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Industrial Symbiosis in the Balkan-Mediterranean Region: The Case of Solid Waste

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Abstract: The treatment of waste and especially solid waste, the type with the highest increase in terms of annual generation over the last decade, is a key issue in the Balkan and Mediterranean region. Piecemeal efforts to deal with it within the prevailing linear economy model were not successful since the techniques used such as recycling and reusing could not be effective with the existing products. A definitive solution requires the switch to a new model, the circular economy model, which will facilitate the tackling of the excessive use of virgin raw materials and waste generation. The design and development of a digital solid waste reuse platform in the context of the EU-funded Interreg Project SWAN involving four countries: Albania, Bulgaria, Cyprus and Greece, was a step in this direction. The present paper based on the evidence drawn from this project examines the current situation and the future trends in the solid waste reuse and industrial symbiosis schemes in this region.

Keywords: solid waste; industrial symbiosis; SWAN project; Balkan Region

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1. Introduction

The increase in waste volume is a burning issue. The United Nations define waste as "materials that are not prime products for which the generator has no further use in terms of their own purposes of production, transformation or consumption, and of which they want to dispose" [1]. In other words, waste is any unwanted or unusable material or any substance that is discarded after primary use or is worthless, defective, and of no use. This can be solid, liquid, or gas, and each type requires different methods of treatment and management.

Solid waste is inextricably linked to urbanization and economic development. As countries urbanize, the economic wealth, standards of living and disposable income of their citizens increase, which leads to higher consumption of goods and services and a corresponding increase in the amount of solid waste, mostly municipal, generated. OECD defines Municipal Solid Waste (MSW) as waste that is collected and treated by, or for municipalities [2]. It covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yards and gardens, street sweepings, contents of litter containers, and market cleansing. Waste from municipal sewage networks and treatment, as well as municipal construction and demolition is excluded.

Various methods of waste management exist, ranging from the most preferred waste diversion methods (reduction, reuse, recycling and recovery) to the least preferred ones (incineration and landfill) [3]. A special mention should perhaps be made for the case of incineration. Many European countries, the USA and China use it as an efficient method for energy generation which, at the same time, reduces the volume of waste to be landfilled.

However, incineration is not generally considered as a responsible way of managing waste as it can have serious negative effects on the environment and does not comply with circular economy principles. The waste management method applied each time depends, obviously, on the specificities of the situation, but primarily on the current economic model. However, for a long time, the prevailing linear economy model seems unable to support the waste diversion methods, thus leading to severe problems, such as the depletion of raw material deposits and the faster rate of waste and gas emission generation. There is, therefore, a strong pressure for the switch to a circular economy model where the products may be used for longer periods and on the other hand are easily dismantled and reused, thus leading to decrease in virgin raw material consumption.

The idea of circular flow of materials and energy as well as the need to move toward a cyclical system of production emerged in 1996 [4]. The term circular economy appeared for the first time in 1998 [5] and very soon afterwards it was used to describe an economic system where waste is reused in the various steps of the production process [6]. In the early 2000s, China adopted this concept and integrated it in its economic and environmental policies and at the same time it was spread to North America, Europe and gradually to most of the countries around the world [7]. The new model of circular development is driven by three principles: elimination of waste and pollution, keeping products and materials in use and the regeneration of natural systems. Hence, the circular economy can be defined as a production and consumption model involving sharing, leasing, reusing, repairing, refurbishing and recycling materials and products [8], thereby minimizing waste.

Industrial symbiosis (IS), on the other hand, is a form of circular economy where exchanges of waste, by-products or other resources between enterprises generate competitive advantages [9]. The term has its origins in biology, where symbiosis represents the "association of individuals of different species in a relationship where there is a mutual benefit" [10]. This concept has been extended to industries as a collaborative approach between firms which enables the utilization of resources in traditionally separate entities, facilitating a physical exchange of waste, water, by-products, and energy [11] and creating economic advantages for firms and environmental benefits for society [12]. Frosch and Gallopoulos [13] introduced the concept of symbiosis as part of a hypothetical industrial ecosystem where the "consumption of materials and energy is optimized; waste generation is minimized, and effluents from one process are used as raw material for another process" [14]. Moreover, it helps to increase the industrial system's circularity [15] and can create economic, environmental and social benefits [15–17], thus promoting local and regional sustainable development [18]. In recent years, IS has been a core strategy [16,19,20] and a key practical approach to promote the circular economy [15,21]. Industrial symbiosis originated over 50 years ago in Kalundborg, Denmark. The five core partners were a coal power station, an oil refinery, a plasterboard factory, a pharmaceutical manufacturer and the municipal authorities. Their partnership emerged spontaneously with main objective to reduce waste by finding alternative ways of using it in order to generate a profit, but they gradually realized that they were also generating environmental benefits. Over the years these entities developed a network of exchanges between each other and with other smaller companies [22]. Industrial symbiosis has started to gain recognition in the scientific literature at the onset of this century, and is now well-recognized as a key subfield of industrial ecology, an environmental framework according to which the industrial world can function as an ecosystem characterized by networks of interaction among companies [22]. These networks can be either spontaneously created by private enterprises or established with the support of associations or public institutions. However, the functioning of industrial symbiosis remains complex and dynamic and the establishment of a symbiotic scheme is a multi-step process that goes from the identification of an opportunity to its implementation and operation [23]. More specifically, the process of developing and implementing IS may be divided into five phases: (a) opportunity identification; (b) opportunity assessment; (c) barrier removal; (d) commercialization and adaptive management; and (e) documentation, review, and publication [24]. Over the last few years, this development has slowed down in Europe due to several, mostly financial, barriers (e.g., new infrastructure and physical space required, economic crisis and strict financial budget implemented for the majority of companies) [25]. Recent research, however, has identified a number of other generic IS barriers (i.e., governmental, technological, organizational) [26] but also country-specific barriers (i.e., low awareness, lack of infrastructure, absence of regulatory framework) [27,28] which may be found mainly in emerging and frontier economies and can be applicable in the case of the Balkan countries. Thus, there is currently the need for national or regional policy frameworks that will facilitate the implementation of IS, resulting in economic benefits for all stakeholders involved and improvement in the environmental performance of the system. Policy and decision-making processes can be enhanced by Information and Communication Technology (ICT) tools.

The SWAN model, developed in the context of an Interreg program, is a step in the direction of circular economy and industrial symbiosis. It can be applied both within a country but also among different countries. The findings from its application to the four countries involved in the project may be certainly utilized in all the countries of the Balkan Peninsula and initiate translational cooperation in the context of the quadruple helix involving academic institutions, private sector, public sector and the civil society. Its main function is the matching between solid waste and demand based on technical and economic criteria which may lead to sustainable symbiotic schemes. The digital platform, the built-in matching algorithm and the library of good practices are the main novelties of this model and the same goes for its application area. Waste management is a thorny and poorly studied issue in the Balkan countries and the findings from the implementation of the SWAN model could pave the way for its better understanding and the taking of appropriate measures.

Following this brief introduction, the paper is structured as follows. Section 2 describes the current state of solid waste generation and its treatment in the four countries (Albania, Bulgaria, Cyprus and Greece). Section 3 gives a brief overview of the SWAN project. Section 4 focuses on the findings of the project, by processing and analyzing the data collected. Finally, Section 5 summarizes the results and makes suggestions for further research.

2. Solid Waste Management in the Balkan

Waste management is globally one of the main challenges towards the achievement of sustainable development, and the Balkan countries face serious problems in this field. The low awareness of the main stakeholders involved in the waste management process and the lack of a clear and well-defined strategy is the main stumbling block. Moreover, only a small proportion of the waste is recycled and/or used as secondary raw material and for certain types of waste there are no viable solutions for materials recovery. Finally, the low absorption rate of European funds, which could be invested in waste management and circular economy projects, is also another long standing and serious problem inhibiting the achievement of their goals. The main reasons for that are the lack of reliable data, which is reflected on the quality of the applications submitted for funding and the difficulties in the cooperation among the authorities assigned with the handling of the funds and the potential beneficiaries.

Over the last ten years, Albania, Bulgaria, Cyprus and Greece have updated their waste management plans and have defined their strategy and targets of waste management on a national level, aligning their policies with EU. Nevertheless, solid waste management remains a major structural challenge for all the above countries despite their differences. Landfilling remains as a general practice the most common method of waste disposal, but the number of illegal landfills that are still operational or in need of relocation has fallen over the years. However, according to the European Commission's 2018 'Early Warning Report', all four countries are at risk of not meeting the municipal waste recycling target of 50% [29]. The following four subsections look in more detail at the present situation and future plans of the solid waste management in each one of the four countries involved in the SWAN project.

2.1. Albania

The country has a developing mixed economy classified by the World Bank [30] as an upper-middle income economy. The transition from a socialist planned economy to a capitalist mixed economy in Albania took place in the last three decades. Albania has made some progress in terms of energy, transport and digital infrastructure development, but a lack of productive expertise, low education levels and technology transfers hinder Albania's competitiveness and integration into international value chains.

The current waste management system in Albania is heavily reliant on disposal to landfill both legal and illegal. There are plans to close the illegal landfills and instead build waste incinerators and sanitary landfills. Separate collection for recycling is not common, and there are no clear enforcement mechanisms supporting separate collection and recycling [31].

As the landfilling rates are planned to decrease, the capacities of the forthcoming residual waste treatment facilities may exceed future demand. Combined with a lack of reliable data (the data are scarce, non-representative and published with annual narrative reports in which it is often impossible to process statistical data from them) and an increase in the quantity of waste generated, there is a significant risk of overcapacity for residual waste treatment, which may be a barrier to the development of the recycling sector. This is a gap that the SWAN project aims to address, providing consistent, homogeneous and reliable data.

Albania has a new National Waste Management Plan (NWMP) for 2020–2035, which has key targets on waste management. The targets for increasing recycling and reducing landfilling are relatively ambitious and require the development of key infrastructure for the treatment of residual MSW. To reach the targets set in the NWMP, infrastructure development, the introduction of an extended producer responsibility scheme and regional waste management planning are required.

Regarding the situation in the Republic of Albania and the adoption of contemporary methods of waste management, this is still at an early stage, although the revised Integrated Waste Management Strategy was developed over the vision or perception of the concept of "zero waste". This means that the waste is collected and treated as raw material and is managed in accordance with the concept of circulatory systems, contributing to the preservation of raw material resources [32].

In conclusion, even though Albania is lagging regarding contemporary waste management practices, some positive steps are taking place. The new NWMP may pave the way for better results, while the efforts for increasing recycling and reducing landfilling consist a major priority for the future.

2.2. Bulgaria

Bulgaria has undergone a significant transformation over the past three decades. It has changed from a highly centralized, planned economy to an open, market-based, upper-middle-income country securely anchored in the European Union (EU). Waste management continues to be a challenge, despite municipal waste generation per capita being below the EU average [33,34]. Bulgaria still has one of the highest landfill rates for municipal waste in the EU, according to the European Commission [34] at 62% in 2017 compared to the EU average of around 24%. However, the landfilled amounts have decreased since 2010, composting has increased, and a small amount of waste has been diverted from landfill to incineration.

Bulgaria reported that all landfills which do not comply with EU standards have stopped accepting waste, but the implementation of this measure needs to be further improved. As a matter of priority, landfills need to be definitively closed and rehabilitated, and illegal dumpsites eliminated. Despite significant progress in the closure of noncompliant sites, their rehabilitation remains a challenge [34].

Recycling of municipal waste (including composting) has slightly increased and it is a fact that some progress has been made over the last years, although the recycling rate remains considerably lower than the EU average of 46% and significant efforts will be needed to meet the EU recycling targets.

One of the root causes of the lack of progress in separate collection of recyclable materials other than metals is the competition between the formal and the informal waste collection systems. This competition affects the incentives both of extended producer responsibility schemes to invest in separate collection and of citizens to participate in it. Furthermore, the capacity of municipalities to organize, procure and manage waste collection and treatment is limited.

According to Vitkov [35], the Waste Management (WM) legislation in Bulgaria is in line with the EU directives. Bulgaria has adopted a good legal basis for fair calculation of waste collection fees, but the law has not yet entered into force, so the 'polluter pays' principle has yet to be applied. The country's strategy regarding waste management policies was expressed by the National waste management program 2014–2020. European funding has been provided for the implementation of these programs. An ordinance for the construction and operation of municipal waste incineration plants has been adopted, including the utilization of the energy generated.

Overall, there are efforts in Bulgaria to modernize the entire waste management model with a focus on separate collection and treatment of biowaste and further reduction of landfilling, while ongoing efforts to prevent illegal dumping have been made, in recent years.

2.3. Cyprus

During the last three decades, the Cypriot economy turned from the agricultural sector to services and light manufacturing. Cyprus is, today, a major tourist destination as well as a modern economy, offering dynamic services with an advanced physical and social infrastructure.

The main priorities of the country's waste management policy are the reduction/elimination of the harmful effects of the generation and management of waste, the promotion of reuse, recycling and recovery and, generally, the environmentally sound management, in order to reduce the disposal in landfills and to reduce the overall impact of the use of resources by improving the efficiency and effectiveness of their use [36].

Following a steady decrease in 2009–2014, the landfilling rate increased again in the last few years. According to recent data from Eurostat [37], 55.4% of the waste treated was landfilled, 20.4% recovered and backfilled, 17% recovered and 7.2% used for energy generation. The corresponding figures for the EU were 44.9%, 10.9% 37.9% and 6.3%, respectively. Based on those facts, the European Commission issued an "early warning report" asking Cyprus to take all the necessary steps to comply with the relevant directives and eventually meet the Green Deal's zero pollution goals. Following these directions, the country's Department of the Environment has taken several measures which are specified in the Municipal Waste Management Plan for the period 2015–2021. These initiatives aim at overcoming several long-standing problems such as lack of both waste collection infrastructure and coordination among the various administrative levels, introducing technical capacity improvement programs and setting-up a more rational co-operation framework among the various stakeholders. [38].

2.4. Greece

Greece has substantially improved its budget balance and current account balance in recent years. However, actual growth has suffered, and large accumulated imbalances remain as a legacy of the economic crisis. According to the European Commission [39], the Greek economy has continued to recover, in terms of both growth and employment.

Tourism is a key contributor and a vital driver for the Greek economy, while in general the sector of services is the dominant sector in the country.

Regarding waste management, Greece relies heavily on landfilling (80% compared to an average 24% in the EU) [39]. Other methods, such as the separate collection of bio-waste, are almost non-existent, although the average municipal waste composition in Greece is about 44% organic Regarding the latter, only a few piloting projects are running in Greece, which will also need significant efforts in reaching the revised recycling targets for the future (up to 65% by 2035).

Some progress has been made through legal and institutional steps to increase waste recycling and expand the Extended Producer's Responsibility schemes. Moreover, it must be stressed the initiative for the establishing of multilevel strategic frameworks for waste management at the national, regional and local level. The strategic framework for waste management is now in place, with the adoption of the national and regional waste management plans. The local (municipal) waste management plans, which have been incorporated in the regional plans, set the separate collection of bio-waste as a basic goal and at the same time they promote reuse of waste. Greece has planned to allocate a large proportion of EU funds to waste management measures and infrastructure such as integrated waste treatment facilities and source separation schemes. In this direction significant support is provided by the EU programs such as LIFE, Interreg, Horizon and generally by the EU's funding instruments.

However, despite the progress that has been made, the country still faces serious problems with the formal adoption and implementation of policies for the reuse of waste, the political will and the stakeholders' involvement. Furthermore, the use of financial instruments to incentivize prevention, reuse and recycling is still insufficient and the existing schemes are performing poorly [40].

3. The SWAN Project: A Brief Outline

The SWAN project ("a digital Solid Waste reuse plAtform for BalkaN") focuses on the Balkans and aims to highlight and address some of the problems faced. It was co-funded by the European Union Cooperation Program "Interreg V—Balkan-Mediterranean 2014–2020" and national funds of the four participating countries: Albania, Bulgaria, Cyprus and Greece. It ran for 24 months between 2019 and 2021. It was coordinated by the Association of Municipalities in the Attica Region—Solid Waste Management (EDSNA) and the consortium also included the Greek Ministry of Environment and Energy, the University of the Aegean, the Albanian Ministry of Tourism and Environment, the NGO ILIRIA from Albania, the Bulgarian Industrial Association, and the Cyprus University of Technology.

The objective of the project was to create a digital ecosystem supported by a Balkan solid waste map and a repository for best practices on solid waste management, towards the development and management of local and transnational value chains for solid waste reuse. SWAN also aimed to facilitate the development of an industrial ecosystem in the same region, i.e., a network of industries producing and using solid waste.

The main contributions of the project are the development of an online platform (available at www.swanplatform.eu, accessed on 6 May 2022), which maps solid waste resources and potential receivers of waste streams and proposes technically feasible and economically viable symbiotic schemes. In the context of this project, data have been collected from all the countries involved and processed to throw light on issues related to solid waste management and industrial symbiosis schemes in these countries. The methodology used to identify and assess symbiotic schemes has been described in detail in Angelis-Dimakis et al. [36,41], but for the needs of this paper its main points are outlined below.

The SWAN platform algorithm carries out the waste supply-demand matching in two levels. At the first level it relates the data collected through the questionnaire from industrial units in the four participating countries with the data collected for the model's database of best practices and proposes the most appropriate potential generic symbiotic schemes for each region. At the second level, the algorithm, based on the data collected in each one of the four countries, identifies solid input streams used as resources in industrial units which could be potentially replaced by output waste streams of other units and suggests potential region-specific symbiotic schemes. To this end, it considers, as already mentioned, technical (i.e., compatibility of the types of waste produced and demanded) and economic (i.e., waste transportation cost between the supply and demand points) criteria. The SWAN model, as designed, may implemented both within a country and among different countries but its application depends obviously on the prevailing conditions in each particular case. Concluding, we could say that the viability of every symbiotic scheme apart from the technical and economic constraints is also subject to several other barriers such as social, environmental and legal. Useful data in this direction have been collected in the margins of the SWAN project but their processing, which was beyond the scope of this particular project, may be carried out in the context of a nest research program.

The results obtained from the application of the SWAN model in the four countries are summarized in the following section.

4. Results

This section summarizes the findings stemming from the processing of the data gathered, through a common questionnaire, from a sample of 556 units (industries and municipalities) in Albania, Bulgaria, Cyprus and Greece. The data collection method included personal or telephone interviews and emails. It should also be mentioned that the sampling was nationwide in the case of Albania, Bulgaria and Cyprus but confined to the Region of Attica in the case of Greece. The reason for this differentiation is that the project's lead partner, the Solid Waste Management Authority in the Region of Attica (EDSNA) had direct and full access to the region's waste data and at the same a sample drawn from Attica, which accounts for about 35% of the country's population and produces about 40% of its waste, could be considered as representative for Greece. The completed questionnaires account for about 20% of the total number of those distributed and around 2% of the respective population, i.e., industries producing substantial quantities of solid waste and municipalities. The data was collected in 2021, but related to 2020, and was organized in three parts.

The first part investigates the familiarization of the respondents with key circularity concepts and their attitude in taking part in circular economy and symbiotic schemes. More specifically, they were asked whether they were familiar with the concepts of circular economy (question Q1) and industrial symbiosis (question Q2) as well as whether they had any symbiotic links in their unit (question Q3) or would be willing to participate in such schemes in the future (question Q4). The second part summarizes the profile of the respondents, i.e., the type and size in the case of industries as well as qualitative and quantitative characteristics of the waste produced and/or required, in the case of both industries and municipalities. Industries are classified according to their size into micro industries (less than ten employees and 2 million Euros annual turnover), small and medium enterprises (less than 250 employees and 50 million Euros annual turnover) and large industries and according to their type on the basis of the NACE code, i.e., the statistical classification of economic activities in the European Community. The waste streams are classified according to the EWC-Stat categories. Finally, the third part identifies the possible matchings between waste supply and demand, which may determine a potential symbiotic scheme. At this point it should be mentioned that very few of the participants provided financial data on waste management and processing and this certainly affects the reliability of the evaluation of the economic viability of the proposed symbiotic schemes.

4.1. Albania

The Albanian interviewees consisted of 30 industrial units and 50 municipalities, with their geographical position illustrated in Figure 1. The findings from the processing of the data collected are summarized below.

Figure 1. Map of Albanian participants (screenshot from www.swanplatform.eu, accessed on 10 May 2022).

Regarding the answers of all the respondents to the four questions concerning their views on the key concepts around 90% declared familiar with circular economy, slightly less familiar with industrial symbiosis and practically all of them interested to participate in symbiotic value chains. At this point however, it should be underlined that despite the high percentages assigned to the respondents' familiarization with these concepts their knowledge seems rather superficial and not well documented. This last comment applies to all four countries involved in the project. Finally, the percentage of those who have come across symbiotic links in their company is very small and obviously indicates the very limited adoption of such schemes in Albania.

The grouping of the sample's industries according to their type is summarized in Figure 2.

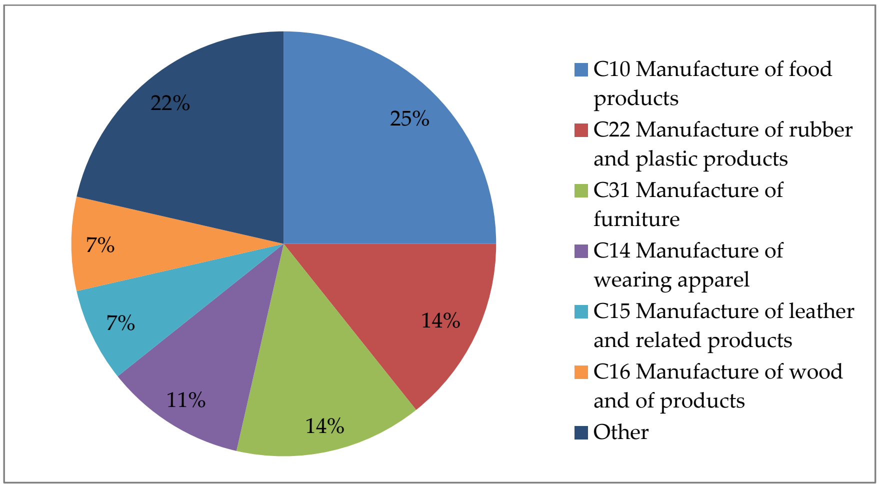

Figure 2. Albanian participants type profile.

Regarding the size of the industrial units, the large industries account for just over 10% of the sample, the micro industries for about 15% and the SMEs for about 75%. This is a finding which reflects the composition of Albania's industrial stock which consists of mainly very small and small light industries. More than 90% of the recorded waste streams were characterized as generic urban waste. These were excluded from the analysis since they constitute mixed waste with diverse characteristics and cannot be further assessed. From the remaining waste streams recorded, the available solid waste streams are, as expected based on participants' type, common and typical of domestic activities (Figure 3).

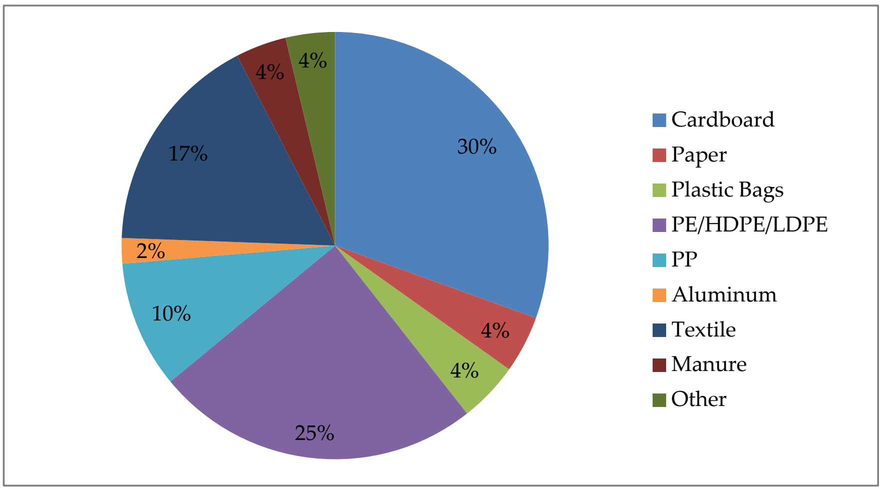

Figure 3. Albanian participants waste type profile.

It should be also noted that half of the large enterprises did not give reliable data. There were inconsistencies in the reporting of wood since it was reported either in mass or in volume. Moreover, plastic related streams were not clearly defined as, for example, film, pieces or other recyclable or not types of plastic. Hence, it is rather difficult to propose a specific sustainable action plan. Nevertheless, based on the available waste flows and the respective distances, of less than 30 km between the sources and the potential receivers, three regions have been identified as potential candidates for the development of symbiotic schemes, as illustrated in Figure 4.

Figure 4. Identified regions for the potential development of symbiotic schemes, with the red circles in-dicating the most favorable regions for IS development (adapted screenshot from www.swanplatform.eu, accessed on 10 May 2022).

4.2. Bulgaria

The Bulgarian sample consisted of 151 industrial units, as illustrated in Figure 5. The findings from the processing of the data collected are summarized below.

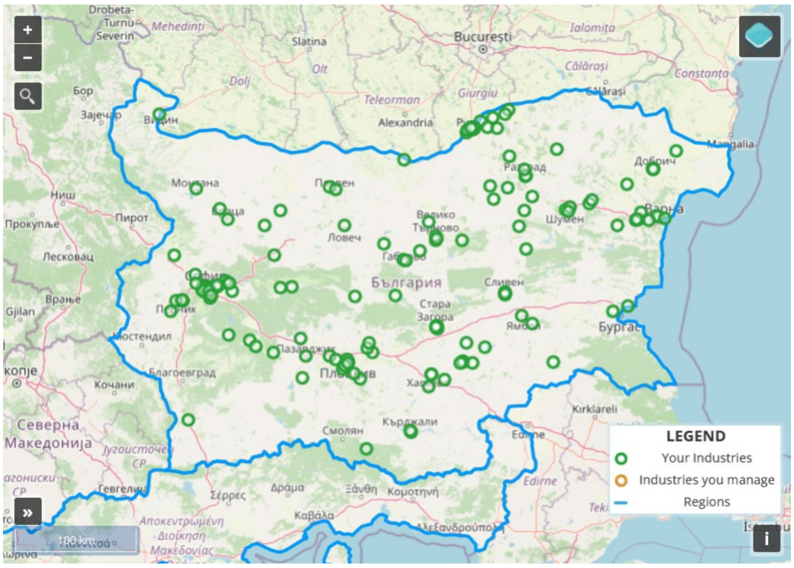

Figure 5. Map of Bulgarian participants (screenshot from www.swanplatform.eu, accessed on 13 May 2022).

Regarding the answers of all the respondents to the four questions concerning their views on the key concepts, around 95% declared familiar with circular economy and a similar percentage interested to participate in symbiotic value chains. The reservations expressed for the high familiarization rates in the case of Albania apply in this case too. Finally, around 45% of the respondents had experienced symbiotic links in their companies which shows a considerable penetration of symbiotic schemes in the Bulgarian industry.

Regarding the size of the industrial units, the large industries account for about 20% of the sample, the micro industries for about 15% and the SMEs for the remaining 65%. Moreover, the sample included 11 electricity generation plants (D35), ten manufacturing plants of bricks, tiles and construction products (C23.3.2) and nine aluminum (C24.4.2), lead, zinc and tin (C24.4.3) production plants. Finally, a considerable number of primary sector installations has been recorded, among which 33 pig and poultry farms (A1.4). The grouping of the sample's industries according to their type is summarized in Figure 6.

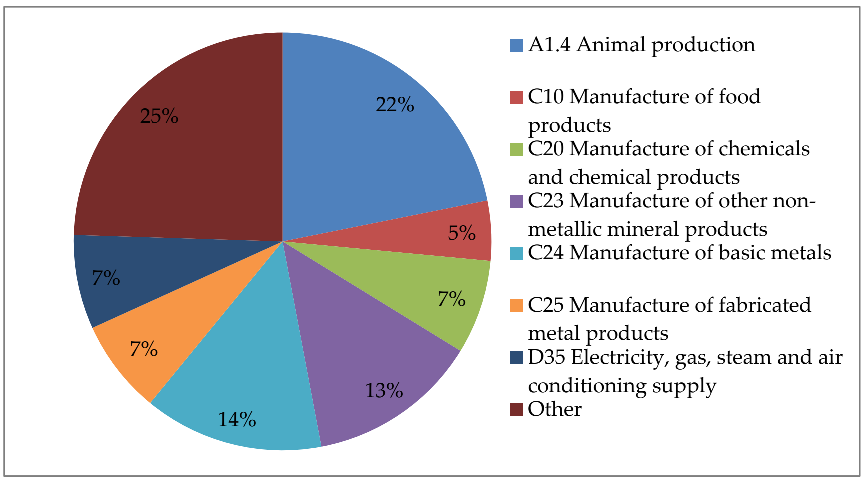

Figure 6. Bulgarian participants type profile.

The composition of the industrial stock (heavier industry and primary sector) is also reflected on the type and the quantity of the waste produced.

Approximately 0.5 million tonnes of solid waste streams were recorded and characterized, with more than fifty different types of waste. There is no point in presenting the findings in a pie chart since most of the categories will have a share of less than 2%. The most significant waste streams and the corresponding quantities annually generated, expressed in tonnes, and rounded to the nearest hundred are presented in Table 1.

The most common use of fly ash from electricity production and slag from furnaces (metal industries or other industries) is in the cement industry [42]. Since there is only one cement factory in the country (at least in the recorded sample), other applications for fly ash should be explored. Coal ash can be also reused in civil engineering applications, as a construction material, in glass ceramics, water and wastewater treatment, as well as in manufacturing of high value products [43]. Different types of slag can be used in construction, as additives or replacing other components. In more detail, copper slag can be reused in high strength building ceramics [44] and to produce pyrometallurgical products, while the non-metallic residue can be used in the glass and ceramics industries [45]. Steel slag can be used as an additive in bituminous paving mixtures [46] and road construction mixtures [47]. Fly ash slag can be used as a cement substitute [48] and electric ash furnace slag in bituminous mixtures replacing the coarse aggregates [49]. Wood waste may have various uses in different industries, such as charcoal production [50], energy generation [51], cellulose and composite production and drying materials [52] and wood pellet production [53].

Table 1. Bulgarian Participants Waste Type Profile.

Waste Type	Annual Quantity (Tonnes)	Share
Fly Ash	63,000	13%
Slag	49,600	10%
Other Waste	43,500	9%
Wood Waste	36,900	7%
Metal Waste	33,400	7%
Industrial Sludge from WWTP	31,500	6%
Construction Waste	17,350	3%
Soil and Stones	16,000	3%
Clay	15,600	3%
Urban Waste	14,600	3%
Sawdust	14,500	3%
Ceramic Waste	12,300	2%
Gypsum	12,200	2%
Molding Waste	12,000	2%
Phosphogypsum	12,000	2%

Construction waste has limitations in its reuse applications, which depending on the material properties, can be mainly in construction, i.e., using asphalt waste in the production of new asphalt [54,55], in geotechnical applications [56] and in the production of prefabricated building materials or as high-performance cement additives [57].

Stone waste can be used in a variety of industries, such as construction, ceramics, iron and steel, and plastics [58]. Fine quarry wastes can be used in the pavement construction sector [59] and natural stone waste may be used as stabilization additives in clayey soil [60]. Clay brick waste can be used in construction and building materials [61,62].

Sawdust can have different reuse applications; calcareous sawdust from marble processing plants can replace expensive additives in the building sector [63] whereas wood sawdust can be used to produce wood-plastic composites [64] and, in wastewater treatment facilities, for the removal of heavy metals such as nickel from aqueous solutions [65]. A furniture industry in Zimbabwe is using wood sawdust to produce briquettes that cover part of its fuel requirements [66].

Similarly to most waste mentioned so far, ceramic waste can be used mainly in the construction sector either as supplementary material in recycled concrete [67,68] or combined with marble dust to completely replace cement in concrete [69]. Another use could be to produce ceramic roof tiles as a precursor in the geopolymerization reaction [70].

Gypsum from electricity production and lead, zinc and tin production is being currently reused in an existing symbiotic scheme as feedstock to a plasterboard manufacturing facility [71]. In the case of phosphogypsum reuse, there are still some challenges to be overcome, but it can be used in different applications: as a construction material [72], in the production of low-carbon sustainable composites [73] and it can replace gypsum in the production of hemihydrate gypsum [74].

Sunflower husk (although not on the table) is another waste stream which could be potentially reused, with an annual production of approximately 5000 to per year. Several potential uses could be examined as input for ceramic products, [75] fillers for epoxy-based composites [76] or as a fuel in small scale boilers and furnaces [77].

Urban and industrial sludge could also be reused for several industrial applications, use several needs, if it is characterized as a non-hazardous waste stream. More specifically, industrial sludges can be used in pulp and paper industries, bricks, tiles, and construction products manufacturing or cement industries [36]. Industrial organic sludge can be combined with organic waste stream and sewage sludge, to produce fertilizer and biogas for vehicles, with a symbiotic scheme installed in Händelö Island Industrial Park.

From all the above, it is clear that the industrial symbiosis potential in Bulgaria is significant. Several schemes could be developed based on the available waste streams. The potential receivers involve industries characterized as C23.1 Manufacture of glass and glass products, C23.2 Manufacture of refractory products (including bricks, tiles and construction products), C23.5 Manufacture of cement, lime and plaster as well as smaller scale electricity production. However, further analysis should be performed on a case-by-case basis to confirm the technical feasibility of these schemes, and to also assess their economic viability.

4.3. Cyprus

The Cypriot sample consisted of 108 industrial units and is illustrated in Figure 7. The findings from the processing of the data collected are summarized below.

Figure 7. Map of Cypriot participants (screenshot from www.swanplatform.eu, accessed on 13 May 2022).

Regarding the answers of all the respondents to the four questions concerning their views on the key concepts over 95% declared familiar with circular economy and just over 80% familiar with industrial symbiosis. The reservations expressed for the very high familiarization rates in the cases of Albania and Bulgaria apply in this case too. Moreover, a percentage of just under 20% declared not interested to participate in symbiotic value chains. This is a rather high ratio and may need further consideration. Is it because of non-familiarity with the term (since a similar share of industries replied that they are not familiar with the concept of IS) or is it another reason behind it? Finally, around 50% of the respondents had experienced symbiotic links in their companies which shows a considerable penetration of symbiotic schemes in the Cypriot industry.

Regarding the size of the industrial units, the large industries in the sample accounted for about 3%, the micro industries for about 8% and the SMEs for the remaining 89%.

The grouping of the sample's industries according to their type is summarized in Figure 8.

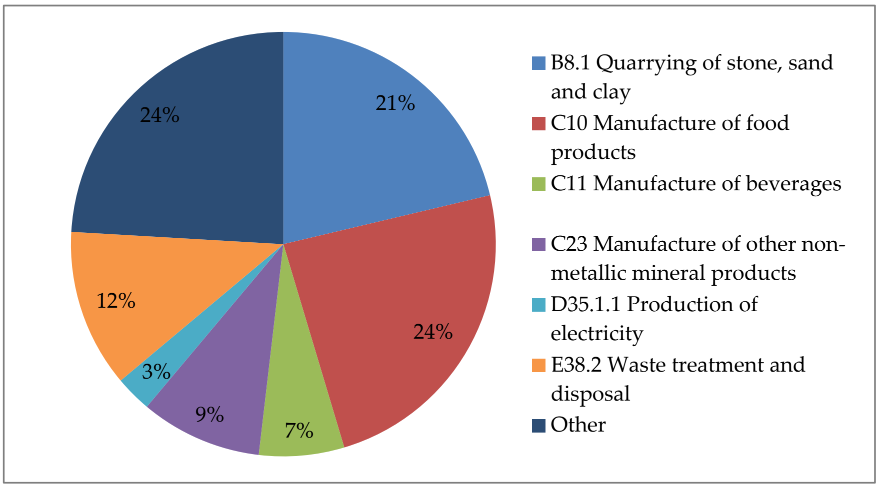

Figure 8. Cypriot participants type profile.

Regarding the available waste streams, the total quantities annually generated, expressed in tonnes and rounded to the nearest hundred, are greater than in Bulgaria, as presented in Table 2. However, in terms of the waste type classification, the categories are very generic, and it is difficult to provide specific symbiotic schemes. The greatest contributor is the (mostly industrial) sludge. Based on the potential input streams that could be replaced, five industries have declared that could consume sludge. Four of them were wastewater treatment plants and only one cement industry which could reuse the waste stream in their production line. However, according to the SWAN best practices database, non-hazardous industrial effluent sludges can be also reused by industry type C23.3. Manufacture of clay building materials. Thus, a symbiotic scheme with some of the eight regional brick manufacturing facilities could be investigated.

It was also suggested by the local experts to examine potential symbiotic schemes, based on the most common types of industries, which will be of a lower magnitude (in terms of waste quantity), but may have greater chances of implementation, due to the impact they could have locally. Emphasis was placed in the C10 type of industries, related to food manufacturing. The main waste streams assessed was manure (approximately 5400 tonnes per year) and grape processing waste (approximately 150 tonnes per year). Apart from the obvious energy producing options (biogas from manure, ethanol from winery residues), manure can be also used for fertilizer production, and the residue of grape processing as a bio-adsorbent for the desalination of water. More details on the potential symbiotic schemes identified and proposed for Cyprus can be found in Angelis-Dimakis et al. [41].

Table 2. Cypriot participants waste type profile.

Waste Type	Annual Quantity (Tonnes)	Share
Sludge	320,900	31%
Organic Waste	191,200	18%
Animal Waste	140,500	13%
Paper and Cardboard	109,200	10%
Mixed Fraction	62,000	6%
Municipal Waste	55,900	5%
Ferrous Metallic Waste	50,190	5%
Compost	43,000	4%
Plastic Waste	26,900	3%
Other	44,900	4%

4.4. Greece

The Greek sample consisted of 188 industrial units and 29 municipalities, all located in the region of Attica (Figure 9). The findings from the processing of the data collected are summarized below.

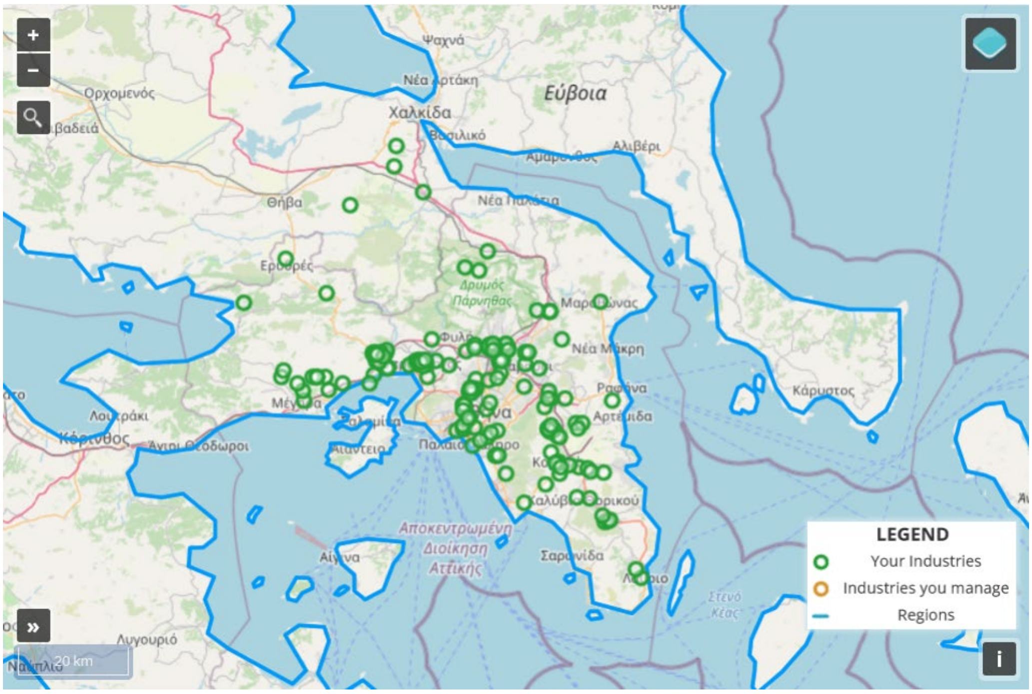

Figure 9. Map of Greek participants (screenshot from www.swanplatform.eu, accessed on 6 May 2022).

Regarding the answers of all the respondents to the four questions concerning their views on the key concepts 95% declared familiar with circular economy and around 75% familiar with industrial symbiosis. The reservations expressed for the very high familiarization rates in the cases of the previous countries apply in this case too. Moreover, just over 25% had experienced symbiotic links in their companies but almost all of them were interested to participate in symbiotic value chains, a finding which may need further consideration.

Regarding the size of the industrial units, the large industries account for about 10% of the sample, the micro industries for about 30% and the SMEs for the remaining 60%.

The grouping of the sample' industries according to their type is summarized in Figure 10. As we can see there is a wide variety of industries in the region (with the highest percentage being 9% for the food industries), which also indicates a potential difficulty in proposing generic symbiotic schemes based on type. It should be also noted that there was a low response ratio from the industrial partners in terms of waste quantity. Around 42% of the respondents did not provide quantitative data for their solid waste streams. This means that they either gave no answer but provided data only for liquid/gaseous streams or provided qualitative data on solid waste streams (e.g., type) but no quantities.

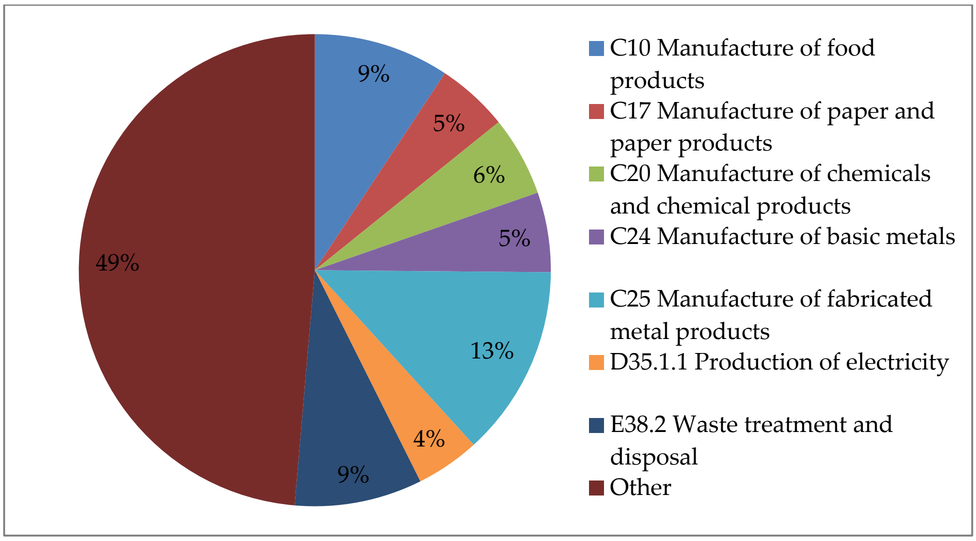

Figure 10. Greek participants type profile.

The total quantities of the waste streams, annually generated, expressed in tonnes, rounded to nearest hundred are presented in Table 3, having in mind that these values represent only 58% of the respondents which gave full answers. All streams are quite generic, and it is difficult to propose very specific waste reuse schemes. The only exception can be then ash and slag waste stream, for which the symbiotic schemes proposed in the case of Bulgaria, can be also applicable. Thus, a more detailed characterization of the waste streams is required. As a step towards this direction, Mathioudakis et al. [78] analyzed the municipal solid waste stream for one of the municipalities that responded to this questionnaire, and estimated the fractions for food waste, plastics, paper and cardboard, glass, and metals. Only after such an analysis, the authorities can proceed to a better-informed decision and policy making. Having that in mind and given the amount of waste that is being produced by municipalities, the urban settlements can play a critical role in the development of symbiotic schemes and facilitate the wide implementation of Industrial-Urban Symbiosis.

Table 3. Greek participants waste stream quantities.

Waste Type	Annual Quantity (Tonnes)	Share
Animal Waste	1,178,000	35%
Municipal Solid Waste	957,900	29%
Plastic	340,300	10%
Scrap Metal	299,900	9%
Mixed Packaging	89,500	3%
Ash and Slag	63,190	2%
Wood	57,800	2%
Biological Waste	45,100	1%
Paper	42,400	1%
Other	272,800	7%

5. Conclusions

The scope of this paper was to look at the findings of the SWAN project in the four countries involved (Albania, Bulgaria, Cyprus, Greece) and (a) give a brief overview of the current state of the solid waste management in each of those and (b) process and analyze the data drawn from the respondents to a common questionnaire distributed in all the countries. The analysis focused on three issues: the degree of the respondents' familiarization with the concepts of circular economy and industrial symbiosis, the profile of the responding industries in terms of their size and type and finally the potential symbiosis schemes that could be established. The main findings are summarized below.

Serious steps have been made over the last years in the waste management field in all four countries but there is still a lot to be done. However, despite the differences in the level of circularity among them, they are still lagging considerably behind most of the EU countries. Hence, there is plenty of room for the introduction of new waste management policies and the further enhancement of practices registered in the context of circular economy.

The familiarization of the stakeholders in the waste management field of all countries with the concepts of circular economy and industrial symbiosis seems high, projects but a further look into whether this degree of awareness is realistic and well documented is required. The same goes for their willingness to participate in industrial symbiosis. These findings reflect the particular interest of the respondents for these issues, which is largely related to both their financial pursuits and the obligation to comply with the prevailing institutional framework. The current rate of implementation of such projects varies between 20 and 40% in all countries with Albania and Greece displaying the lowest figures. The values seem quite high but how industrial symbiosis is perceived by the respondents and what is considered a symbiotic scheme should be questioned and further clarified.

The majority of the industries that participated in the project were SMEs of various types, which constitute the backbone of the national economy, not only in the four countries of the project but in many other European countries as well. Such industries have traditionally had an extra difficulty in adopting new trends, mainly due to the shortage of financial and other means. Hence, their familiarization with circular economy and industrial symbiosis concepts and their willingness to participate in such ventures is very encouraging for their future prospects. The development and implementation of sensitization, familiarization and education strategies and policies targeted to the various groups of stakeholders involved in the waste management field would be a decisive step in the direction of consolidation and propagation of circular economy and industrial symbiosis practices. Focusing on the differences among the four countries, based on the samples drawn, we may say that Albania and Cyprus record the highest percentage of small firms and SMEs, Greece shows a more balanced composition of the industrial stock while Bulgaria exhibits the highest percentage of larger industries.

Regarding the type of industries, the most common economic activity among all countries is C10 Manufacture of food products. The profiles of Greece and Bulgaria are very similar with the main industry types being C20 Manufacture of chemicals and chemical products, C23 Manufacture of other non-metallic mineral products, C24 Manufacture of basic metals, C25 Manufacture of fabricated metal products and D35 Electricity, gas, steam and air conditioning supply. This was also the main reason behind the similarities in the proposed symbiotic schemes between these two countries. The increased level of detail in the case of Bulgaria is due to the higher response ratio and the more detailed description of waste streams (avoiding generic types). A point which may differentiate the waste management strategies in the four countries involved in the SWAN project is the degree of their tourism development. Greece and Cyprus are strong tourist destinations and their economies rely heavily on this activity. Hence, their waste management strategies should consider the increased needs during the tourist season in order to maintain both the level of service provided to the native population and their level of attractiveness as destinations.

Albania had the lowest number of respondents, most of which are less resource-intensive, representing sectors that do not belong to heavy industry (such as C14 Manufacture of wearing apparel, C15 Manufacture of leather and related products and C31 Manufacture of furniture). The small number of industries made it more challenging to find specific 1-to-1 relationships between a solid waste source and a potential receiver. However, three regions were identified where increased industrial activity may be observed and could become a hub for waste reuse (not limited to solid waste).

Cyprus lies between Bulgaria and Greece on the one hand and Albania on the other, with both heavy industries (cement and electricity production) and manufacturing facilities. The lack of specific waste data for the larger industries led to the proposal of waste reuse schemes evolving around the smaller facilities, with winery residues and animal manure being the main waste streams to be exchanged. Despite the differences between all four countries, it should be pointed out that the municipalities are a key player in the solid waste landscape, in terms of annual amount produced. Given the big volume of mixed waste produced in these four countries the design of a more efficient method for their management, the waste separation at the source and the utilization of biowaste may have considerable benefits for the countries. Thus, a properly established waste collection and separation system will enable the wide implementation of Industrial-Urban Symbiosis schemes, with municipalities being in the center of these.

Concluding, we could say that in all four countries there is plenty of room for the introduction of new waste management policies and the further enhancement of practices registered in the context of circular economy. It is obvious that, despite the differences in the level of circularity among their countries, they are still lagging considerably behind to most the EU countries. The need to increase the awareness of all the stakeholders involved, develop a progressive and homogenous institutional framework along the lines of the green deal and the adoption of modern practices and knowledge management mechanisms in circular economy are key prerequisites for every country but also for their network. The fact that three of those countries are already EU members and Albania goes through the accession process facilitates their realization. The development of knowledge and the transfer of best practices through both the European cooperation mechanisms and the free-market synergies could have a significant impact on the shaping of a modern approach to waste management in all four countries. The SWAN model, as already mentioned, may, in principle, be implemented both within a country and among different countries and is certainly a very useful tool for them. Its application depends obviously on the prevailing conditions in each particular case and is subject to a number of constraints technical, economic, social, environmental and legal the mix of which will be different in the case of national and transnational implementation. The deepening climate and energy crises and the urgent need for energy transition may require a continuous monitoring and readjustment of the model's basic parameters.

The analysis of the data which has been carried out so far led to the very interesting conclusions stated above. The research however may be extended in different directions. A first suggestion may be to further elaborate on the economic dimensions (transportation methods and cost) of the solid waste supply and demand matching algorithm in an effort to determine the area around a specific waste producer within which a sustainable symbiotic link may be established but also gradually introduce a number of other additional barriers and suggest ways of removing them. Recent research has highlighted several such barriers. A very interesting classification identifies seven categories of generic barriers including governmental, economic, technological, organizational, informational, cognitive, motivational and safety ones [26]. Other papers examine specific barriers which may be found in the case of emerging and frontier markets and some of their findings may be applicable in our case. Those barriers include, among others, financial barriers to promoting, lack of awareness of industrial symbiosis projects, deficiency of regulatory frameworks and lack of infrastructure [27,28]. Hence, looking into the data already collected, through a PESTLE questionnaire in the margins of the SWAN project, in the light of the recent findings on generic and specific barriers to industrial symbiosis and the ways of removing them [25] seems a very interesting and promising research area. Finally, a second suggestion would be to include in our analysis also liquid and gas waste whose transportation and reuse may be addressed differently.

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