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Review

Decentralized Community Composting: Past, Present and Future Aspects of Italy

Cecilia Bruni [1], Çağrı Akyol [1,*], Giulia Cipolletta [1], Anna Laura Eusebi [1,*], Donatella Caniani [2], Salvatore Masi [2], Joan Colón [3] and Francesco Fatone [1]

1 Department of Science and Engineering of Materials, Environment and Urban Planning-SIMAU, Marche Polytechnic University, via Brecce Bianche 12, 60131 Ancona, Italy; c.bruni@pm.univpm.it (C.B.); g.cipolletta@staff.univpm.it (G.C.); f.fatone@staff.univpm.it (F.F.)

2 Engineering School, University of Basilicata, viale dell'Ateneo Lucano 10, 85100 Potenza, Italy; donatella.caniani@unibas.it (D.C.); salvatore.masi@unibas.it (S.M.)

3 BETA Tech Center, Universitat de Vic-Universitat Central de Catalunya, C/de la Laura 13, 08500 Vic, Barcelona, Spain; joan.colon@uvic.cat

* Correspondence: c.akyol@staff.univpm.it (Ç.A.); a.l.eusebi@staff.univpm.it (A.L.E.); Tel.: +39-0712204911 (Ç.A.)

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Abstract: Italy is among the top biowaste-generating countries in Europe, and has a well-structured waste management framework with quite a number of centralized composting facilities. In recent years, there has also been huge interest from local communities in decentralized composting. Although decentralized community composting is common in some countries, there is still a lack of information on the operative environment together with its potential logistical, environmental, economic, and social impacts. Considering the national Italian legislation on community composting as well as successfully implemented projects at EU level, Italy can set a model especially for Mediterranean countries that intend to build decentralized composting programs. Therefore, in the context of this review paper, a brief overview of the composting process was presented together with main applications in centralized and especially in decentralized composting, while the main focus was kept on the operative and legislative information gathered from Italian community composting. There is a huge difference in the number of composting plants between the regions, and the lack of centralized facilities in the central and southern regions can be supported by decentralized solutions. Decentralizing waste treatment facilities and thus creating local solutions to urban waste management strategies will help to achieve the resource recovery and valorization targets in line with the circular economy.

Keywords: biofertilizer; community composting; decentralized composting; municipal solid waste; recycling; organic waste management

1. Introduction

There is an unavoidable increasing trend of municipal solid waste (MSW) generation worldwide. In 2016, the total waste generated in the EU-28 with respect to all economic activities and households was equal to 2538 million tonnes; furthermore, 486 kg MSW/capita were generated in the EU in 2017 [1]. In a broader food–water–energy nexus perspective, when these streams with a rich mix of organic compounds are wasted, the resources used to produce, collect, treat, process and transport them, are all wasted, and this results in significant losses in energy and water [2,3]. In this regard, decoupling economic growth from the environmental impacts associated with waste generation is a priority target of the EU [4].

Bio-economy seems to be the key factor to follow a sustainable path towards a smart and green future in the EU. Bio-economies are bio-based economical solutions that aim to reduce the dependence on fossil fuels and greenhouse gas (GHG) emissions [5]. EU member states are already obligated to reduce the amount of biodegradable MSW sent to landfills and to recycle organic fractions using more environmentally friendly technologies regarding the Landfill Directive (1999/31/EC) and Waste Framework Directive (2008/98/EC). In recent years, the EU has adopted a series of measures to comply with such requirements [6]. For instance, the European Commission (EC) adopted the "Circular Economy Package", which hosts revised legislative proposals on waste with a greater common target for the recycling of municipal waste and lower limits for municipal waste going to landfills. The target for recycling of municipal waste by 2035 is set to 65% in the revised legislative framework on waste. In this regard, the EU promotes the implementation of precise measures and actions among its members in order to enhance current conditions and build a legal framework for the proper management of MSW [7]. As a result, the amount of waste recycled (material recycling and composting) rose from 39 million tonnes in 1995 to 116 million tonnes in 2017 at an average annual rate of 5.0%. Furthermore, the recovery of organic material by composting has grown with an average annual rate of 5.2% from 1995 to 2017. Recycling and composting together accounted for 46% in 2017 relative to waste generation [1]. In some countries, like Italy, there are explicit and detailed rules set by legislation under waste law. However, the standards on the use and quality of compost differ considerably within EU members, mostly due to differences in soil policies [8]. Platforms such as the European Compost Network (www.compostnetwork.info) brings all European biowaste organizations and their operating plants, research, policy making, consultants and authorities together and creates a network for sustainable recycling practices in composting.

The benefits of reusing or recycling urban waste are neither fully understood nor officially recognised and confirms the fragmentation of policy and institutions along urban–rural lines [9]. While still being a "conventional" method, composting is still considered among the most preferred urban waste management practices. Following the newly developed technologies and innovative processes, composting is now more enhanced and even highly encouraged at the community-scale by governments with recent legislations. Italy is one of the countries that adopts community composting, based on the 2016 national legislation [10]. While many recent projects at EU level have been demonstrating community composting all over Italy, this work aims to review the status of innovative decentralized composting practices in Italy at the community level by discussing institutional structure and site-specific replications for urban biowaste management. The following sections start with the organic waste management structure in Italy, followed by a general overview of composting process and further scale down to a decentralized composting network, and give complementary information regarding the current status in Italy. We believe that the given perspectives in this paper can present a model for Mediterranean countries that are eager to improve their sustainable waste management strategies.

2. Organic Waste Management in Italy

In Italy, as in many other countries, organic waste represents the main fraction of MSW, and the percentage of MSW that is recycled and composted in Italy has more than doubled itself in from 2004 to 2016, according to the European Environmental Agency [11]. Between 1997 and 2017, the amount of organic waste collected separately increased by a factor of 10, and in 2015 nearly 6.1 million tonnes of food and garden waste were collected separately in Italian municipalities, accounting for 100 kg/inhabitant/year [12]. Today, Italy is one of the EU countries leading the separate collection of MSW and specifically of organic waste. In addition, Italy is among the top EU member countries with the greatest proportion of wastes sent for composting [13]. Biowaste accounted for 41.2% of all MSW source separated in Italy in 2016. In 2018, 58% of all MSW was source separated, with peaks of about 72% in the Regions of Veneto and Trentino Alto Adige and other seven Italian Regions with more than 60%. Nowadays, about 35 million of inhabitants in Italy are involved in intensive collection schemes for biowaste (food waste and green waste), diverting about 6.5 million tonnes of biowaste from disposal to recycling [14].

Waste management in Italy is represented by a set of policies, procedures and/or methodologies that identify the management of the entire waste process as its primary objective, from production to final destination. Management involves several stages, such as collection, transport, treatment (i.e., recovery or disposal) and finally recycling and therefore, the possible reuse of waste materials. In a scenario in which the EU sets new recycling targets to meet the principles of a circular economy, as well as the production of municipal waste tending to increase (from 29,651,720 tonnes in 2014 to 30,164,520 tonnes in 2018) [14], the correct management of waste becomes a fundamental tool to meet the objectives of circularity and sustainability. In this regard, Italian legislation has implemented the principles defined by the EU with Legislative Decree 152/2006 "Environmental regulations" (subsequently amended with Legislative Decree 205/2010) (D.Lgs. 152) [15]. In fact, the decree (Part Four, Title I, Chapter I, Articles 179 to 182) contains rules on the correct management of waste. In this sense, particular attention is paid to the waste management hierarchy, in which the priority measures of the best environmental waste management practices are established. Specifically, higher priority is associated with prevention, preparation for reuse and recovery activities, while landfilling is associated with the minimum priority, since it is no longer considered a sustainable way of waste management. Figure 1A shows the changes in the final destination of wastes in Italy over recent years, where there is a decreasing trend in landfilling and increasing interest in biological treatment.

The need to respect this scale of management options requires attention precisely on the initial steps of waste management, i.e., not only the reduction of waste production (where possible) but above all their adequate collection. To this end, each region, on the basis of indications provided by the Ministry of the Environment and the Protection of the Territory and the Sea (MATTM), establishes the criteria for the separate collection of waste (i.e., paper and cardboard, glass and metals, plastic and fraction organic) intending to promote high-quality recycling and to meet the necessary quality criteria for the various recycling sectors. The selective interception of various product fractions allows individual categories of waste to be subjected to specific treatment cycles for the recovery of waste materials and their valorization as a new recycled product.

Special attention is paid to the separate collection of the organic fraction of municipal solid waste (OFMSW) as it represents one of the most critical solid waste flows to be treated both in quantitative and qualitative terms. From a quantitative point of view, OFMSW represented about 40.4% of the total separate waste collection in 2018 and its production is continuously increasing (from 5,720,000 tonnes in 2014 to 7,079,800 tonnes in 2018 in total) [14]. Figure 1B shows the differentiation of OFMSW production between the regions of Italy in 2018. From a qualitative point of view, the OFMSW, being mainly made up of wet (i.e., domestic residues of food waste) and a green fraction (i.e., excerpts and prunings) can become an essential source of renewable energy and compost.

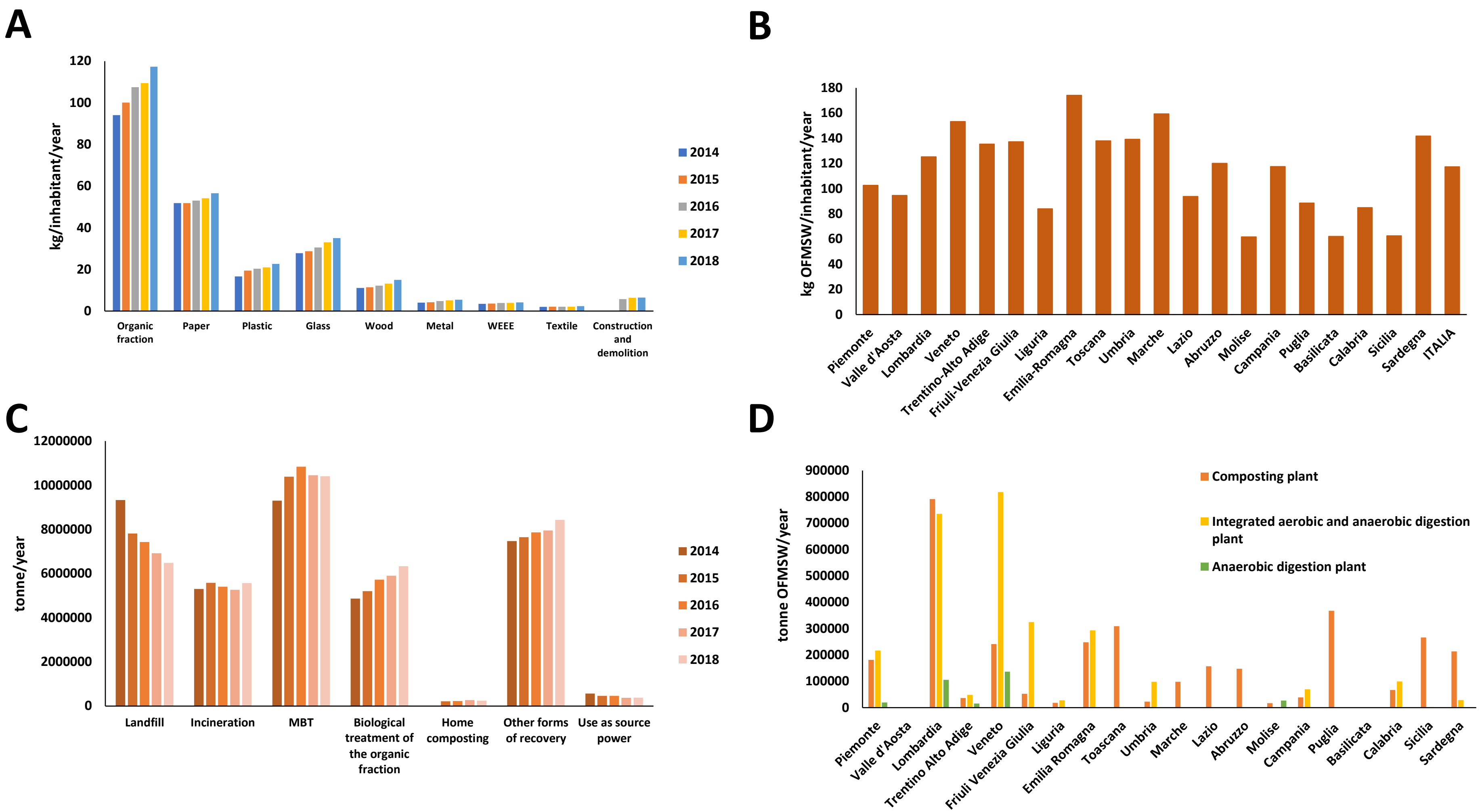

Figure 1. (**A**) Distribution of solid wastes produced in Italy over recent years; (**B**) Region-based comparison of organic waste production in Italy in 2018; (**C**) Distribution of final destination of waste in Italy over recent years; (**D**) Region-based comparison of organic waste final destination in Italy in 2018 (obtained and modified from the official website of Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)).

Enhancement of OFMSW can take place through biological processes that combine integrated anaerobic/aerobic treatment technologies, also thanks to the conversion of some already existing composting plants. Based on the 2018 report of the Higher Institute for Environmental Protection and Research (Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)), the Italian plant equipment includes 339 operating units, with a total authorized capacity of approximately 10.3 million tonnes. In particular, 281 plants are dedicated to aerobic treatment (composting) only; 35 plants have integrated anaerobic/aerobic treatment systems; together with 23 anaerobic digestion plants [14]. It should be noted that, although the treatment capacity of the OFMSW allows the creation of further developments in the sector, the distribution of the plants is uneven across Italy, as can be seen in Figure 1C,D. This fragmentation has an overall consequence of the inability to be able to entirely treat the quantities of waste produced in its territory and therefore depends on the need to export a share of its organic waste to plants located in extra-regional territories. An analysis on waste exports showed a flow direction from Central (Lazio, Marche, Tuscany and Umbria) and South (Abruzzo, Basilicata, Calabria, Campania, Molise and Puglia) Italy to the North (Emilia-Romagna, Friuli-Venice Giulia, Liguria, Lombardy, Piedmont, Trentino-Alto Adige, Aosta Valley and Veneto). Furthermore, small flow entities are detected between the northern regions as they are due to the principle of proximity that it is possible to reach optimal levels of users served by exploiting the territorial proximity that offers better technical-economic opportunities. Overall, it is recorded that the imports of waste are: for Northern Italy equal to approximately 84.7% of the total OFMSW produced; for Central Italy equal to approximately 8%; and Southern Italy equal to approximately 7.3% [14]. The reasons for the variation are mainly due to the late industrialization of the southern regions, difficulties with administrative issues and an economic imbalance between the municipalities that implement the separate collection [16].

3. A Brief Overview of the Composting Process

Composting is defined as the controlled aerobic biological decomposition of organic matter into a stable, humus-like product called compost, where mixing of organic wastes with other ingredients are accelerated to optimize microbial growth [17]. Advantages and disadvantages of composting are widely taken apart in the literature. In the most common sense of the practice, composting enables the recycling of biowaste (i.e., kitchen waste, yard waste, agricultural waste) and reduces the amount of waste going to landfilling, helps to cease greenhouse gas (GHG) emissions when properly managed, increases soil fertility and biodiversity as well as decreases the need for chemical fertilizers when applied as fertilizer, and contributes to raising awareness and promoting community-scale waste management practice [6,18,19]. On the other hand, some concerns are also raised for improperly managed composting applications, such as the formation of malodorous or toxic gases and bioaerosols [6,20], odor [21], leachate [6] and a decrease in soil quality when heavily applied [22]. A general flow scheme of organic waste management by composting is illustrated in Figure 2.

3.1. Critical Process Parameters in Composting

In general, the composting process is considered a consecutive four-phase process that is characterized by changing temperature pattern as follows: 1) initial (mesophilic) phase (25–40 °C) 2) thermophilic phase (35–65 °C) 3) cooling (second-mesophilic) phase and 4) maturation phase. Temperature is the key parameter as it regulates microbial activity [23]. The optimum temperature range for composting is 40–65 °C. The thermophilic phase is of utmost important for hygienization (above 55 °C), where human and plant pathogens are destroyed and weed seeds and insect larvae are killed [24]. Optimum water content of a composting mixture should be around 50%–60%, and at moisture content above 65%, oxygen transfer is inhibited, and the process tends to become anaerobic [25,26]. Aeration is therefore another critical operating parameter for aerobic microbial activity; hence, enough oxygen supply must be ensured [27]. The carbon to nitrogen (C/N) ratio determines the nutritional balance as well as the properties of the final compost product [28]. A C/N ratio between 25 and 30 is usually considered as the optimal ratio for composting [29,30]. A pH of 6.7–9.0 also supports good microbial activity during composting, while acidification during the early thermophilic phase is probably one of the main causes of composting process failure as well as responsible for the emission of odorous compounds (i.e., organic acids) [31]. Particle size and distribution, porosity and mixing are also other parameters that eventually affect the performance of a composting process [27]. Generally, materials used for composting are easily degradable and have nutritional and fertilizing properties; therefore, less-compressible materials with beneficial structuring roles (called bulking agents such as straws, wood chips, sawdust etc.,) should always be added for an efficient composting process. Those materials can help to adjust optimal moisture content as well as give enough porosity to the mass and ensure the oxygen passage within piles for microbial activity [17,32]. Leachate absorption can also be achieved by the addition of bulking agents [33]. In addition, co-composting can help to maintain the C/N ratio, allow the moisture of the mixture to be adjusted to optimal values and even dilute some possible inhibitory substances (i.e., metals). The most recommended option is to mix different wastes or by-products of low or no market value generated in areas close to the centralized composting facilities [34].

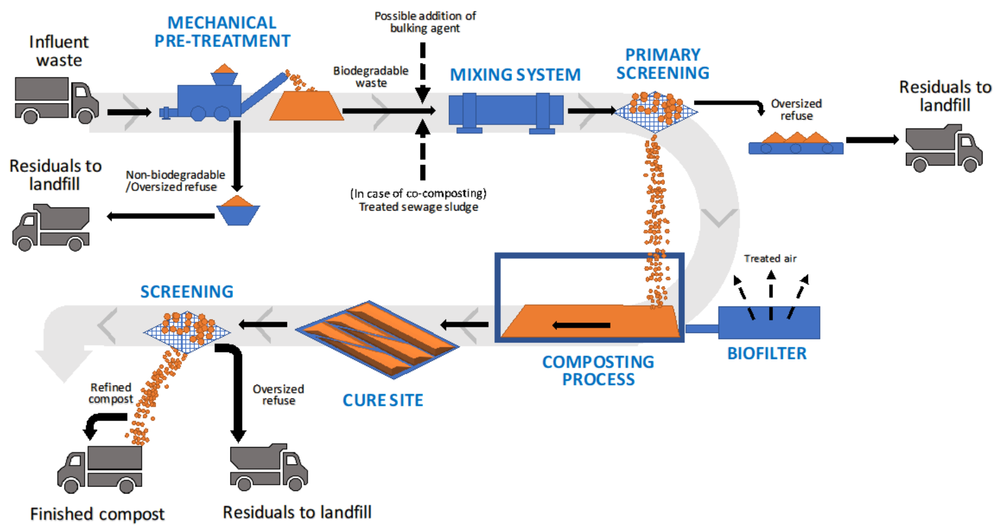

Figure 2. General flow scheme of organic waste management via composting.

3.2. Microbial Ecology of Composting

Microbial activity and diversity of a composting process are highly dependent on the aforementioned environmental and operating conditions. The constant change in conditions (temperature, pH, aeration, moisture, availability of substrates) results in stages of exponential growth and stationary phases of various organisms [23]. The microbial consortia present at any point of time are replaced by others in short intervals. During the composting process, bacteria and fungi, named as nutritionally-specialized groups of microorganisms, are mainly involved in the biodegradation of feedstock components. During the starting (mesophilic) phase, easily degradable compounds like sugars and proteins are first degraded mostly by fungi, generally referred to as primary decomposers. During this phase, fungi compete with bacteria for the easily available substrates and soon are out-competed due to higher maximum specific growth rates of bacteria [24]. In addition to fungi, a special phylum of bacteria, Actinobacteria (or actinomycetes) play an important role in degrading complex organics such as cellulose, lignin, chitin, and proteins, prefer neutral or slightly alkaline pH, and grow best when the environment is moist and the oxygen supply is enough [22,24,25]. Lower thermotolerance as well as higher cruciality of oxygen presence for fungi make them play a negligible role during the thermophilic phase, except for the case of the composting of lignocellulosic substrates. In that case, fungi can remain in the foreground throughout the process. Thermotolerant and thermophilic bacteria can remain active also at higher temperatures. The cooling (second mesophilic) phase is often characterized by an increasing number of organisms that degrade starch or cellulose including both bacteria and fungi. Finally, in the maturation phase, the decrease in water potential favors fungi and bacteria decline. Compounds that are not further degradable, such as lignin–humus complexes, are formed in this phase and become predominant [24].

3.3. Composting Technologies

In a broad classification, composting systems can be divided into two: "windrow" and "in-vessel". The windrow systems refer to the accumulation of compost piles between 1.5–2 m high in the shape of elongated windrows. Meanwhile, in-vessel systems are reactors where the composting takes place and most of the current technologies use these systems. Windrow systems may be subdivided into "turned windrow" and "forced air windrow (static pile)" based on the aeration method. In static systems, air is either forced upwards through the composting mass or is pulled downwards and through it. Meanwhile, turned windrow is a conventional system where piles are manually turned and reconstructed. In-vessel systems, also called bioreactors, can be divided into two main types: vertical and horizontal. Vertical reactors involve some type of cylindrical container or tank with a capacity of more than 1500 m^3. Horizontal reactors are operated in the horizontal position and can be further divided into channels, cells, containers and tunnels. In addition, in-vessel bioreactors can also be classified as a function of the movement of the material as: static and dynamic. Another type of reactor is the "inclined" reactor, or more commonly called rotating drum. Some of the designs of the drums incorporate internal vanes which, combined with the rotating action of the drum, contribute to the size reduction and mixing of the feedstock [35]. Many demonstrative- and/or full-scale composting reactors use rotating drums and reported efficient performances [36–39]. The characteristics of each reactor type were discussed in detail by other authors [35,40].

3.4. Composting Scales

Composting can be broadly applied at three scales of operations: (1) large-scale centralized operations that are complex and serve vast geographic areas and sectors; (2) community-scale or decentralized operations that serve primarily residential neighborhoods or community levels; and (3) home/backyard scale operations that serve individual housing units [19]. At industrial level, centralized composting facilities have been extensively studied and the number of treatment facilities is increasing with respect to current waste management regulations [13,34,41]. Community composting has also gained some attention and has been encouraged by national legislations in recent years, which will be thoroughly reviewed and discussed in the following sections. Meanwhile, home composting presents some potential environmental benefits such as the avoidance of collection, transportation and management of biowaste [42–44]. However, home composting also brings some environmental concerns: generation of GHG emissions and odor due to the absence of gas treatment systems [45,46], insufficient elimination of pathogens due to the lack of adequate heating [47] and uncontrolled leachate [48]. In fact, the GHG emissions from six home composting units were quantified as 0.4–4.2 kg CH_4 and 0.30–0.55 kg N_2O/Mg wet organic household waste, while total GHG emissions (in kg CO_2 eq/Mg wet organic household waste) from home composting of OHW were found to be in the same order of magnitude as for centralized composting plants [49]. Nevertheless, decentralized community and home composting practices are still estimated to reduce costs and greenhouse gas emissions by 34% to 50%, and 40% by 2025, respectively, as compared to landfilling [50].

4. Decentralized Community Composting

4.1. General Overview

Considering the limitations of centralized waste treatment facilities originating from diverting food waste and increased costs for collecting and transporting waste in long distances, some of municipal composting programs may not be fully successful. In addition, high operational costs and operational complexity are other factors that should be taken into consideration for centralized systems [39,51,52]. At this point, alternative strategies must be identified and developed, such as decentralized collection and treatment. Decentralized composting, also known as community composting, refers to a community-scale network in a specific neighborhood that diverts and composts biowaste in a controlled operative environment [19]. The main advantages of decentralized composting over centralized systems are summarized in Table 1. In a broad perspective, decentralized composting can help to decrease the cost and effort for transportation of waste for processing and treatment, and further reduce the need to construct new disposal facilities, enable local reuse of organic matter, create local small-scale enterprises as well as reduce costs associated with commercial fertilizer purchase [19,53,54]. Furthermore, the final compost product is comparatively of higher quality due to efficient separation and less intercontamination of wastes [55,56]. Community composting is thus attracting some attention from policymakers, who consider this as a logical implementation [57]. However, some drawbacks are also faced during decentralized composting. The collection of organic waste in containers may result in an uncontrolled degradation of organic matter that leads to odor problems and leachate generation in the case of poor management [39]. Furthermore, logistic problems can lead to unsatisfactory implementations [19]. In this regard, new composting technologies should be well-addressed, and the information gathered from the operative environments should be thoroughly analyzed for a win-win situation for all stakeholders.

Table 1. Main advantages of decentralized composting over centralized composting [55,58].

Centralized	Decentralized
Transportation costs relatively high	Transportation costs relatively low
High operation and maintenance costs	Comparatively less maintenance costs
A high degree of specialized skills to operate and maintain	Low level skills required
Advanced technology with highly mechanized equipment	Simple technology with labor intense
Large facilities	Small facilities
Low quality of compost due to poor separation of wastes with high risk of contamination	High quality of compost since waste is efficiently separated and risks for contamination are minimized
Final product transported to farms or regional markets	Final product to fields or local markets as soil conditioner

4.2. Community Composting in the Operative Environment

When a decentralized composting system at the community-scale is demonstrated in a specific city or urban area, current and future proposed land use availability, and status of vacant land and community interest are initially considered within the regulatory frameworks. Once the location type and the individual site within each area are selected, the composting capacity is latter calculated within the city or specific region, based on the population size and waste generation trend [19]. The next step is then the decision on the composting technology. Most common composting reactors were discussed in Section 3.3. Community composting reactors can be different, in other words, "simpler", than centralized composters. Plastic bins in any shapes (i.e., rectangular, cylindrical, conical) are often used for community composting reactors [7,54]. Plastic drum reactors were also recently reported [59]. These reactors can be operated in batch, semi-continuous or continuous mode, based on the sustainability of the wastes. The reactor capacity is usually between 100–1000 L [7,59]. In most cases, holes are constructed at the bottom or on the periphery for aeration and turning/mixing is applied manually. Some examples of decentralized composting practices in Europe are presented in Table 2. The biggest drawbacks of these bin-type reactors is the uncontrolled emission of GHGs, such as methane, ammonia or nitrous oxide [41,50]; non-homogenous matrix of the final compost product due to inadequate mixing [46]; odor and leachate [39]. For instance, gas emissions (i.e., (CH_4, N_2O, NH_3 and volatile organic compounds (VOCs)) of a bin-type composter were calculated in the range of 30–148 kg CO_2 eq/Mg leftovers of raw fruits and vegetables [48].

Table 2. Characteristics of selected decentralized composting systems in Europe.

Site	Population	Demographic Characteristics	Waste Origins	Bulking Agent	Reactor Type/Model	Waste/Reactor Volume	Leachate/Gas Collection	Aeration	Mixing	Operation Mode	Composting Duration	Reference
Allariz (Spain)	5982 inhabitants, density of 70 inhabitants/km^2	Residential area with shops and an industrial estate	Yard waste and kitchen waste	Shredded wood	Modular composter made of recycled plastic slat	1000 L	-	-	-	Continuous	-	[7]
Ballymun (Dublin-Ireland)	89 apartments	Apartment complex	Household kitchen waste	Wood pellet	In vessel technology (Big Hanna T-120)	26 t/y	Biofilter to treat exhaust gases from the Big Hanna	-	-	Continuous	-	[60]
Dublin (Ireland)	-	Residential area	Organic waste, primarily catering waste	-	In vessel technology (Big Hanna T-120)	2 m^3	Biofilter	Rotating cylinder	Rotating cylinder	Continuous	-	[61]
Lithuania	-	Catering company	Catering, biodegradable waste	-	Batch reactor (Oklin GG 10s composting machine)	10 t/y	Activated carbon filter	Forced ventilation system	-	Batch	24 h inside the machine plus maturation time outside	[62]
Barcelona (Spain)	-	Universitat Autònoma de Barcelona	Leftovers of raw fruit and vegetable and pruning wastes	-	Bin-type composter Model 400 RRR Compostadores SL	0.5 m^3	-	Holes on the periphery	Mixing tool: Compostadores SL. Shredding tool: electric garden chipper (BOSCH AXT 2500 HP)	Continuous	12 weeks	[48]

Considering the negative impacts of conventional composting reactors on the environment, new generation composting reactors are therefore highly promising. The greatest advantages of these reactors are: pre-treatment units, biofilters, automatic mixing, leachate collection reservoirs and aeration modules. For instance, a community-scale novel drum bioreactor was reported to be a promising system for efficient pre-treatment of organic household wastes [39]. Noteworthy to mention is that the composting process can last between nine and eleven weeks if mechanical mixing is applied, and up to fifty weeks under static conditions. Currently promoted electromechanical reactors can be generally divided in two main categories: systems with only one chamber and systems with a double chamber. In the first case, the composter constitutes a rotating cylinder without any mechanical tool inside, the waste is introduced, and the rotation allows mixing, aeration and advancement of the material up to the exit point [61]. The two most-common producers of this kind of reactors are Susteco AB, which produces the Big Hanna Composter (www.bighanna.com), and Italian City Net (www.city-net.it). The two chamber machines work in a different way, and these systems are usually equipped with a shredder and a mechanical mixing tool in both of the chambers; waste is introduced in the first chamber where it is continuously mixed, and when the chamber is full, the second starts to be filled, while the first is closed in order to complete the composting process. Two main manufacturers of this kind of process are Jora, that produces the Jora Composter (www.joracomposters.com), and Italian Ecopans (www.ecopans.it).

4.3. Socioeconomic Perception

In most agri-environmental programs, the lack of participation of interested stakeholders in designing frameworks, the poor information basis to support policy formulation and the failure to consider local specificities in the scheme design are reported to be the main reasons for low success achievements [63]. In a recent survey [64], the farmers' perception of compost production was found to be 83.9%, in which the participants showed also a high, yet lower, willingness level (63.6%) of the more salient option to produce compost themselves and use it in agriculture. In another survey, 67% of respondents indicated that they are interested or very interested in community composting systems [65]. Without a doubt, public acceptance and encouragement are the key factors for a successful decentralized composting implementation. As the actual processing volume is dependent on the participation of residents in a community, low participation rates can be a major challenge in such cases [19]. By community composting, local resources community participation can be established [66], and people may be more motivated to reduce their food waste when they see it separated out from the rest of their waste [65]. In a common sense, decentralized composting systems should be inexpensive, require low maintenance and easy handling [59]. Identifying a suitable location in a city/region is critical and logistical characteristics such as the distance from waste sources, need/use of compost, demographic characteristics, and environmental characteristics such as drainage, potential or existing environmental conditions, should be all considered during the identification. A lack of technical support in operating and building community composting facilities has also been a critical challenge in maintaining decentralized composting systems [19]. Hence, training and navigating the community within the specific region is crucial.

5. Centralized Composting in Italy

Until a few decades ago, composting activities in Italy were carried out in large outdoor piles, with limited mass turning and a long period of maturation. With the entry of the first environmental protection framework law (Law 319/1976) put into force, the need to switch to solutions more respectful to the environment came forward. Then, about 20 years ago, new draft regulations were mentioned by [67] to win back then ongoing issues. After 20 years, drafts evolved into in-force legislations and remarkable achievements are gathered.

Since 1997, great progress has been made in terms of organic waste management and specifically, composting activities. To reach the EU objectives and targets regarding the recycling of MSW and the sustainable principles, it is mandatory to collect the biowaste separately in order to reduce the non-compostable material for maximizing the recovery through composting and/or anaerobic digestion facilities [12]. As a consequence of the rise of separate collection of organic waste and specifically food and garden waste, there was a big growth in the number of composting facilities that increased from 72 running plants in 1998 [68] to 281 plants in 2018 with an amount of waste treated of four thousand tonnes [14]. The distribution of the centralized organic waste treatment plants in Italy are displayed in Figure 3A.

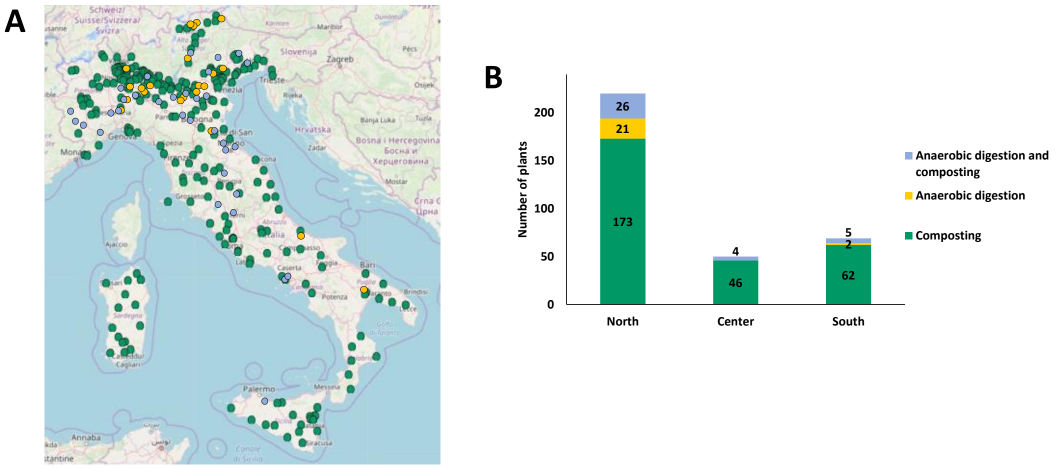

Figure 3. (**A**) Number and distribution of centralized biowaste treatment plants in Italy by the year 2018 (**B**) Share of operating biowaste treatment plants among the north, center and south parts of Italy by the year 2018 (obtained and modified from the official website of Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)).

The actual total capacity is enough to recycle all organic waste separately collected in Italy, but an unbalanced distribution of the facilities is observed as mentioned earlier, with a growing demand of new installation above all in southern regions [12]. As can be seen from Figure 3B, of the 281 centralized composting plants, 62% are placed in the north regions, only 22% in south, and the remaining 16% are in the center of Italy [14].

There are both windrow and in-vessel systems in operation at the moment in Italy. Among the windrow systems, the most common solution is the "turned windrow" which is also the principal composting system present in the Italian plants. Among the in-vessel systems, the most common solutions are the "biocells" which are horizontal, discontinuous, closed bioreactors with forced aeration through the flooring [69].

The material treated at Italian composting plants is mainly the OFMSW that increased from 73% in 2004 [70] to 81.6% in 2018, with a composition of 34.7% of garden waste and 46.9% of food waste [14]. The second main fraction is the sludge and its treatment in composting plants decreased from 17% in 2004 [70] to 10.6% in 2017 [14]. The remaining part is mainly constituted of agro-industrial waste [70]. Based on the input feedstock, compost can be classified in three categories: "End of Waste"—Green Waste Compost (GWC) produced only by green waste, Bio Waste Compost (BWC)—produced by green and food waste and Sludge Waste Compost (SWC)—produced by sludge as a co-feedstock [12]. The use of the compost product can be different, and mostly is used in agriculture (around 70%) [12]. Different studies tested the positive results obtained through the application of compost in Italian culture, for example for soil and plant cultivation [71] or vineyard [72]. The other 30% of compost products are sold for gardening or landscaping uses; but, according to the Italian law on fertilizer, compost can also be used in other organic fertilizers as basic growing substrate, mixed growing substrate and/or organic-mineral fertilizer [12]. The quality of the compost product in Italy is assured by the "CIC Quality Compost Label" (CQL) that was introduced by the Italian Composting and

Biogas Association (CIC) in 2003 as a voluntary program to support the development of the biowaste management sector [12].

6. Community Composting in Italy: Legislation and Implementation

In order to reach the Circular Economy Targets of Italy, the authorities do not have any intention to add more waste treatment facilities (like energy recovery, recycling and composting) in the near future. Rather, they favor waste prevention, and decentralized solutions may potentially be a good move towards achieving waste reduction, recovery and valorization targets. In recent years, the implementation of decentralized composting systems has gained increasing importance thanks to the potential benefits that these systems can bring in the context of integrated urban waste management. In fact, the uneven distribution of centralized biological waste treatment facilities has also paved the way for decentralized solutions in Italy, especially in small towns. The need to follow a more modern approach for the treatment and recovery of waste, to be carried out as close as possible to the places of production and with low environmental impact plants, has made it essential to integrate the legislative landscape with specific rules for decentralized systems. Specifically, the legislation currently in force for decentralized composting is the D.M. (Ministerial Decree) of 29 December 2016, n. 266 "Regulation containing the operating criteria and simplified authorization procedures for the composting of organic waste communities" [10]. This decree sets the criteria and procedures for composting communities (from apartment buildings to associations) with the primary objective of reducing the production of organic waste and the environmental impacts associated with the management of the waste itself. For this purpose, as also defined in the D.Lgs. (Legislative Decree) of 3 April 2006, n. 152 on "Environmental standards" in article 180 paragraph 1-septies, the regions and municipalities encourage the composting practices carried out in the place of production itself (such as home composting and community composting) through specific planning tools and possible reductions on the tax to users who carry out waste reduction practices (D.Lgs. 152/2006) [15]. Furthermore, the implementation of decentralized composting can positively contribute to the achievement of the EU target for the recycling of at least 55% of municipal waste by 2025.

According to the D.M. 266/2016 [10], the provisions apply to structures with a capacity of fewer than 130 tonnes/year, while for higher quantities, the Legislative Decree 152/2006 [15] applies. Additionally, simplified procedures are provided for the start-up of community composting activities according to the collective body (i.e., two or more domestic or non-domestic users established in a condominium, association, consortium, company or other forms of association governed by private law) reports the start of the activity to the territorially competent municipality. The latter comes from the communication for the start of the activity with the local municipal waste manager. The Ministerial Decree 266/2016 also establishes the requirements for composting in terms of not only of biodegradable materials and waste eligible for treatment (Annex 3) but also of the operating procedures and parameters of composting (Annex 4—part A and B). Specifically, the following can be composted: biodegradable kitchen and canteen waste (CER 20 01 08); biodegradable waste produced by gardens and parks (CER 20 02 01); sawdust, shavings, cutting residues, wood, veneers (CER 03 01 05) untreated and with a size of less than 2 cm; bark and wood waste from paper processing if not added (CER 03 03 01); filter material deriving from the periodic maintenance of the biofilter serving the equipment (CER 15 02 03); paper and cardboard packaging (CER 15 01 01); wooden packaging (CER 15 01 03) in quantities not exceeding 20% of the total waste introduced into the equipment; paper (CER 20 01 01) and cardboard (CER 15 01 01) without ink and in quantities not exceeding 20% of the total waste introduced into the equipment. The operating methods of the composting process must comply with the following parameters:

(1) Temperature of the mass in the upper process (exclusively in electromechanical equipment) for at least three consecutive days at 55 °C;
(2) Compost production time not less than six months for static type equipment and not less than three months for electromechanical type equipment;

(3) Residence time not less than one month for electromechanical equipment;
(4) Mixing is carried out according to management needs in the case of static equipment and at least three times a day in the case of electromechanical equipment.

Based on the definition in Article 6 of the Ministerial Decree 266/2016 [10], the compost must comply with the parameters of Annex 6, namely: humidity between 30% and 50%; maximum temperature lower than 2 °C compared to the environmental one; pH between 6 and 8.5; absence of dangerous fractions. Furthermore, for specific applications on agricultural soils intended for the production and sale of products for human or animal use, the compost produced must comply with the characteristics of the mixed composted soil conditioner and the green composted soil conditioner, under the Legislative Decree 29th April. 2010, n. 75 (D.Lgs. 75/2010) [73], regarding fertilizers and its following modification by the Ministry of Agricultural, Food and Forestry Policies, Decree of 10th July 2013 (Official Gazette (GU) of the General Series n.218 of 17-09-2013 [74]).

According to the Legislative Decree and its modification, for the compost categories mentioned above, the minimum requirements of useful elements and/or substances are summarized in Table 3. Furthermore, according to the current legislation on fertilizers, regardless of the type of soil conditioner, the maximum permitted levels of heavy metals expressed in mg/kg and referring to the dry substance are the following: total lead <140; total cadmium <1.5; total nickel <100; total zinc <500; total copper <230; total mercury <1.5; total hexavalent chromium <0.5.

Table 3. Required parameters for final compost products obtained from community composters to be used in soil applications as stated in the Italian Regulations [73,74].

Type Designation	Essential Components of Organic Wastes	Minimum Requirements of Useful Elements and/or Substances		
		Parameter	Unit	Value
Green composted soil conditioner (according to [73])	Ornamental green maintenance waste, other plant materials such as virgin olive residues, crop residues, other wastes of vegetable origin	Humidity	%	<50
		pH	-	from 6 to 8.5
		Organic Carbon on dry fraction	%	>20
		Humic and fulvic Carbon on dry fraction	%	>2.5
		Organic Nitrogen on dry fraction	% of N_{tot}	>80
		C/N	-	<50
Mixed composted soil conditioner (according to [74])	OFMSW from separate collection, from animal waste including zootechnical sewage, from agro-industrial activity waste and from untreated wood and natural textile processing, waste and sludge, matrices for the green composted soil conditioner	Humidity	%	<50
		pH	-	from 6 to 8.8
		Organic Carbon on dry fraction	%	>20
		Humic and fulvic Carbon on dry fraction	%	>7
		Organic Nitrogen on dry fraction	% of N_{tot}	>80
		C/N	-	<25

Compared to the national regulation for fertilizers (D.Lgs. n. 75/2010 [73] and its following decree 10th July 2013 (GU n.218/2013)), the community compost regulation [10] addresses some minor revisions to the main characteristics of the final compost product following to the aspects given below:

- Minimum humidity value addition;
- Maximum temperature value addition;
- No specific restrictions according to the size of foreign fraction in the compost.

Differently from the national regulation, community compost regulation sets some further operating conditions such as:

- The percentage of the bulking agent is not less than 5% (w) of the total amount introduced into the equipment;
- The emissions of electromechanical equipment are treated by a biofilter before being released.

Following the indication of the legislation, the application of community composting in Italy with electromechanical equipment are more common than the one with static equipment, even that the Italian Composting Association (AIC) has been developing a specific guideline for the use of electromechanical equipment for small-scale composting. Actually, research activities related to community composting in Italy started before the release of the community compost regulation D.M. 266/2016 [10], and dated back to 2012 with the "ASTRO" Project, at the Casaccia Research Centre, ENEA, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development, has set up a small electromechanical machine for the treatment of organic waste and its transformation into compost to be used as a fertilizer, as part of a one-year experiment. After that, the experimental activities continued and different composters were tested during the years, including a Joraform JK5100 composter. Following the new technologies, home and community composting in Italy are becoming more widespread and different municipalities are supporting these activities also through the free distribution of home composters to citizens who request them. At the national level, starting from 2016, with the D.M. 266/2016 [10], regions can count the waste sent for domestic, proximity and community composting in the separate collection quota, and specified that only the municipalities that have regulated these activities will be able to insert the portion related to composting in the separate collection percentage calculation. In 2018, the organic waste treated by home composting and considered in the source separation percentage calculation was about 237,000 tonnes [14].

In addition to the research activities, different projects dealt with the implementation of community composting systems. In Rome Airport, for instance, two big electromechanical composters of 1000 tonnes/year each was installed to treat all the biowaste produced by the restaurants and bars of the terminal. In national territory, there are also other examples of smaller machines with a maximum capacity of 130 tonnes/year that can be placed inside cities to collect wastes generated by canteens, apartment buildings or small communities, but more often those systems are placed not in the center of the town but a little decentralized, in a specific area used for waste collection, called "Ecocentro". AIC Association, in collaboration with Agriculture and Environment Center of Crevalcore and the University of Bologna, analyzed the Italian applications of community composting. The study showed that the total capacity associated with community composting in Italy is approximately 6390.5 tonnes/year and regions with the greatest diffusion of this type of activity are Puglia, Lazio, Basilicata, Liguria, Campania and Calabria [75]. Finally, Italy is also largely involved in EU-funded projects on community composting, one of them is "DECOST", financed by the ENI CBC MED Program, that aims to develop a new framework of waste management, building a closed loop system of organic waste valorization integrating decentralized home and community composting systems within urban agriculture (www.enicbcmed.eu/projects/decost).

7. Case of the Basilicata Region

The total source separation percentage in 2018 was of 47% in the Basilicata region. There is a great discrepancy between the two provinces: a higher percentage of 52% is reached in Potenza, while in Matera the source separation value is very low (below 40%) [76]. Figure 4A shows the fractionation of wastes collected in Basilicata, where the total organic waste was of 34,942.7 tonnes and represents 37% of all the source-separated waste in 2018. The other main fraction is the undifferentiated waste, with a total amount of 105,182.7 tonnes in 2018. The main treatment plants of the region are the facilities for the disposal or treatment of undifferentiated waste. As shown in Figure 4B, in fact, there are five landfills, one associated with a mechanical biological treatment (MBT) plant for the stabilization of the organic materials before the final disposal in landfill. There also two incineration plants in the regional territory.

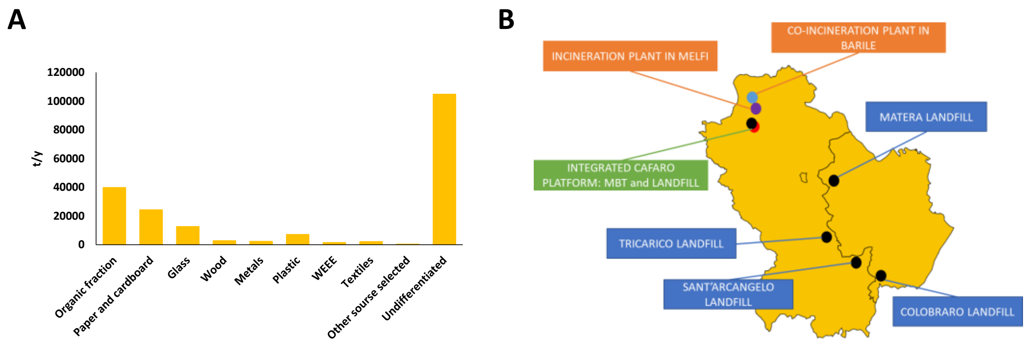

Figure 4. (**A**) Fractionation of solid wastes collected in the Basilicata Region in 2018; (**B**) Biowaste treatment plants in the Basilicata Region by the year 2018 (obtained and modified from the official website of Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)).

The Basilicata Region is below the Italian average (58%) and even ranks as last among the regions in terms of separate waste collection. Furthermore, there are not any centralized composing plants in the Basilicata region by 2020. This creates a wide potential of demonstrative sites for the research and development of waste management activities in Italy. In fact, the Regional Government of Basilicata has decided to allocate €25 million to build four composting plants by 2021 in the regional territory, in response to the absence of treatment plants for the organic fraction of waste [77].

So far, few projects focused on the demonstrative-scale composting practices to treat both agricultural and food wastes in Basilicata. In the context of "EU-Basilicata Region Project" (under MATMM UNCDD Program), a new on-farm composting approach was proposed that aimed to accelerate the maturation of cattle manure using poplar wood chips as the bulking agent. The composting plant was built in Matera Province to provide static piles and forced ventilation for the simplicity of its management. Similarly, the PSR Basilicata Project called "Composta" coordinated another demonstrative study that took place in Potenza Province to compost manure and forestry residues. The composter consisted of a composting cell and a storage platform for the maturation phase [17]. Finally, in this context of the ongoing "DECOST" Project, four pilot initiatives are going to be implemented in different Mediterranean countries to treat 1500–2000 tonnes/year of organic waste in total and to use the produced compost in urban agriculture projects. The Italian side of the activities will take place in the Potenza and Atella provinces of the Basilicata Region. One centralized and a few decentralized community and home composing systems will be designed and integrated into the waste management system of the region with a high expectance of the public involvement. It is expected that a total new waste treatment capacity ranging from 400 to 550 tonnes/year will be installed (200–250 kg OFMSW/inhabitant/year) in each pilot action depending on the size of the targeted town. The application of a decentralized community system together with the urban agriculture program will increase economic, social and territorial cohesion, and reduce pressures on the environment.

8. Future Perspectives and Concluding Remarks

Based on the results of the successfully implemented projects, as well as on the perspectives of the ongoing projects, planners and managers can integrate community composting to the biowaste management framework of Italy, especially in small towns in the central and southern regions. Since decentralized composting systems have often limited support from central authorities, the encouragement and engagement of the citizens is utmost important. In this regard, public awareness and technical expertise should be well established. While developing a decentralized composting framework, the national legislation on community composting should be the main guideline, especially while choosing the pilot sites and reactor systems in order to minimize possible adverse impacts on the environment. In addition, more focus should be given on the community composting rather than home composting, since it exhibits comparatively higher possibility of control mechanisms. Of course, the local stakeholders (in this case, citizens themselves and/or farmers) should be well identified for the valorization of the final compost products. When site-specific solutions are addressed carefully, an added value on the recovery of biowaste within urban systems can be easily achieved. This model applied in Italy can further present a relevant approach for other Mediterranean countries that have similar regional characteristics with the interest of adopting decentralized community composting as a part of their integrated solid waste management system. Especially in large cities, medium-scale centralized composting facilities can be supported by small-scale decentralized composting to build an ideal organic waste management strategy. Hence, local solutions on the recycling and recovery of wastes can help to play a significant role on achieving and adopting national and EU circular economy model in the following years. Further research is needed to identify socioeconomic characteristics and particular needs in the regions where decentralized solutions are intended to be implemented.

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