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Challenges of Digital Waste Marketplace—The Upvalue Platform

Margarida Soares [1], André Ribeiro [1,2], Tomás Vasconcelos [3], Manuel Barros [4], Carla Castro [5], Cândida Vilarinho [2] and Joana Carvalho [1,2,*]

[1] CVR—Centre for Waste Valorisation, University of Minho, 4800-042 Guimarães, Portugal; msoares@cvresiduos.pt (M.S.); aribeiro@cvresiduos.pt (A.R.)
[2] MEtRICs—Mechanical Engineering and Resource Sustainability Center, Campus de Azurém, University of Minho, 4800-058 Guimarães, Portugal; candida@dem.uminho.pt
[3] Síntese Binária—Engenharia e Sistemas de Informação, Lda., 4730-575 Vila Verde, Portugal; tvasconcelos@upvalue.pt
[4] Estamparia Têxtil—Adalberto Pinto da Silva, S.A., 4795-177 Santo Tirso, Portugal; mbarros@adalberto.pt
[5] F3M—Information Systems, S.A., 4715-435 Braga, Portugal; cmcastro@f3m.pt
* Correspondence: jcarvalho@cvresiduos.pt

Abstract: Waste management is a major challenge for contemporary societies, requiring urgent attention since population growth combined with widespread consumerism and industrialization has led to an alarming increase in waste production. To avoid harmful environmental impacts and the misuse of resources, it is urgent to combat this scourge. A potential solution involves the creation of industrial symbioses, characterized by the practical application of circular economy principles. The use of collaborative platforms is a possible way to promote industrial symbiosis. Addressing these pressing concerns and responding to these challenges, the Upcycle4Biz project envisions establishing a digital platform called Upvalue, conceived as a marketplace where companies can exchange waste and by-products. This article aims to provide a comprehensive overview of the challenges and benefits associated with the development of this innovative platform, as well as a presentation of the platform itself.

Keywords: digital platform; industrial symbiosis; waste marketplace; circular economy

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1. Introduction

In the current state of the waste sector, the establishment of a marketplace for buying and selling industrial waste presents several challenges. These challenges encompass the existing legislative framework, barriers that currently exist, and the need for economic and environmental analyses. The key challenges are associated with the licensing process, the role of intermediaries, the reclassification of waste, and determining the most effective technologies and solutions for minimizing environmental impact throughout the waste's life cycle. Presently, there is a growing socio-political recognition of climate change, pollution, and resource scarcity which has spurred an increased focus on environmental concerns and a shift towards a circular economy. This heightened awareness has led to the development of planning tools, evolving legislation, sustainable companies, and an emerging market for greener products and services. As a result, there is a rising interest from consumers [1].

On the other hand, waste management challenges are heavily influenced by the infrastructure and governance systems in place, as well as management plans and the legal framework of a country. Historically, the focus of waste-related policies was primarily on regulating its final disposal and developing end-of-line treatment technologies for industries with significant pollution levels. However, since the 1990s, there has been an increasing public awareness of the environmental impacts associated with waste production and management, leading to a shift in attitudes towards conventional waste disposal methods. This shift has prompted the adoption of new policies that prioritize waste reduction, diversion from landfills and dumps, and the promotion of more sustainable alternatives such as prevention, reuse, recycling, and other forms of recovery [2].

There is a growing concern about the societal attitudes and behaviors that contribute to the depletion of natural resources and the capacity to handle waste and effluents. As a result, environmental policies in Portugal have gained significance in recent decades and are now inseparable from achieving balanced social and economic development [3]. In Portugal, strategic guidelines for waste management have been established through various specific waste management plans, particularly since the late 1990s. These plans consider the characteristics of different types of waste and the available technologies for its collection, transportation, and treatment. National interventions in waste management have focused on improving infrastructure for the collection and recovery of urban and similar waste, managing non-urban waste from industries and other sources, and implementing extended producer responsibility for specific waste streams [2].

Portugal has shown positive indicators in the treatment and recovery of industrial waste. However, it is essential to invest in policies that promote integrated solutions for waste reduction, recovery, and treatment, while also leveraging the country's endogenous resources to develop a new sector of entrepreneurship based on the principles of the Bioeconomy and Circular Economy [4]. The transition from a linear economy to a Circular Economy is driven by a sustainable development model and the principles of a green economy, which emphasize efficient resource utilization, low-carbon practices, and the preservation of natural resources [5].

This sustainability paradigm offers significant growth opportunities and competitive advantages for companies in a dynamic and global market. Embracing industrial and regional symbiosis within the framework of a closed economy concept can foster the emergence of new companies and complementary business models [6]. However, the implementation of industrial ecology practices at an inter-organizational level presents challenges, particularly in terms of companies recognizing the potential value of cooperation and applying the concept of industrial synergy [7]. Industrial symbiosis allows companies to convert their by-products or waste into energy, raw materials, or products for other organizations, regardless of the sector they belong to [8]. To promote industrial symbiosis, there is a need for external entities, referred to as matchmakers, that can facilitate the creation of closed cycles among organizations and foster new forms of inter-organizational cooperation [9].

The success of industrial symbiosis relies on collaboration between companies, always with a focus on financial and economic sustainability. By establishing collaborative networks for knowledge sharing and the exchange of energy and materials between different industrial units, industrial symbiosis networks aim to reduce the consumption of natural resources and waste production in the industrial sector [10]. However, one of the main barriers is the lack of information and knowledge about available opportunities for waste recovery and utilization.

A digital matchmaking platform that aggregates relevant information and provides innovative technical support for matching waste and by-products with potential applications could play a crucial role in facilitating the transition to a more circular economy. Such a platform would require a comprehensive database and automated interpretation of waste properties to determine the technical feasibility of converting waste into a resource and explore options for recovering its value [11]. Proper waste characterization is essential for identifying relevant properties and constituents, which may vary depending on the type of waste or by-product being considered. The platform analyzes waste characterization information, interacts with the database, and identifies possible applications where waste with specific properties could be valuable. The effectiveness of this interaction depends on the quality and quantity of information in the database, and the platform's performance is expected to improve exponentially as more transactions and experiences are recorded in the marketplace section of the platform [12].

Therefore, the Upcycle4Biz project envisions the creation of a digital marketplace platform called Upvalue. This platform will enable companies to transact waste and by-products. The role of Upvalue is to aggregate information and provide innovative technical support in terms of matching waste and by-products with potential applications. Within the scope of the Upvalue marketplace platform, which involves the creation and development of a digital waste marketplace, it is crucial to understand the needs, opportunities, and technological challenges associated with building a resourceful tool.

For this purpose, the current scenario of waste recovery in Portugal was studied, identifying the main needs, opportunities, and technological challenges to the establishment of a transaction platform for waste, by-products, and alternative raw materials.

Section 2.1 is also presented, which includes legal and regulatory requirements, waste declassification criteria, as well as what is required for its correct characterization, a crucial step for the proper functioning of the platform.

Section 3 is dedicated to presenting the challenges and needs associated with industrial symbiosis, as well as the advantages of its application.

Finally, the UpValue platform that is being developed is demonstrated, as well as its potentialities.

Current Waste Scenario in Portugal

According to the publication in December 2021 of statistics related to the environment by INE, Portugal moved away from the urban waste management targets recommended for 2020 [13].

In 2021, Portugal presented a scenario of economic expansion. In turn, the urban waste generated registered an increase. The ratio between urban waste generated in Portugal and GDP improved by 3.2% compared to 2015 (−5.2 percentage points compared to 2020) [14].

However, urban waste management deviated from the stipulated target of preparing for reuse and recycling (−23 percentage points compared to the 2025 target (55%) and −6 percentage points compared to the 2020 result) [14].

Sectoral waste generated by the business fabric in Portugal totaled 13.6 million tons, 20% more than in 2020. With more significant absolute increases, activities associated with the construction sector stand out, with over 944 thousand tons, and trade and services, with over 388 thousand tons. This fact can be justified by the recovery of the economy after the impact of the pandemic associated with the previous year [14].

Different waste streams have autonomous and differentiated management systems, related to their complexity or growing importance in quantitative and/or qualitative terms, of their producers and recipients. Each flow presents specific forms of valorization, with greater or lesser efficiency, depending on the type of waste, but, above all, on the flow adopted for its valorization. Due to this factor, it is fundamental to establish a representative categorization of the waste generated in Portugal, through common, scientific, or commercial definitions, for the different materials which directly influence the type of waste.

To facilitate the process of searching or submitting a waste in the Upvalue marketplace, a taxonomy characterization was defined according to main categories and subcategories. These categories are intended to be based on common classifications in the market, for various types of materials. There are several mass flows generated in Portugal, such as textile waste, footwear, agro-industrial, fishing and forestry, wood, plastics, composites, ceramics, metals and metallurgical, construction and demolition, or specific flows. The identification of the mass flows with the greatest valorization potential allowed the establishment of a set of priority sectors for action to be integrated into the Upvalue platform in the context of a waste purchase/sale marketplace.

2. Challenges and Issues Associated with Developing a Waste Transaction Platform

2.1. Waste Classification

Waste policy seeks to ensure the sustainable management of waste that cannot be prevented, ensuring efficient use of natural resources and promoting the principles of the circular economy. Waste management is based on a hierarchy that promotes prevention first, followed by preparation for reuse, recycling, valorization and, finally, disposal. The management of collection, transport, and treatment of waste is regulated in terms of urban waste and non-urban waste, these last including hospital and industrial waste, as well as hazardous waste.

There are several types of criteria for waste classification, from its origin (domestic waste, urban waste, industrial waste, nuclear waste, agricultural waste, among others), to its form/state (liquid waste, gaseous waste, sludge, powder, among others), its properties (toxic, reactive, acidic, alkaline, inert, volatile), and finally its legal definition (special, controlled, commercial waste, waste from specific flows such as Waste from Electrical and Electronic Equipment (WEEE), End-of-Life Vehicles (ELV)).

These criteria allow the division of waste by certain classifications, such as the waste rows, which vary according to the type of material constituting the waste (e.g., glass row, plastic row, metal row, organic matter row, or paper and cardboard row). The specific waste flows relate to waste categories whose origin is transversal to various sectors of activity, or subject to specific management (e.g., WEEE, ELV, packaging, or packaging waste).

The correct characterization of waste and by-products is crucial for the proper functioning of the platform, and it is essential to carry out physical and chemical analyses that allow the correct identification of the baseline properties of each waste. In this way, users will intuitively be able to perceive the potential of the waste/by-products they intend to acquire and whether they serve the desired purpose.

2.1.1. Legal and Normative Requirements

To determine the matchmaking functionality of waste and by-products, it is necessary to carry out a survey of existing regulatory standards and requirements at a national level to ensure that the platform's role will be framed in a duly constituted organized waste market, assuming a provider posture on commercial exchanges of materials.

Thus, it is fundamental to frame the objectives of the Upvalue platform with national and European strategic planning objectives regarding the classification and declassification of waste.

Waste classification must meet the definitions of community legislation, based on classification according to the European Waste List (LER), or European Waste Codes, present in the Waste Framework Directive, updated by Decision 2014/955/EC. These data relate to a harmonized list of waste that considers their origin and composition. The different residues included in the list are defined by a 6-digit code for residues and, respectively, two and four digits for chapter and subchapter numbers.

It should be noted that, by law, waste producers or holders must proceed with the separation of waste at source, before classification, promoting, whenever possible, its valorisation. In addition, they are required to classify the waste they produce or hold in accordance with the European Waste List [15].

Furthermore, there are three different groups consulted according to a defined order, in the rules for using the LER. There is a group related to the source of waste, whether for example an industrial activity, a health care activity, or an urban origin. There is another group associated with the nature of the waste, such as waste oils, solvents or packaging. There is also a group for waste not specified elsewhere in the list, which concern specific flows.

After classification according to the LER, the process is followed by the assessment of the hazardousness of the waste. Regulation N.° 1357/2014 updates the hazardous characteristics of waste, as well as establishing a methodology, based on the principle of evaluating the individual hazardousness of the substances that constitute it, based on their concentration. The objective of the process is to correctly assign the LER code that best characterizes a given waste, so that it can later be sent to the most appropriate destination [16].

In an initial phase, the study of the classification of waste according to the European Waste List, allowed reconciling different lines (type of material constituting the waste) and specific flows (categories of waste subject to specific management), families (industrial sectors of waste), and subfamilies (associated LER Codes), so that the platform works in an integrated way, implemented in a plan suited to the relevance of the different industrial sectors.

The defined ranks, which fit the categories for the taxonomy to be applied on the Upvalue platform, were the following: plastics; paper and cardboard; glass; metals; organic; wood; textiles; chemicals; construction materials; packaging; used oils; used tires; batteries and accumulators; end-of-life vehicles; and electrical and electronic materials.

The defined families were extractive industry waste; waste from the manufacturing industry; waste energy; waste from agriculture, forestry and fisheries, construction and demolition waste, waste from water distribution, sanitation and effluents, trade and services waste, and specific flow residues.

In addition, the study of the normative criteria for classifying waste leads to a set of guiding questions for the establishment of key concepts as starting point for data to be included in matchmaking [17]:

(a) What is the source of the waste? Example: cement plant, bakery, bakery industry; glass production industry;
(b) What process gave rise to the waste? Example: Waste resulting from the casting process of raw materials for glass production? Waste resulting from the glass molding process? Waste resulting from the packaging process of glass products?
(c) Detailed description of the waste. Example: empty cartons used to package glass bottles;
(d) What are the constituents of the residue? Example: 95% cardboard, 5% heavy metals.

The generating source, the process, the description, and the constituents (nature of the waste) stand out. These indicators must be deepened, to enhance the application of artificial intelligence (AI) mechanisms to identify potential alternatives for their correct referral to a valorization action, from the perspective of industrial symbioses of waste and by-products.

2.1.2. Market Models

In line with the understanding of the waste system within the legal planning entities, and in view of implementing its classification, current markets for the purchase and sale of waste were also studied. These studies included waste classification, and the criteria underlying the submission of a quest for sale and purchase.

An exhaustive analysis of the markets for buying and selling of national and international waste was carried out, allowing the definition of a set of main categories and subcategories corresponding to waste streams and relevant transversal sectors in the context of waste in Portugal, as well as the opportunities for its valorization. These categories make a concrete taxonomy, facilitating the process of searching for or submitting a waste in the Upvalue marketplace: plastics; paper and cardboard; glass; metals; organic; wood; textiles; chemicals; construction materials; packaging; used oils; used tires; batteries and accumulators; end-of-life vehicles; and electrical and electronic materials.

In total, there are 288 subcategories comprising the 15 main categories defined, with each subcategory corresponding to an option of the type of waste, depending on the characteristics of the material and its origin. Like other market requirements, it was possible to identify a set of key indicators that should compose the classification of waste offered for sale on the marketplace. These main requirements include name, description, LER code, origin, shape and color, and additives.

2.1.3. Characterization of Waste Streams

Recognizing the economic, environmental, and technological opportunity associated with the waste mass flows with greatest potential for valorization at national level, research and development work should be focused on these categories. The characterization of these mass flows aims to identify potential restrictions and potentialities to their valorization, via the characteristics associated with each of them.

To obtain a complete and adequate characterization for any type of waste, a set of properties were selected based on data from Portuguese companies and their waste, which include: total organic carbon (TOC), BTEX (benzene, toluene, ethylbenzene and xylene), pH, heavy metals, elemental and chemical analysis, among others. These properties stand out as examples, as far as the functioning and development of matchmaking are concerned, and for each of them, limit values and/or intervals can be established, based on scientific studies, and existing applications, targeting the identification of opportunities for valorization and industrial symbiosis.

Having carried out the characterization of these flows, and the grouping of waste into families with well-defined criteria by industrial sector, the importance of mapping the origin of waste is highlighted, with a view to its quantification and geographic distribution at the national level. This geographical distribution proves to be essential in defining one of the main criteria for matchmaking, location. This variable will make it possible to optimize industrial symbiosis chains between companies which are located closer together.

2.1.4. Waste Declassification

According to current legislation, certain resources may not be considered wastes, due to certain characteristics, identifying themselves as by-products or alternative raw materials [18]. It is imperative to understand the classification criteria in this context so as to better frame the matchmaking algorithm. Based on the properties indicated by the waste producer [19], the resource will be registered in a database, allowing it to be classified as a potential by-product or declassified as secondary raw material capable of being used in another industrial process or in the design of a new product.

2.1.5. Classification of By-Products and Alternative Raw Materials

By-products are substances or objects that result from a production process whose main objective is not their production, and which are used directly, without any other processing, other than normal industrial practice [19].

From the by-product classification conditions result a set of factors whose relevance is fundamental for the attribution of key indicators, whether in terms of waste properties or in terms of technologies, to be applied in matchmaking.

For example, by fulfilling condition b of the by-product Classification Guide, the substance or object can be used directly without any further processing other than normal industrial practice. It is understood that processing considered "normal industrial practice" may include physical processes only, such as homogenization, gradation/sieving, compression/pressing; dehydration/drying, packaging, fragmentation/crushing, milling, mixture (as long as it does not change the dangerousness), washing, centrifugation, and cutting [20].

At the level of classification of alternative raw materials, the 'end of waste status' applies to waste submitted to a valorization operation, including recycling, through which it is considered that the waste is transformed into a raw material, ready to be incorporated into the manufacture of products [21]. This status meets the following conditions:

- The substance or object is intended to be used for specific purposes;
- There is a market or demand for that substance or object;
- The substance or object meets the technical requirements for the specific purposes and respects the legislation and standards applicable to the products;
- The use of the substance or object does not lead to globally adverse impacts from an environmental or human health point of view.

In the absence of definition of criteria at the European Union level, each member state has the authority to define criteria relating to certain types of waste [21] which fulfill the aforementioned conditions, and which include:

1. acceptable waste for valorization operations;
2. authorized treatment processes and techniques;
3. quality criteria for non-waste materials resulting from valorization operations in accordance with applicable product standards, including limit values for pollutants, if necessary;
4. requirements applicable to management systems for the purpose of demonstrating compliance with 'end of waste' criteria, including quality control and internal monitoring and certification, if necessary;
5. a model declaration of conformity and the conditions for issuing and using it.

These factors are essential in establishing matchmaking, given the need to associate waste with valorization technologies, their properties, and technical declaration documents, whether by-product or 'end of waste' status.

2.2. Industrial Symbioses

Industrial symbioses are characterized as the practical application of circular economy principles. The concept of circular economy is based on an economic model that seeks to preserve the added value of products for as long as possible, maximizing the recovery of waste, and consequently minimizing the extraction of raw materials [22].

The development of a sustainable, low-carbon, resource-efficient, and competitive economy requires the transition to a circular economy. The European Union has made efforts to integrate the principles of the circular economy (CE) into the policies of countries regarding waste management and product policy [23]. However, in addition to this legislative ambition, a paradigm shift is needed so that the reincorporation of resources into production processes becomes a reality.

The growing number of scientific publications on industrial symbiosis, and its incorporation into regulatory and community policy programs, such as the Waste Framework Directive—EU 2018, the Roadmap to a Resource Efficient Europe (EU 2011), and the expansion of environmental action consultancies, demonstrate that this concept is a promising path for sustainable development.

Industrial symbioses stand out as collaborative models that allow expanding competitive gains—economic, environmental, and social [24]. Cumulative network gains will always be greater than those a company could achieve acting alone. This type of collaboration may involve various types of actions, such as:

- Use of collaborative platforms;
- Identification of opportunities to replace raw materials with waste/by-products or create new businesses;
- Redesign of supply systems to accommodate products and services that use renewable resources or that allow the collection and reprocessing of equipment, to expand the useful life within the activity.

Despite the recent increase in the development of technical-scientific knowledge on industrial symbioses, their potential has not yet been realized, largely due to legal and administrative obstacles associated with the use of waste in industrial processes and the ease of access to low-cost raw materials. After a series of international efforts, this concept, which has always been present in inter-industry relations, has been increasingly put into practice as a strategic tool for economic development, innovation, and efficient use of resources [25].

This strategic tool requires the study of industrial circular synergies at local, national, and international levels. It is important to characterize the industrial interactions of waste and by-products in order to realize the valorization potential of each waste mass stream.

2.2.1. Industrial Symbiosis Modelling Tools

Industrial symbiosis is a promising business model that drives companies to move from linear to circular production. However, this transformation is complex, as it requires companies to rethink and redesign their production chains considering different aspects, from the involvement of new stakeholders, the introduction of waste, its impact on product development, and economic investments and resources [26].

As a result, companies need innovative modelling tools capable of capturing, investigating, and quantifying the results of these directives and changes, and working in the strategic planning, design, implementation, and management of their industrial symbiosis networks.

In this context, a literature review was carried out to investigate the most used modelling approaches to analyse industrial symbioses and research their characteristics in terms of simulation methods, interaction mechanisms, and simulation software. The results suggest that an agent-based hybrid dynamical system approach is an appropriate method for the design and analysis of industrial symbiosis [27].

Following this type of approach, it is important to classify each waste exposed by the agent (waste management operator, waste treatment operator, producing company, receiving company), and associate with one or more recovery operations, as a by-product or alternative raw material. Thus, in industrial symbiosis modeling tools, an integrated database for the different material flows must also be included.

Figure 1 presents a diagram of the sequential approach of an industrial symbiosis database processing and analysis methodology [28]. The information contained in the Industrial Symbiosis databases must be analyzed.

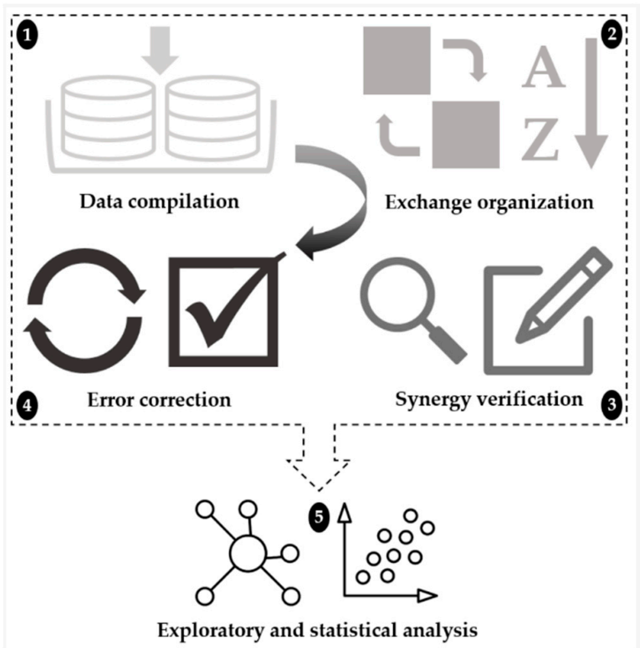

Figure 1. Diagram of the sequential approach of a processing methodology and analysis of industrial symbiosis databases.

In a first step, the existing databases must be identified to allow the compilation of previous case studies. Then, the exchanges contained in the pre-selected databases are organized according to different criteria, including the type of company that provides and receives, as well as the type and purpose of use of the waste.

Subsequently, there is a process of verifying the synergies found by evaluating the relationship between the waste, indicators and classification and characterization criteria and the recipient company.

Afterwards, errors and incomplete fields are identified and corrected in the databases selected in the first stage. Finally, the results are evaluated through exploratory and statistical analyzes [28].

The most appropriate recovery technologies for waste are identified depending on the database, using the methodology expressed above, reported in the literature.

2.2.2. Waste Circularity Potential

Following the definition of industrial symbiosis modelling tools, it is important to evaluate waste according to its circularity potential.

To establish the situation regarding the application of the circular economy in Portugal, data on the incorporation of waste into new products were investigated. Thus, the indicators of the rate of use of circular material stand out, covered in Sustainable Production and Consumption, one of the Sustainable Development Goals (SDG) of the UN.

Compiling data from EUROSTAT, National Statistical Institutes, and other entities, resulted in a graph of the rate of use of circular material, by country, over time, shown in Figure 2 [29].

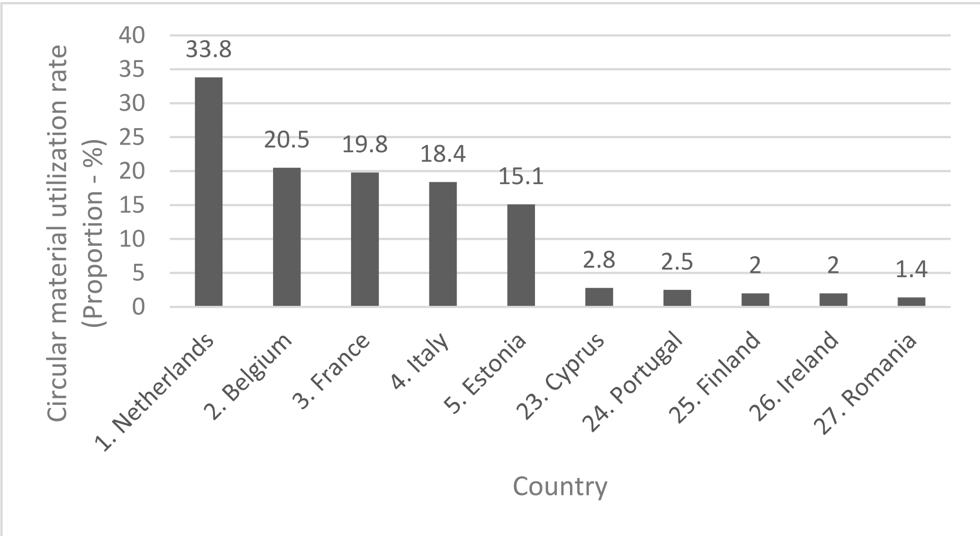

Figure 2. Circular material utilization rate in 2021.

Over the past 13 years, the rate of use of circular material has not varied significantly. According to data from 2021, Portugal is in 24th place in the use of circular material among the countries of the European Union.

Even though there has already been a growing trend in the last decade towards waste valorization, the poor position of Portugal when compared to other European countries in terms of this metric is remarkable and encourages the improvement of the waste destination operations system.

As discussed previously, determining the most appropriate valorization operations for different types of waste entails several challenges, with the assessment of the circularity potential of each mass flow being essential to define the most adapted strategies and methodologies for the development of R&D in different areas, and future industrial application of valorization technologies.

According to data from the consultancy EY Portugal, as well as INE, a sectoral prioritization matrix was compiled relating the circularity potential and the economic potential for various economic activities and sectors, which is shown in Figure 3 [30].

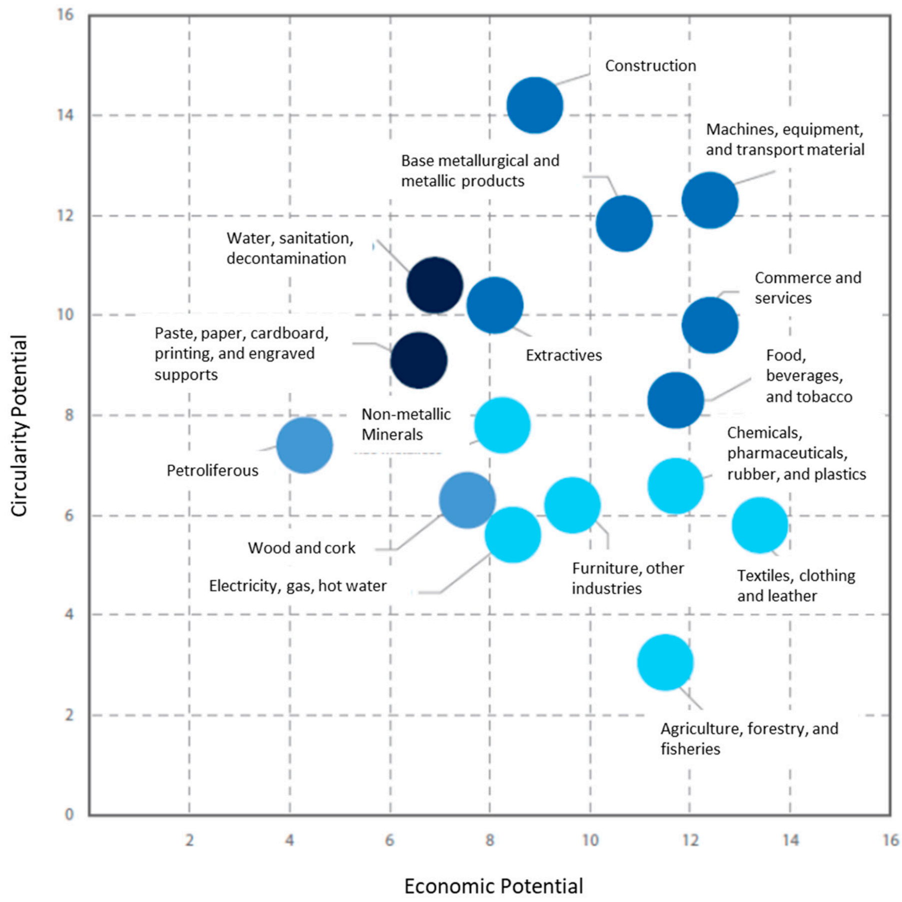

Figure 3. Sectoral prioritization matrix in terms of potential circularity and economic potential.

Understanding that the exploitation of opportunities should consider the compromise between circularity and economic potential, the sectors of activity with the greatest opportunity are identified:

- Basic metallurgical industries and metallic products;
- Machinery manufacturing industries;
- Equipment and transport material;
- Construction sector;
- Commerce and services sector.

In addition, other sectors stand out, namely extractive industries, food, beverage and tobacco industries, and non-metallic minerals. Further, the fashion industry (textiles, clothing, and footwear) and the chemical, pharmaceutical, rubber, and plastic industries [30].

2.2.3. Identification of Needs and Opportunities

Industrial symbioses presuppose a business strategy between entities that collaborate in the efficient use of resources to improve their joint economic performance, with positive consequences for the natural system (sharing of infrastructure, common equipment, common services, and use of resources).

This collaboration, carried out in a network, allows the transformation of environmental problems into business opportunities, which present economic and social benefits at various levels: business, regional, and national.

Extending the life cycle of products is achieved through the process of converting waste into new materials or products. The development of new business models, dematerialization and digital transformation is demanding on several levels. The establishment of a market for the purchase and sale of waste, by-products, and alternative raw materials entails a set of technical and legal needs that must be identified.

At a legal level, it is important to clarify the role of a waste transaction platform that will act as an intermediary, providing services to traders, waste holders, and sellers according to an Organized Waste Market.

At a technical level, it is necessary to bring together all players in the sector, from planning and management entities to waste management and treatment, as well as production and transport companies. In addition, it is essential to also add technological centers that will help with the declassification of waste and its integration into the new industry. Finally, the companies that will accept the material/by-product to be reincorporated into their production cycle.

Moving from needs to opportunities, it is important to identify which factors of interest can boost the development of the market for buying and selling resources.

A 2022 study, published in the Journal of Cleaner Production, explored key drivers for improving waste-to-resource recovery, and the potential macroeconomic determinants of waste recovery across 34 OECD countries, spanning data from 1995 to 2019 [31]. In this way, the long-term balance of waste valorization with environmental technology, renewable energy consumption, economic growth, globalization, and industrialization was analyzed. The study highlighted the positive roles of environmental technology and renewable energy consumption in improving waste-to-resource performance. Thus, technology-based factors are significant determinants of the performance of the recovery of waste into resources, implying that the implementation of modern technologies in the economy would help to increase resource efficiency and reduce environmental degradation, improving sustainable performance [31].

In terms of opportunities, there are several benefits associated with Industrial Symbioses, highlighting the increase in the value of waste and the consequent reduction in the consumption of primary resources.

From an environmental point of view, there is an opportunity to reduce the impacts arising from the disposal of waste and the extraction and import of raw materials, namely:

- Decreased consumption of raw materials;
- Decreased disposal of waste in landfills;
- Reduction of consumption of energy and water from the network;
- Reduction of environmental impacts from a life cycle perspective;
- Relief of pressure on the carrying capacity of ecosystems.

From an economic point of view, the advantages are associated with the reduction of costs with raw materials and waste treatment.

In turn, from a social point of view, the main benefits are associated with the creation of jobs in new activities necessary for the transformation of resources, but also with the ability to make greater use of labour resources in the face of lower costs for raw materials.

2.2.4. Challenges Inherent to Industrial Symbioses

Regarding the challenges inherent in industrial symbioses, over the last fifteen years, more than 130 million euros have been invested in Europe for the development of tools that enable their wide implementation [32]. However, it appears that there is still potential for further exploration, given the barriers associated with its development.

The development of industrial symbioses, as part of a comprehensive strategy to improve resource efficiency, presupposes several barriers [33]. These barriers materialize in the following factors:

- Lack of commitment to sustainable development. There are several reasons for the lack of commitment by companies regarding sustainable development, and specifically industrial symbioses, since companies only consider the economic side, neglecting the socio-environmental dimension and long-term corporate strategy.
- Lack of information sharing. Confidentiality reasons and technological problems limit the sharing of information through the network, affecting the performance of industrial symbioses.

- Lack of cooperation and trust. Cooperation is key to industrial symbiosis. The resilience and robustness of the industrial symbiosis network are crucial issues for the companies that integrate it.
- Technical infeasibility. Some industrial symbiosis projects require the introduction of emerging technologies to create ways to use certain wastes as raw materials.
- Uncertainty in environmental legislation. Environmental and energy legislation changes quickly, and companies fear that they will not be able to recoup their investments.
- Lack of community awareness.
- Economic unfeasibility. Industrial symbiosis must consider economic sustainability as a driver of competitiveness, tax reduction, and resource efficiency.

One of the barriers consistently identified by companies is the difficulty of obtaining, from the public entities with responsibility in the matter, the necessary decision for a given substance to be considered a by-product. In this way, an agile communication channel must be created that allows responding effectively to the necessary criteria for substances to be considered by-products or obtain end of waste status [34]. The existence of a market or demand should also be more flexible, insofar as purchase and sale commitments should not be necessary, but rather support market studies for the material in question [34].

Another current challenge is the context of collective platforms for waste management. Portugal has its own legal framework for Organized Waste Markets. This table establishes rules applicable to the transactions carried out in it and the respective operators.

In addition, another challenge is the weak legal framework for industrial symbioses. Despite the relevance of industrial symbiosis in the context of sustainability and the circular economy, as well as industrial competitiveness, the concept is not referenced in the national legal framework, except for the National Waste Management Plan 2014–2020. Thus, a legal framework for industrial symbiosis should be promoted, integrating it with legislation for the territory and for the industry, guaranteeing the effectiveness of the instruments.

On the other hand, there is the challenge of the weak dynamics of cooperation in the waste sector between different intervening entities. Even though R&D and innovation play a very important role in promoting the circular economy and closing the material cycle, the waste sector in Portugal has a low intensity of expenditure on business R&D (0.6%, less than half of national average). The dynamics of cooperation between researchers, companies, universities, waste management and treatment operators, among others, will leverage the transition to a more circular economy. In this sense, more research and development should be carried out on this topic, and the dynamics of cooperation can be achieved through the establishment of markets for the purchase and sale of waste, and spaces for sharing knowledge, enhancing circular synergies.

3. Methodology

For the development of the platform, a theoretical layout was carried out in order to understand all the parameters and menus necessary to obtain a complete and intuitive platform.

Subsequently, a graphic and technical layout of the platform's needs was developed, always with technical and scientific support in decision-making, based on the needs of potential stakeholders, legal needs, and problems associated with the various types' of industry and waste managers.

More specifically, the functional architecture of the logical architecture was built, as well as the entire construction and programming of the digital platform. The algorithm modules were later integrated in order to consolidate the platform itself.

4. UpValue Platform

Despite the uniform legislative context within the European Union (EU), the waste markets within the various member states present different technical and legal details, which creates some barriers to the development of these markets in certain geographic contexts.

There are some online platforms based in Portugal or in other EU countries that operate in the waste market, however, they either operate very vertically in certain sectors of the market, or they do not have all the necessary functionalities to attract all potential users of an online waste market. In recent years, given the evolution of E-Commerce platforms, the use of this type of mechanism for product transactions on a global scale has increased the interest of various types of users.

In this context, the UpValue platform is a digital solution that aims to promote the waste market with a focus on industrial symbioses, enhancing its valorization and the development of innovation mechanisms that promote it in ecosystems and industrial and technological synergies. Thus, it is a useful tool for all interested parties in the market, having been thought and designed according to their needs, without jeopardizing the legal requirements associated with the market.

During the tool's development processes, stakeholders were consulted, including entities that regulate the market, namely the APA—Agência Portuguesa do Ambiente. The UpValue platform is aimed at the various players in the waste market, which justifies its use through a register that allows users to monitor compliance with legal and functional requirements.

The main objective of the platform is to absorb stakeholders from the waste market into an ecosystem that allows for fluidity in a market with high potential and with specific technical-legal definitions that allow flow channels for both treatment and industrial symbioses or for R&D partners that act as innovation partners. Based on this premise, a research and structuring work on the platform based on the flow of the waste market was started, considering the needs of potential interested parties, as well as legal needs that allow the fluidity of the process. Figure 4 presents the description of the waste flow and the positioning of the UpValue platform at different times and intermediaries.

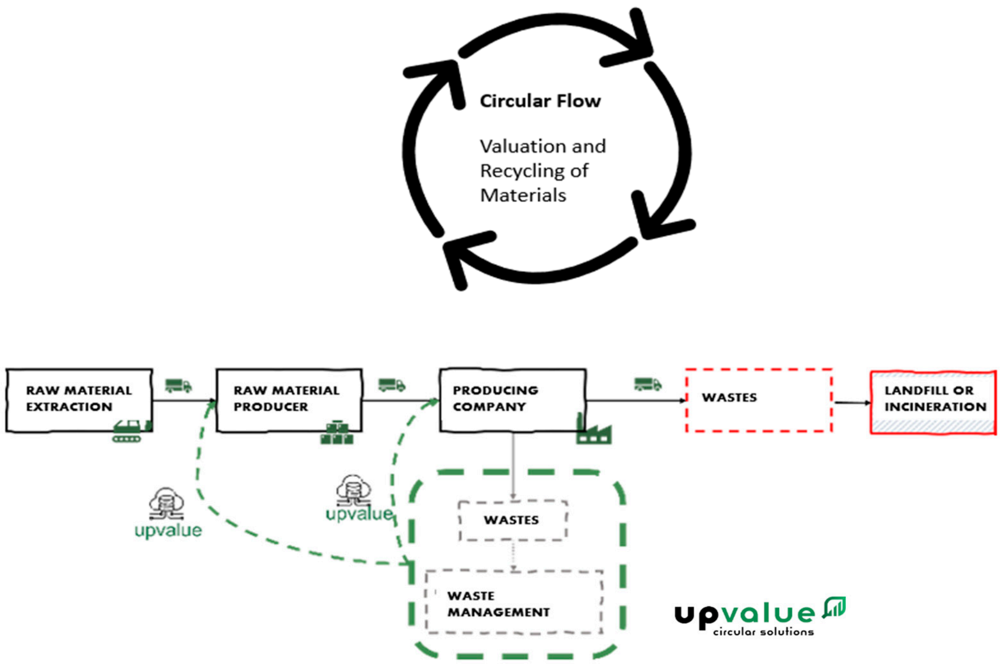

Figure 4. Description of the waste flow and the positioning of the UpValue platform at different times and intermediaries.

Subsequently, a work of theoretical, graphic, and technical schematization of the needs of the platform with technical and scientific support in decision making was carried out. Figure 5 shows the appearance of the UpValue waste digital platform, specifically the marketplace homepage.

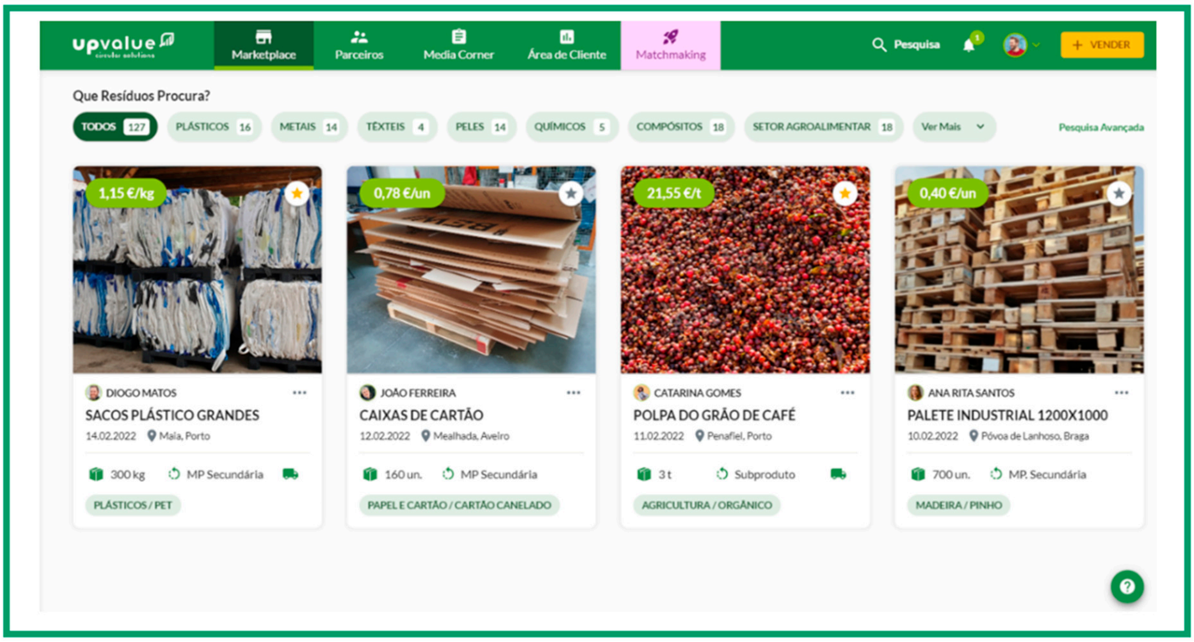

Figure 5. Marketplace access homepage—UpValue Platform.

As in Figure 5, the Marketplace's home panel presents a set of tools for any user, allowing them to quickly access the platform's main features, create a sale ad, search for waste, notifications, and access their profile for editing. The launchpad is divided into two parts. On the left side, users can access several tabs that allow access to (i) Marketplace, (ii) Partners network, (iii) Media Corner, and (iv) Customer Area. These four blocks correspond to the functionalities available to any user of the platform. The second part of the bar allows access to: (i) a search field, (ii) a notification icon (bell) for interactions/messages received by the user, and (iii) an icon with a profile image that includes a list button for interaction that will present: username and email, profile access, access to favorites (to view waste cards marked as favorite, see Favorites section), access to the user's subscription, settings, an "about UpValue" button for more information, and the link to exit this area. Finally, the "+ sell" button appears more prominently, which quickly allows the user to publish a new waste advertisement.

Considering the variety of waste from different industrial sectors, the UpValue digital platform will be divided into demonstrative industrial sectors that permit major specificity and more operational treatment of the waste/by-product in question. The digital platform will be supported by a partners' network that will facilitate enterprises interested in matters such as characterization, declassification of waste, logistics, and studies on the inclusion of waste/by-products in technological processes.

At the same time, given the legal restrictions associated with the possibility of buying and selling waste through appropriate licensing, conditions for purchase/sale were defined, based on the user profile and the license held. Regarding waste, which relevant information to present in the markets of waste, by-products, and alternative raw materials was specified according to the benchmarking and bibliographical review.

From the formative point of view, in addition to creating a section dedicated to the publication of scientific, opinion, and informative articles in a Media Corner area, alerts were created for best practices associated with waste that explain the need to obtain a license to obtain permission for that action.

5. Conclusions

Industrial symbiosis can be considered as direct application of the circular economy within the industrial framework. From a technical point of view, industrial symbiosis is already a viable option for most industries. In fact, for almost all wastes, there are technologies available to convert and recycle them into resources. However, there are still barriers that are of a non-technical nature, which are based on the lack of trust and cooperation between the participating companies, lack of information resulting in knowledge gaps, and absence or rigidity of environmental regulations regarding waste.

In this context, the digital platform UpValue will function as a marketplace where companies can transact waste/by-products made available by other companies. This platform is intended to leverage a transition to a more circular economy with a direct impact on the three pillars of sustainability: Environmental Sustainability (recovery of waste/by-products); Economic Sustainability (possibility of reducing costs in terms of raw materials); and Social Sustainability (fostering principles of industrial synergies through the creation of potential new partnerships).

The UpValue digital platform presents a business model based on digitalization and the principles of the circular economy. On the one hand, it will include a digital database of waste/by-products from different industrial sectors, thus promoting progress in the digitization of the waste sector in Portugal. Regarding the economic aspect, this business model will leverage a transition to a more circular economy as it keeps waste/by-products in the value chain, inserting them into a new life cycle by incorporating them into a different product.

Given the holistic nature of the platform, it will be possible to identify opportunities for incorporating waste/by-products between different industrial sectors from a matchmaking perspective between waste/by-products and new materials and/or products. This matchmaking will result in a database that will support the identification of potential industrial synergies, thus facilitating the connection between the company generating waste/by-products and the company interested in incorporating the waste into its products. Finally, considering a change in the paradigm of the current value chain through the new business model driven by the platform, a reduction in environmental impacts associated with products is foreseeable.

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