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Article

Organic Waste for Compost and Biochar in the EU: Mobilizing the Potential †

Daniel Meyer-Kohlstock *, Tonia Schmitz and Eckhard Kraft

Biotechnology in Resources Management, Bauhaus-Universität Weimar, Coudraystr. 7, Weimar 99423, Germany; E-Mails: tonia.annick.schmitz@uni-weimar.de (T.S.); eckhard.kraft@uni-weimar.de (E.K.)

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* Author to whom correspondence should be addressed; E-Mail: meyer-kohlstock@gmx.de; Tel.: +49(0)3643-584630; Fax: +49(0)3643-584639.

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Abstract: While several EU member states have working compost markets, only about one third of the bio-waste, around 35 Mio tons is used to produce compost, and to some degree, biogas. The major part is still incinerated or landfilled together with other waste. This paper proposes the improvement of existing and the creation of new compost markets based on the integration of biochar and the implementation of obligatory recycling targets with flexible implementation approaches. Based on a literature review, the production of compost with biochar reduces some of the nitrogen and carbon losses and accelerates the composting process. This indicates economical benefits for the compost producer and the farmer, as well as reduced greenhouse gas emissions. An obligation to recycle organic waste, may it be on a national or on EU level, together with the implementation of appropriate collection systems, could provide the economic and societal base to mobilize the currently unused bio-waste. Should this scenario be realized, the annual amount of biochar-compost out of bio-waste could be used to serve around 3.7% of all arable land in the EU. This would demand no large-scale application, but instead specific uses for specific soil-crop constellations.

Keywords: biochar; compost; European Union; feedstock; potential; bio-waste; collection

1. Introduction

As a soil amendment, biochar can play a beneficial role in agriculture [1], as well as in numerous preceding processes [2]. However, fresh biochar has, depending on its feedstock and on the pyrolysis process, hardly any nutrients available and it can even immobilize them when added to a soil, resulting in crop losses. In addition, fresh biochar shows little tendency to support microbial diversity and abundance, a main feature found in the Terra Preta soils, on which the biochar research was initially based. Therefore, it makes sense to introduce fresh biochar to an environment rich in nutrients and microorganisms before applying it to soils.

A field-tested way to add nutrients and microbial life to biochar is its use as co-substrate in composting [3,4]. While it is possible to mix biochar into matured compost, it yields more benefits when it is already introduced to the composting process. There, it accelerates the composting process and it even can reduce the losses of nitrogen and carbon [5–9]. The resulting biochar-compost, rich in carbon, nutrients and microorganisms can have a high agronomical value. Of course, the value depends largely on the soil it is applied to and on the kind of crops produced on that soil [10,11]. As with every soil amendment, biochar-compost should not be applied on a massive scale, but specifically to the needs of the soil and the farmer, respectively the gardener.

In addition to turning a rather inert material very quickly into a beneficial soil amendment, this new product could easily be integrated into existing compost markets, since the application technology could remain the same. The only technical changes necessary would be on the production and on the quality assurance side. Yet, it is to mention that several EU member states, still lack the necessary waste managements regulations to establish a rudimentary compost market in the first place.

This paper intends to illustrate not only the potential for European biochar-compost markets based on organic waste, but also the necessary prerequisites. For this, the available feedstock for compost and biochar, as well as its current use is shortly reviewed. In a second step, the legal framework and various waste collection systems are highlighted to illustrate several barriers and solutions to establish working compost markets.

For a quick overview, the contents of the following chapters are shortly summarized.

- Section 2 Organic Waste Potential and Use
  Graphical and tabular overview about theoretical potentials and their current use.
- Section 3 Legal Framework
  The influence of EU legislation on the regional and local management of organic waste.
- Section 4 Waste Collection Systems
  Case studies highlighting the key parts of a successful mobilisation of organic waste.
- Section 5 Conclusions
  Summary of the previous chapters, including EU policy recommendations.

2. Organic Waste Potential and Use

This paper focuses on municipal organic waste for biochar and compost. Yet, organic residues from agriculture and forestry can be used as feedstock as well. Therefore, the analysis about municipal resources is followed by a short overview about agriculture and forestry.

2.1. Municipal Resources

The major part of organic waste for compost in the EU is bio-waste. It is defined by the Waste Framework Directive (WFD) [12] as "biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants". Accordingly, bio-waste does not include sewage sludge, paper, cardboard and wood. Especially sewage sludge could be partly integrated into composting processes—carefully taking into account its high water content and possible contaminations [13]—while for the other substrates different processes like paper recycling or energy recovery might be the ecologically and economically better alternative.

The theoretical potential of bio-waste can be extrapolated from waste analyses together with the reported amount of municipal solid waste collected. While the data for the amounts of waste collected in the EU is good, the situation is less informative for the available data on waste qualities. Especially the different analysis methods make it difficult to compare the results.

In 2010, Arcadis Belgium nv and Eunomia undertook the challenge to estimate the bio-waste potentials and their future development for each member state of the EU-27 [14]. Table 1 provides the detailed data of their estimates as well as their collected data on bio-waste utilization for compost and biogas in 2008. In contrast, Table 1 provides also Eurostat data regarding the bio-waste utilization for the EU-28 member states in 2008 and 2011. Both data sources cover aerobic (compost) and anaerobic (biogas) treatment, with the exception that the Arcadis study included also home composting (around 3% of the total amount).

If the Eurostat data are correct, the 2010 study largely underestimated the bio-waste utilization. While Eurostat data adds up to 35.2 Tg in 2008, the Arcadis study estimated only 20.1 Tg. For 2011 Eurostat shows 34.1 Tg, while the Arcadis study for casted—not contained in Table 1—an amount of 24.6 Tg, including 3.1% home composting.

Figure 1(a) illustrates in addition to Table 1 the bio-waste utilization not only on a national but also on a regional and local level. The visualized data are from national statistics, as well as from the Eurostat urban audit program and cover a time frame of around 10 years. Therefore, the data in Figure 1(a) is not identical to Table 1. The composed map rather highlights the diverse levels of success for bio-waste utilization. Sections 3 and 4 provide some reasons for the heterogeneity of the map.

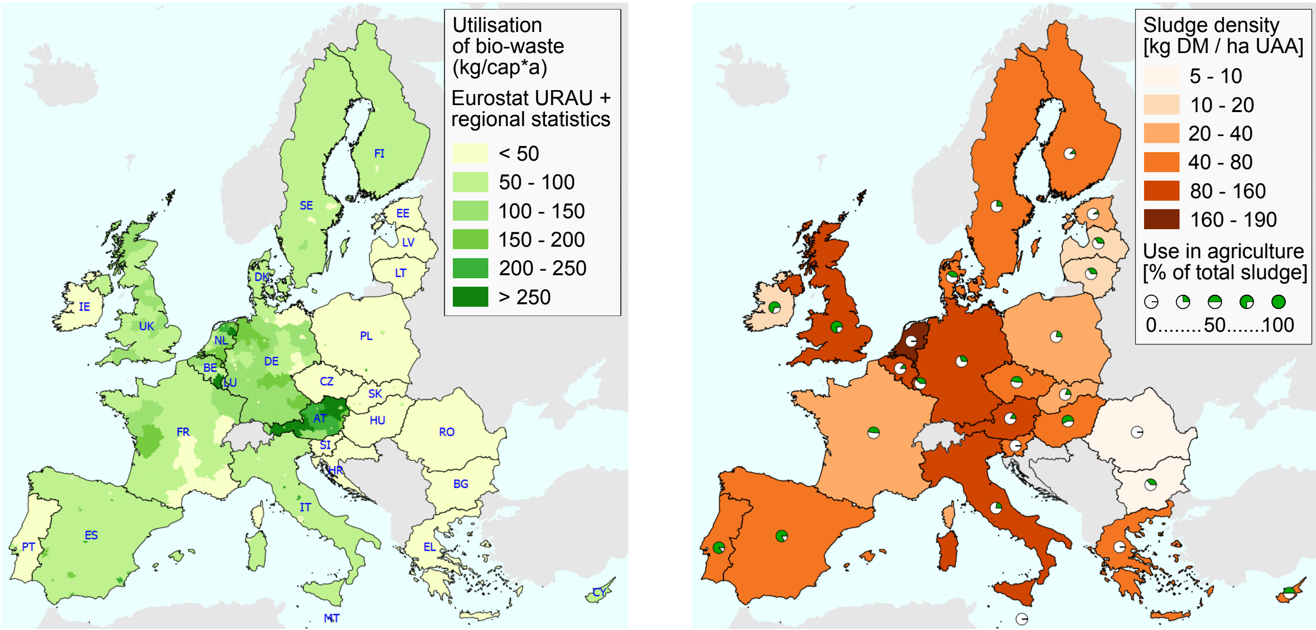
In addition to the municipal bio-waste potential of around 88 Tg_{FM}, industrial sources such as food processing may provide another 30–50 Tg_{FM} of bio-waste [16].

The municipal potential to produce biochar from organic waste depends mainly on the amount of green waste, *i.e.*, the woody part of bio-waste. If it is estimated that around 30% of the supposed bio-waste potential (88 Tg) is green waste and that its conversion would yield 30% biochar, than this would amount to around 8 Tg biochar. The remaining 61 Tg bio-waste could be composted together with this biochar, which would also function as structural material. Besides the production of a user-friendly compost-biochar blend, the biochar addition of over 10% should also result in a measurable reduction of carbon and nitrogen losses during the composting process [4]. Taking this into account, it could be estimated that the bio-waste would be converted into compost with loosing only nearly 50% of its mass, resulting in a product consisting of 32 Tg compost and 8 Tg biochar. If this biochar-compost blend would be applied at a rate of 10 Mg/ha, which is 1 kg/m^2, then 4 Mio ha could be treated with this amount annually. This corresponds to 3.7% of all arable land in the EU (around 108 Mio ha). While this means that only a small fraction of the arable land could be served with bio-waste compost, it implies also that agriculture should have no problems to take up this sustainable resource.

Table 1. Estimates and statistical data about the bio-waste potential and utilisation in the EU provided in 1000 tons (Mg) per year (a).

Member State		**Est. Potential of Bio-Waste (Arcadis [14]) [Gg/a] (2008)**	**Bio-Waste Utilisation (Composting and Anaerobic Digestion)**		
			(Arcadis [14]) [Gg/a] (2008)	**(Eurostat [15]) [Gg/a] (2008)**	**(Eurostat [15]) [Gg/a] (2011)**
AT	Austria	1525	569	1683	*1510
BE	Belgium	2098	1114	1103	1042
BG	Bulgaria	907	28	0	84
CY	Cyprus	130	0	0	48
CZ	Czech Republic	1271	64	*50	*74
DE	Germany	16,979	8490	8082	8498
DK	Denmark	1273	554	606	486
EE	Estonia	350	31	28	35
EL	Greece	1903	0	100	68
ES	Spain	9776	479	*6158	2272
FI	Finland	965	212	234	355
FR	France	12,453	498	5581	5703
HR	Croatia	-	-	15	14
HU	Hungary	1592	493	85	183
IE	Ireland	712	85	107	157
IT	Italy	7938	1588	3081	*3980
LT	Lithuania	493	89	15	*23
LU	Luxembourg	88	57	68	62
LV	Latvia	269	0	5	8
MT	Malta	61	0	0	9
NL	Netherlands	2703	1324	2330	2360
PL	Poland	2960	672	386	*951
PT	Portugal	1875	56	382	447
RO	Romania	4006	92	3	15
SE	Sweden	1905	528	597	653
SI	Slovenia	308	31	17	45
SK	Slovakia	546	22	80	100
UK	United Kingdom	12,630	3789	4402	*4922
EU-28		87,718	20,865	35,198	34,104

Note: * Eurostat estimates.



(a) **(b)**

Figure 1. Bio-waste and sewage sludge utilization in the EU-28 (data from Eurostat [15]). (**a**) Bio-waste utilization in kg per capita and year based on Eurostat Urban Audit and regional statistics; (**b**) Amount of sewage sludge in kg dry matter in relation to hectare utilized agricultural area; and agricultural sludge use.

Figure 1(b) provides the annual sludge potential from municipal wastewater treatment in kg dry matter per hectare of utilized agricultural area. Therefore, it represents the theoretical recycling potential of sewage sludge in agriculture. The actual utilization is given in percentage of the total annual amount. Table 2 contains all data used for Figure 1(b) and in addition the year of the data collection. For most member states corresponding data are available for 2008 or 2009, whereas the least current data is from 2000 and no data is available for Croatia. Thus, the data collection for wastewater sludge is a temporal aggregation, similar to Figure 1(a). Nonetheless, it can be concluded that roughly 45% of the total municipal sludge is applied in agriculture. Another 10% is composted, although the corresponding data is even more fragmentary. This would leave around 45% or 4.6 Tg_{DM} unused (incinerated or landfilled), which could potentially be converted to compost if enough bulking material in form of biochar or woody material would be available.

2.2. Agricultural and Silvicultural Resources

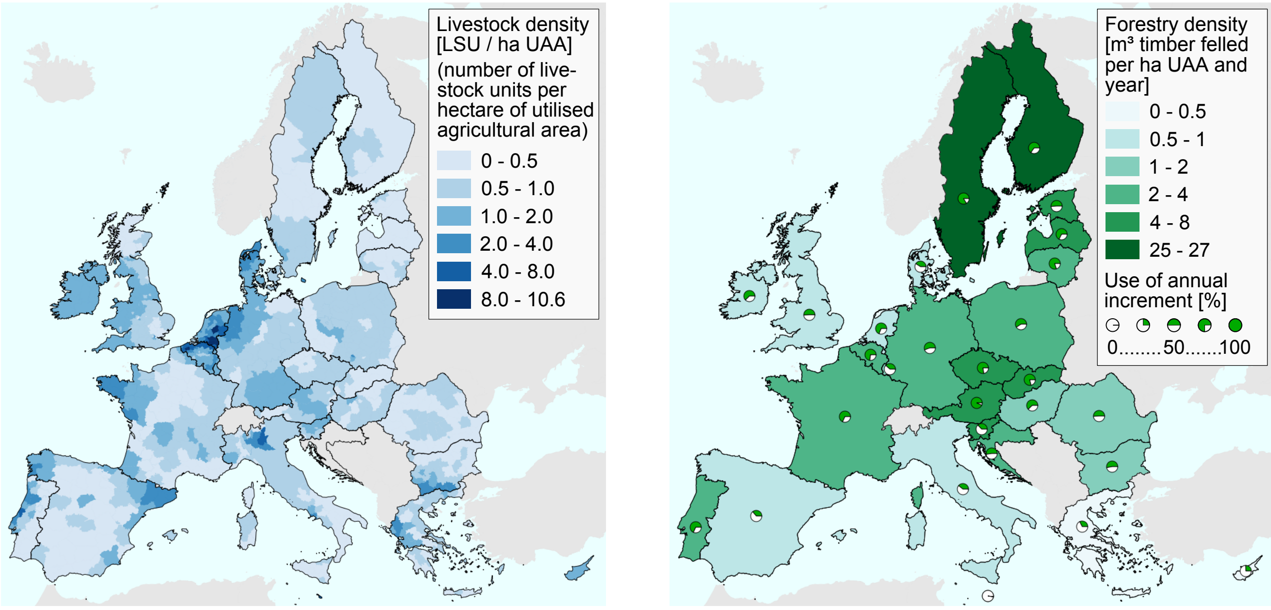
Although organic waste for compost mainly comes from urban areas, agriculture and forestry also have the opportunity to produce large amounts of compost and biochar-compost blends. Because this paper focuses on municipal organic waste, the following remarks are only about rough indicators which could be used as starting point for a dedicated discussion about agri- and silvicultural resources for biochar and compost.

Figure 2(a) and Table 2 provide the livestock density for all member states, except Croatia. The livestock unit (LSU) is a reference unit to aggregate livestock from various species and age, based on nutritional or feed requirements. One LSU is the equivalent of a grazing adult dairy cow, producing 3000 kg of milk annually [17].

Table 2. Indicators for the feedstock potential for biochar and compost in the EU-28 (data from Eurostat [15]).

MS	Pop. 2010 [1000]	UAA 2010 [1000 ha]	LSU 2010 [1000]	Municipal WW Sludge Total [Gg_{DM}/a]	Agri. Use [Gg_{DM}/a]	Year [20xx]	Timber Volume 2010 Increment [1000 m^3]	Fellings [1000 m^3]
AT	8375	3166	2517	254	40	08	25,136	23,511
BE	10,840	1358	3799	140	19	08	5289	3852
BG	7564	5052	1149	39	14	09	14,677	7781
CY	819	115	201	8	4	07	38	10
CZ	10,507	3524	1722	220	103	08	23,086	17,940
DE	81,802	16,704	17,793	1957	589	**09	107,000	59,610
DK	5535	2676	4919	108	43	09	5796	2371
EE	1340	949	306	22	2	08	11,201	5714
EL	11,305	3684	2407	152	0	09	4511	1463
ES	45,989	*24,190	14,831	1205	995	09	45,842	16,577
FI	5351	2292	1121	160	19	00	91,038	59,447
FR	64,659	29,311	22,674	1087	512	08	94,367	64,316
HR	4426	1334	1020	-	-	-	9888	5186
HU	10,014	5343	2484	260	148	07	11,099	6899
IE	4468	4563	5787	88	61	07	4524	2826
IT	60,340	12,885	9912	1056	236	05	32,543	12,755
LT	3329	2772	900	50	17	09	10,750	8600
LU	502	131	168	13	5	08	650	249
LV	2248	1806	475	23	8	07	18,333	12,421
MT	414	11	42	1	0	09	0	0
NL	16,575	1872	6712	353	0	08	2250	1552
PL	38,167	14,603	10,377	563	123	09	68,519	40,693
PT	10,638	3632	2206	189	164	07	19,087	13,042
RO	21,462	14,156	5444	120	0	09	33,984	17,232
SE	9341	3074	1752	212	50	09	96,486	80,900
SI	2047	483	518	27	0	09	9165	3401
SK	5425	1922	668	56	10	05	13,193	10,418
UK	62,027	17,234	13,308	1814	1394	***08	20,700	10,500
EU	505,510	154,651	135,212	10,177	4,556		779,152	489,265

Notes: * value for 2009; ** data from Destatis [24]; *** includes data for Scotland from 2005; MS = member state (as country code of the EU Nomenclature of Territorial Units for Statistics); UAA = utilised agricultural area (in 1000 hectare); LSU = live stock unit, an equivalent of a grazing adult dairy cow (in 1000); WW = waste water sludge (in 1000 tons dry matter per year).



(a) **(b)**

Figure 2. Livestock density and timber use in the EU-28 (data from Eurostat [15]) as indicators for agricultural and silvicultural residues. (**a**) Livestock density; (**b**) Timber utilisation.

The livestock density relates to the potential feed production for livestock, as well as to the recycling potential of the accompanying manure. Where the density is high, surplus manure might be available for composting or biochar production since the agricultural area is too small to take up all the manure. While this would not reduce the current surplus of nutrients, it could transform them into more stable forms. In the long term this should reduce the risks of nutrient leaching [18–20] and therefore increase the crop yields. In this hypothetical scenario, where biochar-compost is applied instead of manure, the productivity of the land could slightly level up to the intense livestock farming and alleviate the need for manure exports or reductions of the livestock density.

Figure 2(b) and Table 2 provide the amount of timber felled compared to the utilized agricultural area. This can be used as an indicator for available amounts of forest residues for biochar production, or even for a combined biochar-bioenergy production. Since biochar can yield far higher sales prices than compost, the export of biochar throughout the EU internal market would be economically viable. A look at the current trade flows for charcoal in Europe [21] supports this assumption. Therefore, countries with a large forestry sector but comparatively small agricultural sector, like Sweden and Finland, could provide a large amount of the biochar feedstock from forestry residues. However, this depends strongly on the existing utilization of timber and on the current management systems.

3. Legal Framework

When considering the fate of bio-waste, mainly three EU Directives influence the quantities and qualities available for further uses, such as the production of compost or biochar.

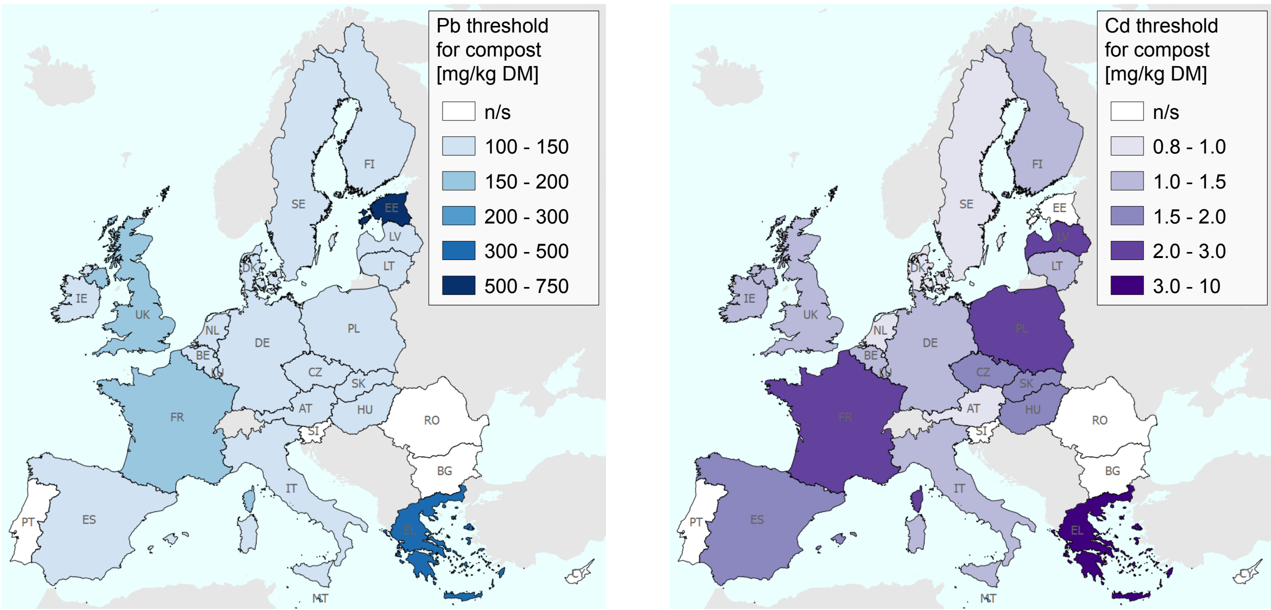
By regulating the disposal of inert, hazardous and non-hazardous waste, the Landfill Directive (1999/31/EC) [22] aims at preventing and reducing the negative effects of landfilled waste on the environment in the short as well as in the long-term perspective. For this purpose, several procedural and technical measures improving waste management are declared mandatory. Above all, to limit leachate and methane emissions, each member state is compelled to develop a national strategy for the reduction of biodegradable waste going to landfills by enhancing separate collection, recycling, composting, biogas production and material/energy recovery. To achieve measurable progress, each country shall gradually reduce the amount of biodegradable municipal waste going to landfills by 25% in 2006, by 50% in 2009, and by 65% in 2016, compared to the total amount of biodegradable municipal waste produced in 1995. However, an exception was made for member states that landfilled over 80% of their municipal waste in 1995, namely the UK, Greece and the 10 member states joining the EU in 2004, as well as Bulgaria and Romania joining the EU in 2007. These countries have to reach the respective target values within a 4 year extension, respectively in 2010, 2013 and 2020.

Unfortunately, the Commission had to report that in 2009 "the overall implementation of the Directive remains highly unsatisfactory" [23]. Ten years after the adoption of the Directive, the majority of the member states did neither meet the deadlines for the diversion of biodegradable municipal waste from landfills, nor the reduction of landfill emissions, nor the overall improvement of their waste management systems. Nonetheless, due to the fines the commission can impose, this Directive makes the landfilling of biodegradable waste financially unattractive and thus contributes to the recycling of bio-waste.

In addition to these restrictions on landfilling, member states are compelled by the Waste Framework Directive (2008/98/EC) [12] to develop national waste management plans in line with the following waste hierarchy: prevention, preparing for reuse, recycling, other recovery, e.g., energy recovery, disposal. More specifically, the Directive stipulates that by 2015, separate collection is to be set up for paper, metal, plastic and glass. By 2020, the amounts of these waste types being recycled or reused are to be increased by at least 50% (by weight). Further on, member states shall take measures to encourage the separate collection of bio-waste as well as to promote environmentally sound treatment and application methods for it. However, as no specific reduction target has been set, the overall impact of the Directive on bio-waste management might remain limited.

By contrast, the "Biofuels-Directive" (2009/28/EC) [26] is strongly influencing the overall handling of bio-waste. member states are compelled to develop national action plans allocating specific renewable energy shares for the transport, the electricity and the heating sector. By setting specific target values for each member state, the Directive aims to reduce primary energy consumption as well as greenhouse gas emissions by 20% and to include 20% of renewable energy in the overall supply by 2020 ("20-20-20 goal"). In addition, the transport sector shall increase its renewable energy share to at least 10% of its total consumption by 2020. From January 2017 on, a reduction of greenhouse gas emissions of 50% is to be achieved. Since this Directive considerably increases the demand for biomass in the energy sector, it necessarily reduces its availability as feedstock for compost or biochar. While energy can be recovered from pyrolysis or from a prior anaerobic digestion of bio-waste, there is always an underlying competition between carbon for soil and carbon for energy. Depending on what is most wanted, based on regulation induced market prices, the process conditions can be adjusted to produce a maximum of this or that. When carbon is primarily turned into pyrolysis gas or into biogas, then that share is lost for the soil.

European legislation is implemented and generally refined in national laws and regulations by the definition of more specific targets. When considering the production and handling of compost, it becomes clear that the member states have developed substantially different regulations. Some countries defined end-of-waste criteria; others still regard compost as waste while nevertheless allowing its use as an agricultural soil improver. In each member state, different threshold values for the contamination of compost with heavy metals or glass/plastic particles were set (see Figure 3(a) and Figure 3(b) for the threshold values for lead and cadmium), through legislation or quality assurance organizations. Several of the latter are members of the European Compost Network, which also developed a European Quality Assurance Scheme (ECN-QAS) [27]. This was done to provide consistent quality standards for compost in regard to ongoing revisions of EU agricultural and environmental regulations.



(a) **(b)**

Figure 3. Lead and Cadmium thresholds for compost in the EU-27 (data from ECN [25]). (**a**) Lead threshold in mg/kg dry matter; (**b**) Cadmium threshold in mg/kg dry matter.

For biochar, two major certification schemes exist. The first is the Swiss based European Biochar Certificate (EBC) [28] and the second is the certification programme of the US based International Biochar Initiative (IBI) [29]. Since 2012, when both standards were first published, IBI and EBC collaborate in the further development of their certification and guidelines, taking national and continental differences into consideration [30]. How these certification schemes will be regarded in the revision of national and EU regulations remains to be seen. However, based on the positive experience with voluntary compost certifications and their influence on the establishment of compost markets [27,31], it would make sense to recognize their potential role.

4. Waste Collection Systems

As can be seen in the following case studies, the collection services offered by a municipality have a large impact on the quantities and qualities of the collected bio-waste. When a city only provides for a mixed waste collection, some citizens may start home-composting, but most will likely just dispose of their recyclables (including bio-waste) with the residual waste. If these recyclables are to be used as feedstock for further uses, they first need to get separated from the residual waste stream in extensive pre-treatment processes. At the end of this chapter such a solution for partly mixed municipal waste in France is presented. However, in most member states with a composting sector, source separation is the chosen method.

For given framework conditions the case studies highlight different appropriate solutions. It can be concluded that:

- Citizens provide separated bio-waste in high quality and quantity if provided with a comfortable and transparent collection system, based on:
  short ways and simple separation rules, extensive promotion of source separation and appropriate collection intervals
- How collection systems are technically implemented depends largely on the economic framework and on the existing infrastructure, for example:
  housing density, road space and labor costs
- High quality input material for composting can also come from mixed collection if:
  hazardous waste, like batteries, is strictly collected separately and mixed waste is pre-treated with sophisticated separation systems

4.1. Large Wheeled Bins in Germany

In Germany, bio-waste is usually collected together with green waste in large wheeled bins (120-240 l), only differing by color from the conventional residual waste bins. Accordingly, one single fleet of conventional waste collection vehicles can be used for both the bio- and the residual waste collection. Furthermore, municipalities often increase the cost efficiency of their fleet by applying an alternating collection system for both waste types: as most municipalities provided a weekly collection of residual waste in the past, switching to an alternating fortnightly collection of bio- and residual waste does not increase the collection costs. [32]

However, the long collection intervals have led to some protests from citizens fearing hygienic issues and bad smells—even though several decades of daily practice have shown that a properly used bio-waste bin does not need to be a nuisance after 14 days in Germany's climate. Additionally, even if bad smells occur, hygienic risks are highly unlikely [33]. Nonetheless, most municipalities made the concession to provide weekly bio-waste collections during the summer months [32].

Others even chose a more sophisticated system to spare their citizens to adapt to new collection intervals. Drolshagen for instance, a small German town with 12,000 citizens, provides a combined collection of residual and bio-waste in two chamber bins (MEKAM-System) [34]. These bins can be emptied using special collection vehicles separated midway into two compartments. Both chambers can thus be loaded, compacted and emptied separately. However, despite its popularity among the citizens—less space required for waste bins, frequent collection—the MEKAM-system is still rather uncommon in Germany. The spread of bin weighing to calculate individual fees, which is not possible if one bin contains two differently charged waste fractions, will reduce the number of MEKAM-systems further. In addition, the trend for unified collection systems on district level will also likely eliminate such specific systems.

4.2. Small Portable Waste Bins in Northern Italy

Until 2010, about 87% of the northern Italian municipalities had implemented a comprehensive waste management system including the separate collection and treatment of organic residues [35]. According to Favoino [36], one of the major challenges was to offer a user friendly and affordable collection system, as most citizens were accustomed to very high collection frequencies for their residual waste. This is typical for southern countries, as they are confronted with the accelerated putrefaction of organics as a result of the warm climate. To achieve high participation and diversion rates, most municipalities therefore chose to adapt the food waste collection interval to the habitual residual waste collection interval: twice per week, while some municipalities even increased the collection frequency to 4 times per week in summer [37].

Due to these short collection intervals, the northern Italian system had to be particularly cost-efficient, while also being user-friendly. Each household has been provided with two small bins (5–10 l kitchen bin and 20–30 l outdoor bin) to be used with inlays made out of paper or biodegradable plastic. Some municipalities even distributed vented bins with semi-permeable bio-plastic bags specifically conceived for the food waste collection. These bags are permeable for water steam, but not for liquid water. By allowing the water to evaporate, the bio-plastic bag reduces bio-degradation in the waste bin and thereby reduces odor emissions. [36,37].

Independent of the type of bag used, the bio-waste is collected with small bulk lorries fitting through the narrow streets of Italian cities. Due to its high density (0.6–0.8 kg/L), food waste does not need compaction - besides, since the investment and maintenance costs for large waste compaction vehicles are substantially higher than for simple lorries, the latter are economically advantageous for the municipalities. Furthermore, the small bio-waste bins can easily be emptied by hand, which is 4 to 8 times faster than emptying a bin with a mechanical device. Nonetheless, to service large food waste producers, some lorries have been equipped with a mechanical device allowing the additional collection of wheeled road containers used by canteens, restaurants or residents of larger apartment buildings [36].

Altogether, the user-friendly system as well as the high collection frequencies provided by northern Italian municipalities reduced the organic matter content in the residual waste to less than 15% [36]. Nonetheless, it is important to note, that this system is not economically reasonable for the joint collection of food and garden waste, since the latter typically has a rather low bulk density (0.15–0.30 kg/L) and should thus be compacted prior to transportation [36]. As a result, many Italian municipalities chose to promote home-composting of garden waste.

4.3. Roadside Containers in Catalonia

In Catalonia, an autonomous region in Spain, most municipalities collect all recyclables (bio-waste, glass, paper and packaging) separately in 240 to 1100 l roadside containers. The collection frequency generally ranges between three to four times per week, or even daily in some urban centres during the summer months. However, according to Giro [38], this roadside collection achieves only poor results, which is detailed in Table 3.

Table 3. Comparison of collection performance between roadside and door-to-door collection in Catalonia, according to Giro [38].

Performance Indicator	Roadsite Collection	Door-to-door Collection
overall diversion rate for recyclables	15%–20%	60%–85%
bio-waste per inhabitant and day	100–150 g	300–400 g
bio-waste impurities	10%–15%	3%–5%

Furthermore, the containers are often highly unpopular as they take up a lot of public space and are considered a nuisance because of the dirt and smells in their vicinity.

As a result, some municipalities have implemented a door-to-door collection for recyclables, analogous to the Italian model for bio-waste. The frequency of collection has been slightly reduced to three times per week in general and four times per week in summer. As can be seen in Table 3, the door-to-door collection achieves significantly better results than the roadside containers.

Altogether, roadside containers in public spaces in Catalonia seem to be rather ineffective in providing high participation rates for the collection of recyclables. Nevertheless, it should be considered that some of their drawbacks, such as the occupation of public space or the odor nuisance, could effectively be reduced by installing underground containers.

4.4. Vacuum Pipes in Stockholm, Sweden

The city of Stockholm, elected "European Green Capital" in the year 2010, aims to increase the amount of food waste separately collected and treated from 11% in 2010 [39] to at least 40% by 2050 [40]. To facilitate the separate collection and to increase the food waste diversion rate, two pneumatic collection systems have been installed throughout the city and in some residential areas [41].

Single large food waste producers or small residential areas are connected to a pipe system collecting different waste fractions through input inlets, installed for instance in a restaurants' kitchen or a central courtyard. Underneath each inlet is a small storage tank connected via an underground pipe to a docking point situated at a maximum of 300 m from the inlet. To collect the waste, a vehicle equipped with a vacuum generator simply connects to the docking point and draws the waste out from the different storage tanks.

Both systems have the advantage that the inlets are not considered as annoying as smelly waste bins and that they can therefore be placed in exposed, central locations such as the hallway of a building, courtyards or even playgrounds. This not only provides a good accessibility of the waste inlets, but also ensures a social check on each one's recycling practice.

Both the mobile and the stationary pipe systems are quite popular and might even increase the value of the properties—not least because of their good accessibility for elderly or physically disabled persons [41].

4.5. Mixed collection in Launay-Landic, France

Since the Landfill Directive (1999/31/EC) made it compulsory to reduce the amount of biodegradable waste going to landfills, mechanical-biological treatment of municipal solid waste (MSW) has become a rather common process in Central Europe [42]. However, only a few countries (above all France, Spain and Italy) actually try to gradually improve the quality of the MSW composts produced to allow their use as a soil amendment in agriculture. Until recently, the quality of the recycled materials, including the compost, was very poor, since most plants used hammer mills or shredders as a first treatment step to reduce the particle size of the incoming MSW. Thus, the resulting compost was often heavily contaminated with heavy-metals (for instance due to the shredding of batteries [43]) and glass/plastic particles too small to be screened out. [44]

Nowadays, French MSW composting plants achieve remarkably low contamination levels, as can be seen in Table 4. It displays the heavy-metal values measured in 2012 in the composts from plants processing MSW and from plants processing bio-waste, together with older values for European composts published in 2004 [45]. According to these, huge progress has been made in MSW composting: whereas in 2004, MSW composts exceeded every single heavy metal threshold set in the German bio-waste ordinance [46], all recent values (except for copper) lie distinctly below. This is worth mentioning, because the relevant French compost standard NF U 44-051 (in force since 2009) has higher thresholds for all heavy metals. Even the Cerafel agreement between compost producers and vegetable growers in Brittany has higher thresholds for some heavy metals.

Table 4. Heavy-metal threshold and contamination values for European composts.

All in mg/kg$_{DM}$	Bio-AbfV [46]	EU Composts from: MSW [45]	EU Composts from: Bio-Waste [45]	French Thresholds for: NF U 44-051 [47]	French Thresholds for: Cerafel [47]	French Composts from: MSW [47]	French Composts from: Bio-Waste [47]	French Composts from: Launay [48]
As				18		2.96	4.9	4.8
Cd	1.5	**2.7**	0.5	**3**	1	1.01	0.5	0.5
Cr	100	**209**	23	**120**	100	40.02	24	24
Cu	100	**247**	45	**300**	**300**	**122**	60	84
Hg	1	**1.3**	0.14	**2**	1	0.37	0.2	0.2
Ni	50	**149**	14.1	**60**	50	28.16	17	15
Pb	150	**224**	49.6	**180**	100	108.9	47	46
Zn	400	**769**	183	**600**	**600**	356.1	198	245

Note: Values which exceed the German Bio-Waste Ordinance (BioAbfV [46]) are marked **bold**.

Thus, when considering the heavy-metal contamination in European composts, the technical state of the art in mechanical-biological waste treatment seems to enable the production of high quality composts comparable to composts produced from source separated bio-waste (see Table 4). The case of the MBT plant operated by SMITOM in Launay-Landic illustrates how this can be achieved.

The plant pre-treats the municipal solid waste stream within two Rotating Drum Reactors (RDR). These RDR, installed in most modern MBT plants, are equipped with sharp knives in the inside to slit plastic bags open and reduce the particle size of all fractions (paper, glass, plastic, and organics) in order to facilitate the following mechanical sorting processes. In the plant of Launay-Landic the waste remains for 3.5 days in the rotating drum reactor and is afterwards screened (30 and 150 mm) and classified using magnetism, ballistics and additional screening (at 10 mm) [49]. After the biological treatment of the organic fraction in windrows, the compost is sold:

- at 15 EUR/Mg to small buyers (< 10 Mg);
- at 3.81 EUR/Mg to medium sized buyers (10–100 Mg) and
- at 2.28 EUR/Mg to large buyers (> 100 Mg) [50].

The achieved prices are rather high, when compared to the average selling price of 4 EUR/Mg for certified (RAL) bio-waste compost in Germany [31]. It could be argued that these high prices can only be justified by the composts high quality and low contamination levels (see Table 4). However, this is not only the result of the improved mechanical processing technology, but above all of the community's effort to participate in the source separation of inert recyclables and most importantly, toxic materials. This is being extensively promoted by the authorities of Launay-Landic in community meetings, learning classes at schools and via brochures explaining the limits of the waste treatment facilities [50].

5. Conclusions

Regarding compost production in the EU, only about 35 Tg_{FM} of bio-waste — *i.e.*, one third of the potential feedstock available — is currently used. Around 5.5 Tg_{DM} of 10 Tg_{DM} sewage sludge is currently used in agriculture, directly or after composting. The remaining amount could provide additional feedstock for composting, provided that contamination with heavy metals or persistent organic compounds do not exceed threshold limits for safe composts.

Based on this, there remains a large potential for compost production in the EU. However, the distribution of compost producers varies greatly between and even within EU member states. Therefore, some areas have more potential to improve their recycling rates than others.

The woody part of bio-waste, *i.e.*, green waste would suffice to produce enough biochar for biochar-compost blends based on the whole bio-waste potential. Although not the focus of this paper, the potential of forestry residues for biochar was shortly discussed, as well as the agricultural resources to produce compost.

Regarding the legal framework for biochar and compost, it can be concluded that several EU regulations support the recycling of organic waste. However, based on the review of the unused waste potential, three recommendations were formulated to improve the current legislation:

- Obligatory rules to treat municipal organic waste are necessary to increase recycling rates. The current market for compost is characterized by low prices and heavy subsidies (waste fees) for its production. Therefore, the current plans for a revised Fertilizer Regulation with harmonized trade regulations and End-of-Waste criteria will hardly boost organic waste recycling under this circumstances.
- Obligatory information on biochar and compost products—input material, origin, substrate composition, and also directions for use—could strengthen responsible consumption and consumer

trust. Such labelling could easily be regulated on EU level, e.g., in the revised Fertilizer Regulation, without interfering much in heterogeneous national regulation approaches.

- Voluntary certification schemes should be recognized and possibly supported. They could cover aspects which are not easily included in regulations for the whole EU internal market. Examples are premium quality standards or the support of local economic circles. Especially new innovative operations could profit from the resulting customer loyalty and would have the potential to introduce innovations to the whole market.

The provided case studies about bio-waste collection and pre-treatment systems highlight a diversity of specific solutions for different circumstances. While there cannot be one optimal collection system for the whole EU, it is possible to transfer certain successful strategies to other regions with similar circumstances. This could optimize the multitude of existing systems and would increase the utilization of the available bio-waste.

The same approach of exchanging knowledge about successful strategies could be recommended for the utilization of sewage sludge and specific organic wastes from the food industry. Also for currently unused organic residues in agriculture and forestry it should be equally useful to allow for specific approaches and to support the exchange between regions.

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Author Contributions

Tonia Schmitz provided Section 3 about the legal framework and examined the waste collection systems in Section 4. Daniel Meyer-Kohlstock contributed the abstract, the introduction (Section 1), and Section 2 about the organic waste potential and its use. The conclusions in Section 5 were revised by Eckhard Kraft.

Conflicts of Interest

The authors declare no conflict of interest.

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