. On December 31, 2021, ERP Portugal managed 668 producers with active contracts, having signed 64 new contracts during that year (Figure 1).

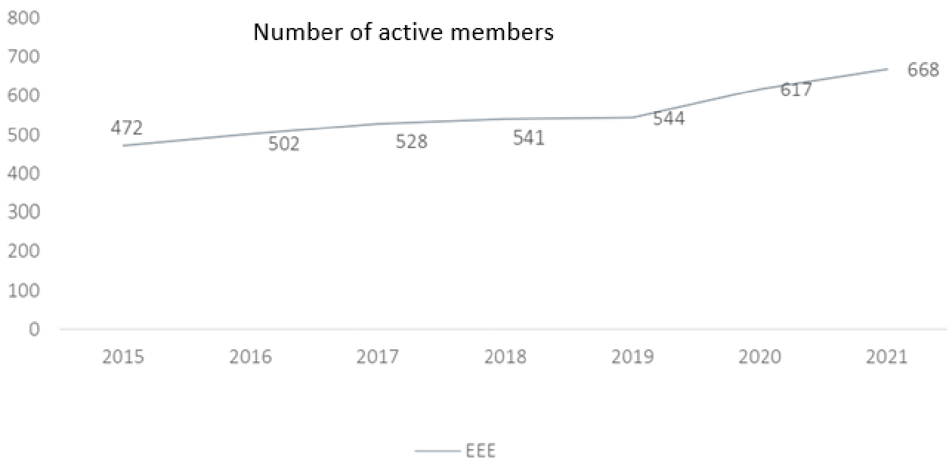

Figure 1. Evolution of the number of active producers belonging to ERP Portugal Reprinted/adapted with permission from Ref. [31]. Copyright 2021, copyright ERP.

The management of WEEE was only accounted for in 2021 as the quantities selectively collected and properly documented. This data is shown in Figure 2, in tons, by waste collection network.

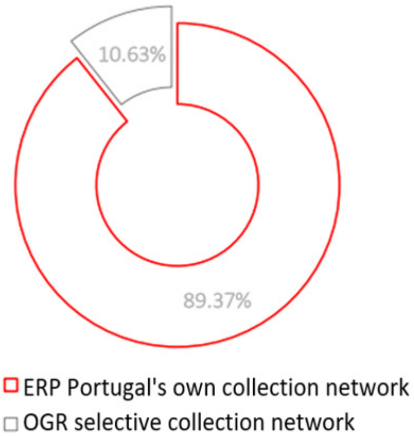

Figure 2. Percentage of WEEE, selectively collected vs. Waste Management Operators Network (WMO). Reprinted/adapted with permission from Ref. [31]. Copyright 2021, copyright ERP.

Following the legal orientations defined in Decree Law No. 152-D/2017, this methodology is based on data from categorization studies, supported by characterization and sampling tests carried out over time in WEEE management and treatment facilities. Table 1 presents the numbers of collections in 2021, by legal category.

Table 1. Quantity of WEEE collected in 2021, by legal category. Source: adapted from [31].

Legal Categories	Description	Quantity of WEEE Collected (tons)
Cat. 1	Temperature regulating equipment	2752
Cat. 2	Screens, monitors, and equipment with a surface greater than 100 cm^2	1006
Cat. 3	Lamps	103
Cat. 4	Large equipment (any external dimension greater than 50 cm) except for equipment in categories 1, 2 and 3	2716
Cat. 5	Small equipment (no external dimension more than 50 cm) except for equipment in categories 1, 2 and 3	3517
Cat. 6	Small IT and telecommunications equipment (no external dimension more than 50 cm)	600
	Total	**10,695**

2.5. Valuation by Type of Waste

This is any logistics operation whose main result is:

- The transformation of waste so that it serves a useful purpose, replacing other materials that would otherwise be used for a specific purpose;
- The preparation of waste for a particular purpose, in a facility or in the economy as a whole in a way that leverages the SC.

Currently there are some entities, namely ERP (European Recycling Platform) [31], ELECTRÃO (previously known as AMB3E; Portuguese Association of Waste Management) [32] and ANREEE (National Electrical and Electronic Equipment Registration Association) [33], among others, that are responsible for the management and organization of systems oriented to selective recovery and recycling of specific flows:

- Waste electrical and electronic equipment;
- Used lubricating oils;
- Used batteries and accumulators;
- End-of-life vehicles;
- Plant protection packaging waste;

- Packaging waste;
- Out-of-use medications;
- Used tires.

2.6. Definition of the Strategy and Process, for the Management of Reverse Logistics in WEEE

Currently, the worrying scarcity of raw materials worldwide and the high increase in demand for environmentally "friendly" products (green logistics) [34] associated with the growing awareness of people and institutions for the problems and issues of environmental and economic natures, has increased the need to manage the reverse logistics flow (between the point of final consumption and point of origin).

As previously described, the mission of reverse logistics [28] is to plan, implement and control, in an efficient and effective manner, the recovery of waste, advocating a reduction in the consumption of raw materials, using means such as recycling, replacement and reuse of materials, disposal, repair and remanufacture of products, closing the circuit of the supply chain [35]. Christopher assign a designation of reverse flow only when the direction of the flows shared the same distribution channel. However, it was admitted that in the waste recovery phase different distribution channels are used [36].

Products to be recovered have to be put into the reverse flow for several reasons: manufacturer returns, commercial returns [B2B (Business to Business), B2C (Business to Commerce) and B2G (Business to Government)], in-warranty product returns, end-of-use products and end-of-life products. Depending on the state of the product, contractual obligations with the seller and demand, the companies may have several options as to how to recover them. In any reverse flow, one of the crucial objectives is to recover as much value as possible from the products.

It is therefore necessary to develop waste processing and storage facilities, as well as transportation systems that effectively link the points between where waste is collected to the facilities where it will be subject to treatment, reprocessing and/or disposal operation(s). However, we must consider that there are a number of paradigms that can be identified in a reverse logistics system. The most relevant is associated with the centralization and decentralization of the management system [36]. In a decentralized system, all decisions regarding the destination of the waste are made at the retailer level. Although some transportation costs are avoided, since not all waste is routed to a central processing center, the total cost of transporting the products increases, since all products from secondary markets are dispersed in the organization's network of outlets and, directly or indirectly, the retailer has to pay the cost of collecting them [13].

Centralizing waste collection is more efficient than if it is done by distribution centers. Centralizing the reverse flow creates larger volumes, which promotes not only critical mass for the acquisition of specialized equipment, but also allows focusing activities on reverse logistics [37]. This, in the past, has been considered an independent module of the traditional supply chain. It focuses primarily on managing the processes that occur in the reverse direction in the supply chain [10]. Optimization of the processes affected by it is done locally. If integrated into the supply chain it can contribute to a further reduction in both the overall costs of the entire supply chain and the environmental impact, despite its increased complexity. With the integration of reverse logistics in the supply chain, it can be seen that:

- Transport network planning is more complex;
- The lead times for delivery/provisioning are longer, since the time associated with picking up the products must now be included;
- More storage space is needed, since the products to be recovered have to be stored;
- More complex information systems are needed as they have to include "tracking/monitoring" of products in recovery;
- More training is needed, as workers need to be trained to carry out the activities associated with waste management, as well as investment in new technologies, namely mechanical and software following the evolutionary thinking of Industry 4.0 and 5.0 [38] and Logistics 4.0 and 5.0 [39].

2.7. Real Cases of Material Recycling

Now, we are going to refer some materials that can be extracted from the components of some electrical and electronic equipment. We can use, as an example, computers which in the casing alone, we can find aluminum and plastic. Recycling aluminum is economical, while recycling plastic requires slightly more resources and time [18]. There are up to six different types of plastics in the carcass, 3% of which is contaminated with toxic compounds and needs a special process to be recycled. The processors contain noble metals; however, their recycling is harmful to health and should only be done by specialized companies. The hard drive (HD), like other parts, yields little if it is assembled. A kg of hard drives has a value of approximately EUR 10. When it is disassembled, the value increases. One kilogram of HD boards can be worth as much as EUR 40 and the motherboards have 2300 parts on the boards containing 16 noble metals. However, the plates also have toxic elements such as mercury, lead and tin, which are dangerous for the soil and water.

Another example is cell phone batteries which contain cobalt, nickel, copper, and other metals. They can thus be used for new batteries, stainless steel, speakers, etc. Cell phone casings contain gold, palladium, copper, etc. that can be used for jewelry, electronic components, and medical applications, among others. Cell phone covers made of plastic can be used for traffic cones and other items [40].

3. Case Study

3.1. Waste Management and Valorisation in the North of Portugal—Alto Minho

The current recognition of the relevance of the sustainability of natural resources and environmental issues in industrial activities by various institutions and economic agents comes from the significant impacts generated by EEE. Currently, the urgency and depth of new approaches to the processes of design and development of products will create a perfect symbiosis with the management of reverse logistics of waste [37]. This is characterized by the adoption of new strategies to deal with the rapid obsolescence of equipment and the consequent generation of vast quantities of used products.

Resulima is responsible for the selective collection of the municipalities of Arcos de Valdevez, Barcelos, Esposende, Ponte da Barca, Ponte de Lima and Viana do Castelo. It is a case of success and sustainability of resources and environmental issues. Established in 1996 by the Portuguese Law 114/96 of 5 August, it is the concessionaire for the management and operation of the multimunicipal system of recovery and treatment of solid waste of the Lima Valley and Lower Cávado. In addition, the construction of the Waste Valorization Unit was completed in 2020, which integrates the Mechanical and Biological Treatment Facility (TMB), the Automated Screening Plant (CTA), the landfill and the Eco-center (Figure 3) [41].

Figure 3. Facilities of Resulima in Viana do Castelo, Portugal.

3.2. Materials and Methods

This research was based and supported by official reports from the company Resulima, the ERP, APA, Interecycling, United Nations, National Institute of Statistics, and by a review of the literature.

To achieve the proposed objectives of this study, the research was conducted in two distinct phases. The first phase consisted of the analysis of the entire process related to reverse logistics in the production chains and its impact on the recycling of WEEE and its recovery, and the importance of its integration in the production chains and its positive impacts, especially at the moment we are living in, namely the war in Europe. In the second phase, we studied the waste [42] treatment process that ends in the production of biogas [43], its impacts on society and its sustainability. Biogas production is a process with great potential. It uses the biodegradable raw materials of animal, vegetable and municipal waste. The amount of municipal waste is increasing every year. This waste is an unmanaged and nuisance waste, and using it in biogas plants reduces the amount of waste increasing its economic value. Biogas production is part of the EU's policy to reduce dependence on fossil fuels and use energy from renewable sources (diversification of energy sources). Its importance is certain to increase in the future as energy demand increases [44]. The EU has established the ambitious goal to reach 80–95% GHG emission reduction by 2050. According to the EU, the share of renewable energy could reach between 55% and 75% of gross final energy consumption in the European Union by 2050 [44]. One of the most important factors that has considerably contributed to the largest fraction of biogas valorization (Table 2) is the application of tariffs for the sale of electricity generated by biogas production [44].

Table 2. Progress of biogas for energy in the EU (2005–2020) in PJ and MW. Reprinted/adapted with permission from Ref. [44].

	2005	2010	2011	2012	2013	2014	2015	2016	2017	2020
Biogas-el (PJ)	46.2	115.8	138.0	169.4	194.0	208.7	220.5	227.0	230.9	229.5
Biogas-th (PJ)	30.5	64.9	88.0	90.7	109.6	124.2	137.1	150.5	163.7	188.4
Biogas-el capacity (MW)	3113	6711	8289	9560	9883	10,456	10,986	11,410	11,821	11,128

Figure 4 reflects the importance of biogas and specifically for Portugal. For moderate biogas electricity markets, the main obstacles are linked to the stability of the financial support schemes for the sustained development of these projects.

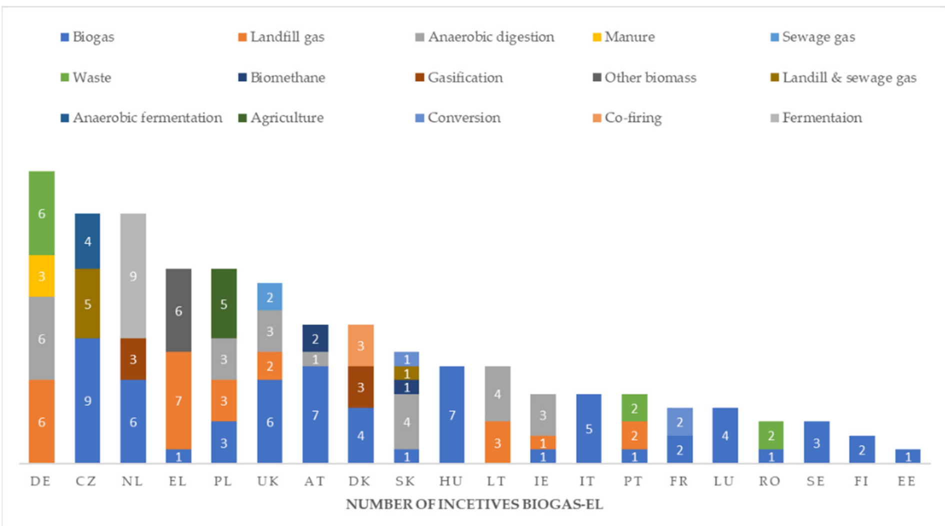

Figure 4. EU Countries—Current number of incentives in EU countries to support biogas in electricity sector. Source: adapted from [44].

3.3. Results and Discussion

Resulima operates in a geographical area of 1743 km^2 and serves an average resident population of 310,000 inhabitants, as shown Figure 5, accordingly to the data retrieved from the INE [15].

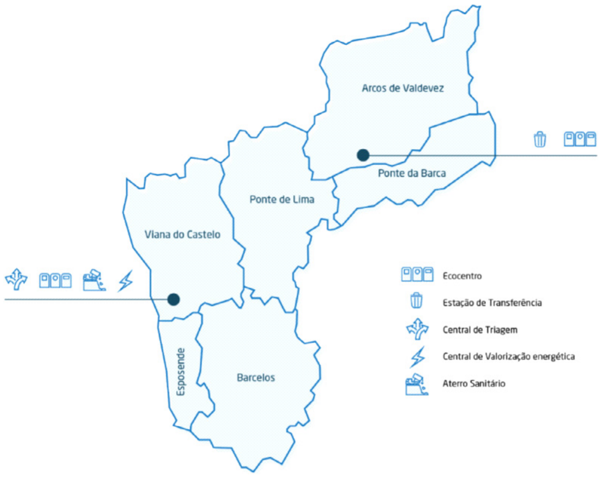

Figure 5. Resulima's geographical area of intervention. Source: adapted from [21].

The operation of the respective unit receives about 15,859 tons of waste—packaging, WEEE, used tires, used batteries and accumulators, used food oils and others—for recovery and recycling.

In the technical containment, Resulima stores approximately 126 thousand tons of waste, and the gases from the process of anaerobic decomposition of the waste are captured and conducted through an extraction and drainage network consisting of 30 biogas collection wells and several pipelines, observing all the requirements applicable to the disposal of waste in landfills (Figure 6), and generate the subsequent sale of about 12.3 GWh of electricity to the national grid. This electricity results from the energy recovery of the biogas captured in the landfill, that is generated in the two generators of the Biogas Energy Recovery Plant (CVEB) [45]. The CVEB consists of two containerized internal combustion moto generators, with powers units of 1200 kW and 800 kW, totaling 2000 kW [45,46].

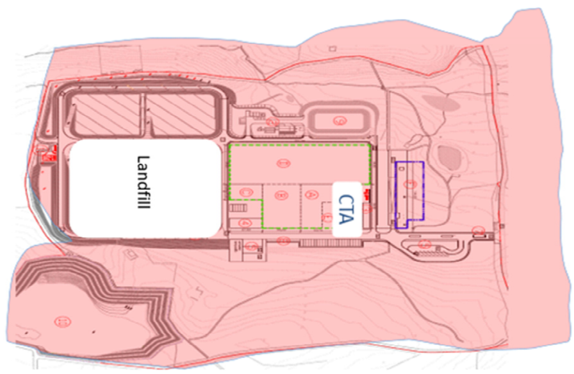

Figure 6. Capacity: 35 ton/h of RU—urban waste. Source: adapted from [21].

In this regard, the amount of energy recovery from the landfill biogas is fundamental, as it may achieve an export of electricity worth 12,333 MWh. However, regarding this value, it is possible to observe a decrease by 2.5% compared to the same period last year. This decrease results from the prudent reduction of the operating load of the two engines, allowing the production of energy to continue even with the fluctuations in biogas quality caused by reengineering operations and refilling in almost all the surface areas of the cells in the landfill. The graphic in Figure 7 represents the evolution of electricity sales in the last 4 years [45].

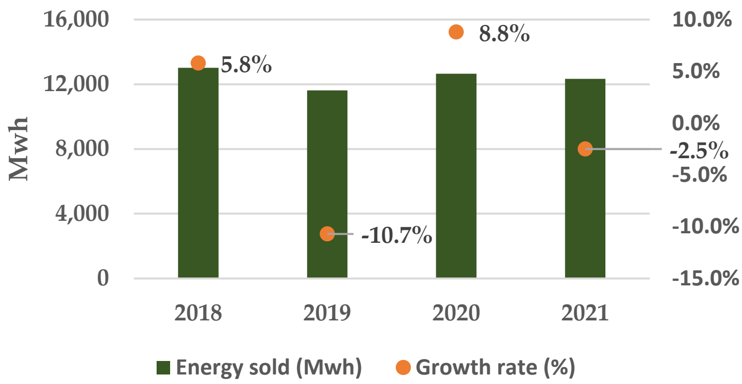

Figure 7. Energy sold. Source: adapted from [21].

From the analysis of the data of Figure 7, there was a trend towards a systematic decrease in energy production, for the reasons presented above. The electricity produced by Resulima allowed for a reduction in Greenhouse Gas (GHG) emissions in the equivalent order of 4.6 thousand tons of CO2, as well as a reduction in energy dependence equivalent to the consumption of 7.3 thousand barrels of oil. On average, it met the energy consumption needs of one thousand families for the year in reference. In summary, this facility has a production capacity of 2.0 MWh, consuming about 1100 Nm3/h of biogas with a methane (CH4) content of around 56%. The electricity generated by Resulima's CVEB, injected into the National Electric Network, is on the order of 12 GWh per year [45].

Resulima, as one of its operations, also collects WEEE. It is possible to analyze the evolution of WEEE in Portugal (Figure 8), provided by the Portuguese Association for the Management of Waste Electrical and Electronic Equipment [47].

Specific waste stream	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Waste Electrical and electronic equipment (1)										
Total placed on the market	157, 065	129, 732	117, 001	121, 582	121, 944	130, 404	137, 592	157, 966	185, 212	203, 921
Total collected	46, 660	55, 779	39, 808	44, 499	50, 255	53, 100	59, 993	62, 727	73, 686	52, 772
Total valued	40, 549	50, 140	35, 088	42, 076	47, 076	48, 070	55, 877	57, 227	66, 993	44, 904
Proportion of waste recovered (2)	86.9	89.9	88.1	94.6	93.6	90.5	93,1	91.2	90.9	84.5

Figure 8. Specific waste streams. Source: adapted from [48]. Unit = t; (1) quantities referring exclusively to managing entities; (2) proportion of recovered waste in relation to the total waste collected.

Analyzing Figure 9, it is possible to observe a strong decrease in 2019, due to the pandemic situation [15].

The data represented in Figure 10 give an overview of the quantities of the waste from electrical and electronic equipment (WEEE) processed in the European Union (EU), resulting from Directive 2012/19/EU [49]. The purpose of the WEEE Directive is to promote the collection of waste electrical and electronic equipment and its recovery, recycling and preparation for reuse of such waste in order to reduce the disposal of WEEE. In 2020, the collection rate of WEEE in the European Union was 45.9% (measured as the weight of WEEE collected compared to the average weight of electronic equipment placed on the market in the previous three years, i.e., from 2017 to 2019).

Figure 11 shows the trends for EEE placed on the market and WEEE collected, treated, recovered, recycled and prepared for reuse in the EU in the years 2012 to 2020. The amount of EEE placed on the market in the EU has developed from 7.6 million tons in 2012 to a peak of 12.4 million tons in 2020. In this period, the lowest level was recorded in 2013, with 7.3 million tons. Over the whole period from 2012 to 2020, the amount of EEE placed on the market grew by a value of 62.2%. Total WEEE collected increased from 3.0 to 4.7 million tons (+57.8%), while total WEEE treated increased from 3.1 to 4.6 million tons (+49.1 %). WEEE recovered increased from 2.6 to 4.3 million tons (+65.1%) and WEEE recycled and prepared for reuse increased from 2.4 to 3.9 million tons (+61.7%) from 2012 to 2020 [49].

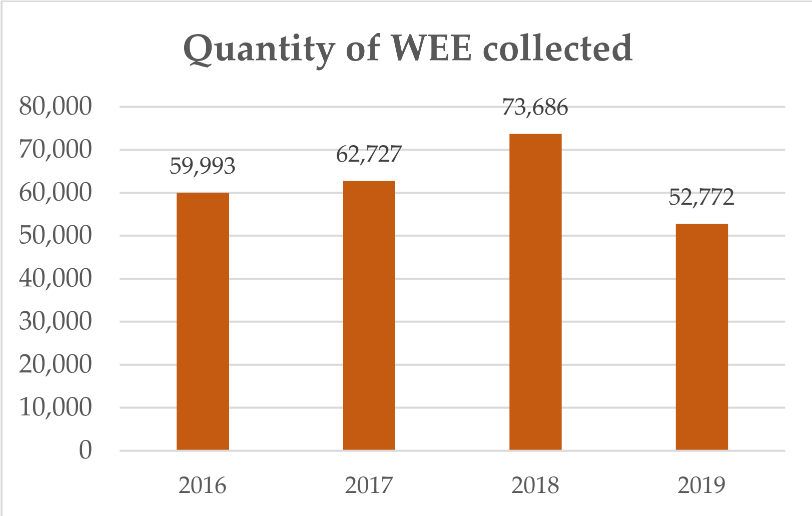

Figure 9. Waste electrical and electronic equipment. Source: Adapted, APA [48].

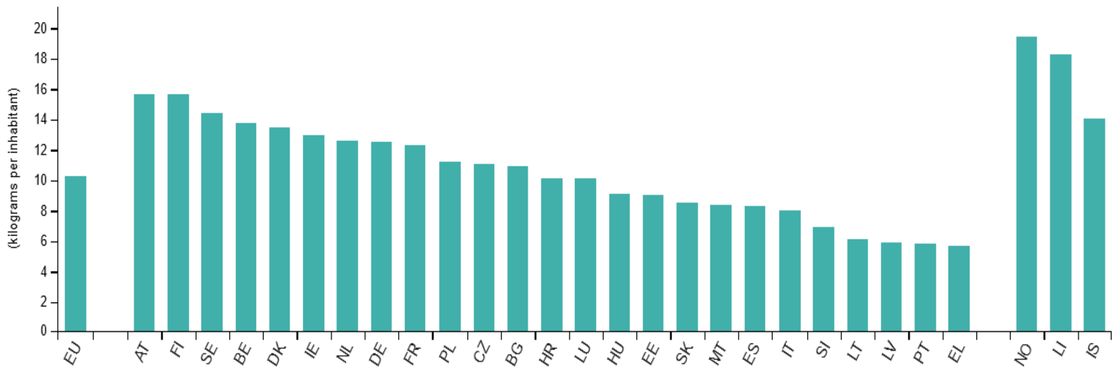

Figure 10. WEEE collected in 2020. Source: adapted from [24].

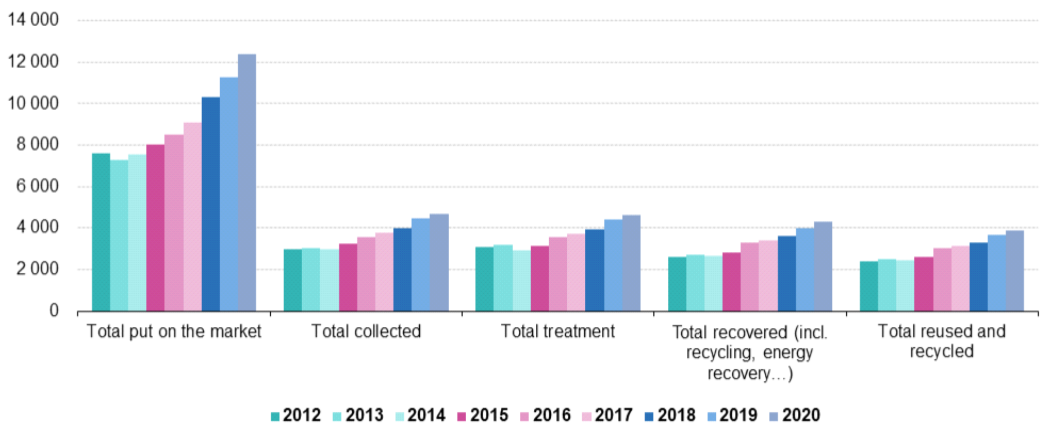

Figure 11. Electrical and electronic equipment (EEE) placed on the market and waste EEE collected, treated, recovered, recycled and prepared for reuse in the EU, 2012–2020. Source: adapted from [24].

In Figure 12, the collected WEEE is shown as the share of EEE placed on the market. The share is calculated as the ratio between the amount of WEEE collected in 2020 and the average amount of EEE placed on the market in the previous three years (2017–2019). These ratios provide an overview of the collection performance of EU member states against the collection targets of 45% and 65% for WEEE and EEE, respectively. By 2020, 15 EU member states exceeded the collection target of 45% of WEEE. In addition, seven more reported rates between 40.1% and 44.3%. Three EU member states reached a more ambitious target of a 65% collection rate in 2020, and five other EU members had rates from 60.4% to 62.4%. Notably, Portugal has made efforts in this direction, but there is still much to do in order to achieve the established goals. Notice that the reintroduction of raw materials in production chains is beginning to occur, being more relevant in this phase of the war in Europe [49].

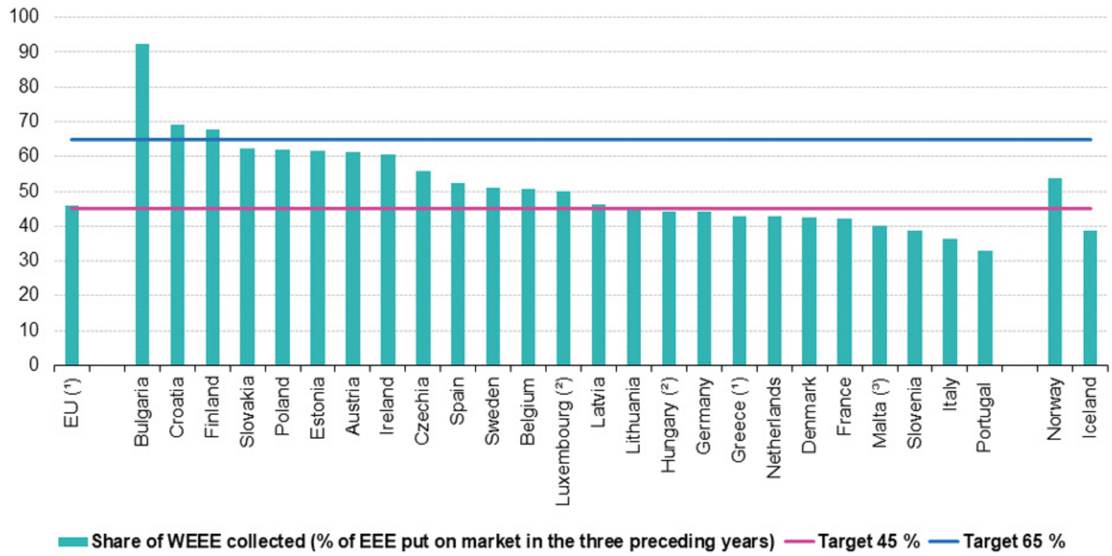

Figure 12. Total collection rate of waste electrical and electronic equipment (EEE), 2020. Source: adapted from [24].

4. Discussion

Macroeconomic Framework

After the new recession that began in 2020 following the world pandemic (COVID-19), the year 2021 was marked by a recovery across the board in all countries worldwide. The economy grew by 5.9 percent, as a result of 5.2 percent growth in advanced economies and 6.4 percent growth in emerging market and developing economies. Despite this recovery in economic activity, the pandemic, with its various variants and effects distributed across countries at different times, continued to cause strong disruptions in the production chains of the world economy. The maintenance of the high level of demand because of governmental supporting programs, made it possible to mitigate drops in disposable income, in parallel with the disruption in the production chains, contributed to the increased inflation pressure which started in the second half of the year. In the eurozone, economic growth that averaged 1.4% between 2010 and 2019 stood at −6.3% in 2020 and recovered to 5% in 2021 [50].

With the current deterioration of the economic situation worldwide and in particular in Europe, due to the sustainability of production chains and worsening by the war [8] in Ukraine [51], we see an inflation rate in the world economy. After a prolonged period of decline, inflation increased significantly in 2021 and in 2022, having reached a maximum that was last observed 30 years ago, as a result of the disruption of production chains, the maintenance of high demands and the rise in the prices of energy goods. In the advanced economies, the inflation rate rose from 0.7% to 8.3%, an evolution similar to that of the eurozone whose inflation rate was at 10.7, on average, in 2022. The price of oil (brent) registered a strong increase of 59% when compared to the same period of the previous year [52].

In this sense, it is important for all countries on a global scale, focusing on Europe and in particular on Portugal, to be able to optimize their resources directly or indirectly, as the case study of the company Resulima has shown. This has contributed to the development of the region in which it was inserted, in the quality of life of its inhabitants and will continue to make every effort in this direction. Resulima, and other entities with the same alignment, can play a significant role in the future of the energy system in Portugal and particularly in Alto Minho. Renewable electricity can be transformed through methane storage. This bioprocess [53] technology can be used in aqueous solutions and near room temperature.

The current developments, namely the war in Ukraine, has already caused thousands of deaths, but also serious economic damage worldwide. We have to deal with the impact of this asymmetric shock, the third in 15 years, inside and outside of the European Union. The strategy of EU leaders was to strengthen Europe's economic resilience, to radically reduce our energy imports from Russia and to press ahead with a major strengthening of European defenses. However, the consequences are also being felt in Europe, with energy prices and various other prices rising—a trend that is likely to continue. Within the EU we must also pay a price to end this scandalous war as the future of our security and our democracies depends on it. The price to be paid is the price of "freedom".

Figure 13 reflects the annual inflation rate in the eurozone and its main components from February 2012 to February 2022.

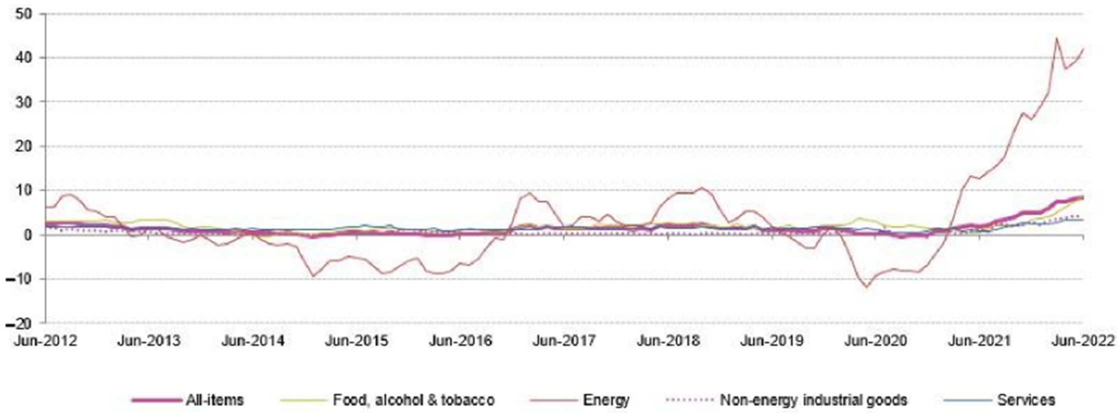

Figure 13. Euro area annual inflation, 2022. Source: adapted from [49].

The war in Ukraine is the so-called third asymmetric shock that the EU has experienced in the last two decades, after the financial and economic crisis of 2008 and the subsequent euro area crisis and the pandemic of COVID-19 [8]. An asymmetric shock is a sudden change in economic conditions that affects some countries in the Union more than others. The war in Ukraine is indeed having a much greater impact on the countries around it due to the influx of refugees and their heavy dependence on Russian gas and oil. To prevent asymmetric shocks from weakening the EU, we must intensify our ability to quickly be able to circumvent the problems of energy dependencies [54].

The three ways to reduce our dependence [55] on Russia are the diversification of energy supplies, energy efficiency and accelerating the transition to renewable energy; in this specific case, Portugal has done a remarkable job, despite the fact that there is still a long way to go. To achieve this goal we need, in particular, more infrastructures capable of receiving and processing LNG (Liquefied Natural Gas). These infrastructures are currently very unevenly distributed in Europe, with several in Spain and Portugal, for example, but almost none in Germany or in central and eastern European countries. However, currently there are not enough pipeline connections between Portugal and Spain connecting to the rest of the European continent. Therefore, Europe must create new infrastructure and jointly organize the supply of LNG [56].

The economic cost of Russia's war in Ukraine is hitting Europe hard. The disruptions in supply chains, as well as the rising costs of many raw materials [57], have pushed up the cost of food and other basic goods and services. This puts a strain on business and less money in our pockets. The EU has cut its economic growth forecast from 4 to 2.7% for this year and from 2.8 to 2.3 for next year. Already, suppliers are returning with higher prices or longer delivery times. It is imperative to find alternatives. We do not have single sources, but this requires more time and more effort on our part and in supply chain management. Raw materials have an exponential increase and therefore, the impact of recycling is increasingly becoming an imperative. Note that the price of fossil fuels has had very significant cost increases for companies, putting their sustainability in question. Thus, the biogas produced and transformed into electricity has a very positive financial impact and must also be considered for the sustainability of companies [56].

The vision of this study translates, in a comprehensive way, a set of intentions and aspirations for the future. It is imperative to have a strategy through which to obtain and maintain the good performance of organizations for these new paradigms. Thus, we must take into consideration the current demands where the objectives will only be feasible if the improvements in processes and products are introduced. This practice will lead to a perfect symbiosis regarding the advance planning for the destination of recovered materials at the end-of-life, thus tapering the processes for the reverse logistics of WEEE (inputs/outputs). A better environmental performance in the creation of products requires the integration of environmental aspects in the design and development process, and there must be a significant change in the way this has been conducted.

From a broader perspective, the introduction of changes in products (with recyclable raw materials) should be complemented by the transformation of the production processes through the implementation of automation and intelligent control systems, as propelled by the industry 4.0 and 5.0 [38] paradigms, simultaneously contributing to more efficient and effective, as well as cleaner, production systems. Thus, to obtain a sustainable service, it will be necessary to have a well-defined structure at the level of technical and/or scientific knowledge. In this sense, this study of the management of reverse logistics [9] in WEEE in times of war, is defined by the importance of a perfect symbiosis between technological know-how and technical and/or scientific research.

In summary, with the current developments it is essential to channel and increase efforts both in the WEEE field and in biogas production [46].

5. Conclusions

Currently, organizations seek to be and remain competitive, adapting their strategy to the constant changes in the market. Logistics management is undoubtedly the differentiation factor, and is an important tool in obtaining this advantage, as it serves as a link between the market and the various areas of an organization, managing the physical and organizational flows, within and between companies. The purpose of this article was to identify the financial and consequently environmental impacts of logistics activities such as supply chain management, information systems, transportation management, reverse logistics, green logistics, inventory management, warehouse management and WEEE management.

It was possible to highlight the importance of reverse logistics management of waste electrical and electronic equipment (WEEE) [58] in the supply chain, since this is a challenge because it is one of the most complex areas in organizations, both by the financial effort in the separation and movement of all the waste, both by the human resources assigned to these processes, as well as by the considerable environmental impacts generated by the equipment throughout their life cycle. It was also concluded that the end-of-life phase is of great importance, since the processes of equipment reuse and material recycling will allow, in the future, the elimination of environmental impacts [34].

The complexity of WEEE storage is effectively one of the biggest challenges, even for short periods. It is therefore also in the end-of-life phase that the efforts of the WEEE industry should be concentrated, in which the management of reverse logistics assumes relevance, not only for the manifest danger of the substances contained in the equipment, but also for the legal requirements set forth in EU directives. In addition, reverse logistics mainly leverage the economic value that these activities have, particularly with regards to the reintroduction of raw materials in production chains and in reducing environmental impacts, thus producing emerging benefits on the quality of life of populations [59].

Currently, the revolution in production has caused one of society's biggest dilemmas: how to face the dichotomy between mass consumption versus environmental sustainability? This paradigm leads to an increase in disposable products and consequently an imbalance between discarded and reused quantities, generating huge volumes of products and WEEE. Strategically, one of the ways to mitigate these impacts is the awareness on the part of representatives of organizations that reverse logistics is an integral part of business actions, and thus revolutionize the system of production processes to have at its base, a new eco-design [60].

In general, the overall composition of WEEE includes metals, plastics and glass as the most abundant components. In the processes used for the recycling and treatment of WEEE, the fractions obtained are mostly able to be forwarded to new recycling and recovery processes, with only a few elements subject to disposal processes. The processing of these WEEE streams results in a high diversity and complexity of materials, namely motors, electric cables, electronic boards, metals, plastics, glass, capacitors, batteries and processors, among others.

In short, the management of reverse logistics [37] will go hand in hand with the recovery of WEEE, becoming a priority for industrialized countries and underdeveloped countries. An integrated EEE waste management [61] policy translates, as a priority, into the prevention and reduction of waste by maximizing recovered quantities, with a view to minimizing waste sent for disposal. Therefore, the targets set by the EU (reflected in Directives/Law Decrees) are extremely ambitious for waste management systems. To meet the targets set, it will be necessary to change production and management philosophies, and material and information flows, in order to reduce both resource consumption and waste generation. The two-way flow of materials will have to encompass not only traditional logistics activities, but also and above all reverse logistics, which is the decisive factor in maximizing profits.

It is also important to understand the importance of the production and use of renewable energy—both in a global and national context—in the synergistic effect of climate change and long-term, continuous increases in fossil fuel prices with a greater impact due to the war in Ukraine, resulting in a strong impact on the EU economy and the world. The main reasons for the spread of renewable energy sources must increase the security of energy supply or, under certain conditions, to realize full energy independence. The importance of biogas is in addition to energy has environmental aspects justified by EU requirements and considerations, because the conservation of the state of our environment and efficient, economically satisfactory energy needs can be solved by the harmonization and application of traditional and renewable energy sources [44]. It is necessary to create a complex system of production and use of biogas for energy, while focusing on the environment and waste disposal [43]. The center of the system should be integrated (logistics management) waste management and environmental energy utilization.

In conclusion, in the near future it is urgent to implement/monitoring the directives created by the EU as a way to obtain a homogenization of the processes of collection, reuse, recovery and/or recycling of EEE, among other waste [49]. There is still a long way to go, despite much that has already been implemented. It is essential that there is a greater awareness of society on a global scale, through education/study programs. Thus, it is also relevant to implement reverse logistics management in the WEEE transversally as the aggregating factor of all upstream and downstream processes in the supply chain.

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