REVIEW OF SCIENTIFIC LITERATURE ON COMPOST PRODUCED FROM FOOD AND GARDEN ORGANIC WASTE

FINAL REPORT TO NEW SOUTH WALES ENVIRONMENT PROTECTION AUTHORITY FROM WCA

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EXECUTIVE SUMMARY

The New South Wales Environment Protection Authority (NSW EPA) required a critical scientific review of literature and other information from across the globe on the compost derived from source separated food organic and garden organic (FOGO) waste. The primary objective of this review was to determine the physical, chemical and biological characteristics of FOGO derived composts internationally and provide a critical comparison with 'Mixed Waste Organic Outputs' (MWOO). Specifically, the objectives of this project were to:

1. Undertake a critical review of the open and grey literature to collect and compile physical, chemical and biological data on FOGO derived compost;
2. Carry out a consultation exercise with FOGO compost producers from across the globe, in order to develop a characteristic profile of FOGO; and,
3. Compare and contrast the chemical profile of the compost derived from FOGO with the previously developed profiles of MWOO, from Australia.

Data for FOGO-derived, and green waste composts were identified from at least 10 countries around the world. These were mostly European, reflecting the changing status of the regulatory landscape for sustainable use of materials, formerly identified as wastes, being recycled to land. Only a limited amount of literature and studies from North America were identified in the time available for this project. Directly obtained information from processors was also limited to European processors due to the short timeframe available.

Data on persistent organic chemicals in 88 samples of composts and digestates from Europe indicated that concentrations of polycyclic aromatic hydrocarbons (PAHs) and dioxins are relatively low compared to national and European Union (EU) limit values and are in line with other published data on FOGO and green waste composts. Persistent organo-chlorine compounds have been found in some FOGO derived materials, but this is uncommon and often the concentrations in composts are relatively low or below the limits of detection. A review of European compost data concluded that while most composts did contain PFAS the concentrations in FOGO and garden organic derived composts are at a trace level and well below any existing national limit or guideline value.

The data and characteristics comparison contained in this report provides a relatively high-level view of the different organic materials. There are many factors that can influence compost quality and it has not been possible to detail all of these in the data sets we have collated. However, it has been possible to draw conclusions, and these include:

- Concentrations of physical and chemical contaminants in FOGO derived compost generated from source separated food and garden waste are consistently lower than those measured in MWOO.
- A key difference between FOGO derived and green waste composts and MWOO is related to the consistency of the characteristics. MWOO, as a non-source separated material, remains highly heterogeneous between plants and over time.
- The greatest challenge reported by the producers of FOGO derived composts related to meeting the appropriate certification limits, particularly parameters related to physical contamination and specifically, plastic content. Compliance with certification

standards ensures market confidence in the resulting compost and subsequently greater availability of markets for FOGO use.

- The biological characteristics of composts are strongly related to the effectiveness of the compost process and perhaps less to the specifics of the feedstock.
- The chemical comparison indicates that metal concentrations in MWOO are routinely much higher than those in FOGO derived composts.
- The persistent organic pollutants polybrominated diphenyl ethers (PBDEs) are significantly higher in MWOO (and MBT CLO) compared to FOGO derived compost. This is due to the presence of these brominated flame retardants in plastics, fabrics and electronic equipment that are components of commercial and domestic waste streams. The plasticiser DEHP is also found at much higher concentration in MWOO.
- Organic chemicals, where they have been determined in FOGO composts, present consistently low levels of potential risk. This is reflected in the general lack of requirements to measure organic chemicals in certification schemes, as these are considered unlikely to be found in FOGO derived compost.
- It is clear, from both the certification scheme descriptions and from the characteristic data we obtained, that FOGO derived composts contain low levels of contaminants and present consistently low environmental and human health risks when applied to land appropriately, i.e. following 'good practice'.

The importance of source separation of biodegradable materials (biowaste) has been recognised in Europe, where from the end of 2023, biowaste must be completely separated or recycled at source[1].

[1] https://legislationupdateservice.co.uk/directive-eu-2018-851-amending-directive-2008-98-ec-on-waste/

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1 INTRODUCTION

The New South Wales Environment Protection Authority (NSW EPA) engaged wca to undertake a critical scientific review of literature and other information from across the globe on the compost produced from food and garden waste.

Potential hazards from compost derived from these sources may be physical, including stones, glass, painted or treated wood and plastics, or chemicals such as metals and pesticides (depending on the source of 'green waste'). In similar organic materials used as compost there have been concerns over banned industrial chemicals (e.g. Brändli et al. 2006), veterinary medicines (e.g. Zhang et al. 2014) and petrochemicals from fuels and oils but these are unlikely to be present in compost from food and garden waste as these substances are unlikely to be found as inputs from these sources.

In addition to physical and chemical hazards there are also biological hazards that may not be rendered harmless during the composting process, such as pathogenic microbes (e.g. Bloem et al. 2017), seeds (especially from exotics or weed species) or spores and pathogens[2]. While the above have been identified as potential hazards questions remain over how likely they are to represent a significant risk through land application of composts derived from source separated food organics and garden organics (FOGO). The NSW EPA requested the FOGO compost be compared to the physical, biological and chemical characteristics of composts derived from these waste streams and compare with mixed waste organic outputs (MWOO) or other possible sources, including animal waste derived composts.

1.1 Project objectives

This project is aimed to determine the physical, chemical and biological characteristics of FOGO derived composts internationally and to provide a critical comparison of FOGO with MWOO. Specifically, the objectives of this project are to:

1. Undertake a critical review of the open and grey literature to collect and compile physical, chemical and biological data on FOGO derived compost;
2. Carry out a consultation exercise with FOGO compost producers from across the globe, in order to seek published or unpublished data to assist in the development of a characteristic profile of FOGO (recognising process technology and utility);
3. Compare and contrast the chemical profile of the compost derived from FOGO with the previously developed profiles of MWOO, from Australia; and,
4. Produce a clear, well-written, unambiguous report, that includes the appropriate datasets (where permission has been granted) and evidence sources.

1.2 Background

It is understood that some councils in NSW that utilise Alternative Waste Treatment (AWT) facilities (generators of MWOO) have reservations in regard to the likely quality of compost derived from FOGO, considering it to be similar (specifically in relation to physical and chemical

[2] http://www.wrap.org.uk/sites/files/wrap/PAS%20100_2011.pdf

composition, NOT agronomic performance) to that of MWOO. This report will inform further discussion on this issue.

The key first step in the production of compost of a quality that facilitates the sustainable spreading to agricultural land is source separation. Comesaña et al. (2017) noted in a study in Galicia in Spain that the biodegradable component made up over 40% of the total amount of household waste. The importance of source separation of biodegradable materials[3] (biowaste) has been recognised in Europe, where from the end of 2023 biowaste must be completely separated or recycled at source. Food wastes also have characteristics that are somewhat different to green wastes, specifically they tend to have a higher moisture content and organic ash ratio, lower calorific value and an amorphous physical structure, that can require different process considerations (Cerda et al. 2018).

In regard to compost quality, there has been a focus in developed countries, in recent times, to attempt to control quality through source control and process, recognising that there are numerous biological or chemical hazards that could potentially be an issue and that is entirely impracticable to test for all. Indeed, national protocols for production in countries in Europe are relatively common[4]; these define source segregation, composting requirements from production to use and minimum quality requirements for general use, giving a transparent audit trail for processors and end of waste markets[5]. In the UK the minimum quality requirements to deliver a certifiable compost are defined in a Publicly Available Specification (PAS 100)[6]. Table 1.1 shows the minimum requirements to deliver a certifiable compost (discussed further in Section 4), including biological, chemical and physical aspects of quality. High level risk assessments suggest that the source separated materials present relatively low levels of risk to human and environmental health when used across a range of land application scenarios. For example, Longhurst et al. (2019) noted that hazard quotients for chemical identified source-separated compost and anaerobic digestate were insufficient in magnitude to prompt detailed quantitative risk assessments.

The chemical quality requirements shown in Table 1.1 have been heavily influenced by the scientifically outdated UK Sewage Sludge Code of Practice from 1989[7]. This lists just a few metals and gives limit values that are included in PAS out of political convenience, but arguably little else. No organic chemicals are included.

A non-legally binding voluntary Australian Standard (AS 4454-2012[8]) for composts, soil conditioners and mulches give similar compost quality criteria to those shown in Table 1.1[9]. This includes limits of <1000 faecal coliform MPN g^{-1} dry material, absence of *Salmonella spp*. and physical contaminant limits on glass, metal and rigid plastics ≤0.5% and plastics-light,

[3] Effectively waste in the form of food from households, canteens, commercial facilities and green waste from parks, gardens etc. (Council Directive 2008/98/EC).
[4] E.g. https://www.compostnetwork.info/about-ecn/
[5] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297215/geho0812bwpl-e-e.pdf
[6] http://www.wrap.org.uk/sites/files/wrap/PAS%20100_2011.pdf
[7] https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland
[8] www.standards.org.au
[9] In NSW the requirements of the Compost Order 2016 and Compost Exemption 2016 are legally binding and must be complied with in order to land apply compost outside the boundary of your own premises.

flexible or film ≤0.05%. Importantly, there are no requirements for source separation in the standard.

Table 1.1 Minimum compost quality for general use (there is also a requirement for stoniness) (from: PAS100)

Item	Parameter	Test method	Unit	Upper Limit [a]
Pathogens (human and animal indicator species) [b]				
1	*Escherichia coli*	BS ISO 16649-2	CFU / g fresh mass	1000
2	*Salmonella spp*	Schedule 2, Part II of BS EN ISO 6579	25 g fresh mass	Absent
PTEs				
3	Cadmium (Cd)	BS EN 13650 (soluble in aqua regia)	mg / kg dry matter	1.5
4	Chromium (Cr)	BS EN 13650 (soluble in aqua regia)	mg / kg dry matter	100
5	Copper (Cu)	BS EN 13650 (soluble in aqua regia)	mg / kg dry matter	200
6	Lead (Pb)	BS EN 13650 (soluble in aqua regia)	mg / kg dry matter	200
7	Mercury (Hg)	BS ISO 16772	mg / kg dry matter	1.0
8	Nickel (Ni)	BS EN 13650 (soluble in aqua regia)	mg / kg dry matter	50
9	Zinc (Zn)	BS EN 13650 (soluble in aqua regia)	mg / kg dry matter	400
Stability/maturity [c]				
10	Microbial respiration rate	ORG 0020	mg CO_2 / g organic matter / day	16
Weed seeds and propagules				
11	Germinating weed seeds or propagule regrowth	OFW004-006	mean number / litre of compost	0
Physical contaminants				
12	Total glass, metal, plastic and any 'other' non-stone fragments > 2 mm	AfOR MT PC&S [d]	% mass / mass of "air-dry" sample	0.25 [e], of which 0.12 is plastic

The focus on metals, as sometimes the single measure of chemical quality for many regulatory jurisdictions and compost certification organisation across the globe, was emphasised by Wei et al. (2017) in a critical review of the environmental challenges from composting municipal solid wastes. Table 1.2 also highlights the lack of consistency across jurisdictions in regard to assessment of compost quality with limits for zinc, for example, varying by a factor of 37.

Table 1.2 Trace element concentration limits in composts from different regulatory jurisdictions (from Wei et al. 2017)

Country	Compost type	Cd	Cu	Cr	Hg	Ni	Pb	Zn	As	Se	Mo
UK		1.5	200	100	1	50	200	400			
Italy		1.5	150		1.5	50	140	500			
Spain	A	0.7	70	70	0.4	25	45	200			
Spain	B	2	300	250	1.5	90	150	500			
Spain	C	3	400	300	2.5	100	200	1000			
Germany	I	1	70	70	0.7	35	100	300			
Germany	II	1.5	100	100	1	50	150	400			
The Netherland	Compost	0.7	25	50	0.2	10	65	75	5		
The Netherland	Clean compost	1	60	50	0.3	20	100	200	15		
Switzerland		1	100	100		30	120	400			
California, USA		39	1500	1200	17	420	300	2800	41	36	
USA		39	1500	1200	17	420	300	2800	41	100	
Canada	A	3	400	210	0.8	62	150	700	13	2	5
Canada	B	20	757	1060	5	180	500	1850	75	14	20
China		3		300	5		100		30		

A desk-based investigation into potential organic chemical hazards in organic materials destined for land application undertaken by the Scottish Environmental Protection Agency (SEPA) in 2014 identified tetracycline, ivermectin, triclosan and doramectin as being chemicals that could potentially present ecological risks in green waste composts (SEPA 2014). Importantly, the source of these veterinary medicines and biocides was not entirely clear, but they are thought likely to originate from animal manures. A follow up project by SEPA (2019) updated the risk-based screening prioritisation of chemicals in green waste and FOGO derived composts using more recent European data and identified dieldrin and benzo(a)pyrene (BaP) from a health hazard screening, and di(2-ethylhexyl)phthalate (DEHP) due to its general potential environmental risk. A full semi-volatile organic compounds (SVOCs) and organo-chlorine pesticide suite of analysis was undertaken in a Scottish sourced green waste and FOGO compost. The results for those substances detected in the chemical analysis are shown in Table 1.3. DEHP is found in plastics and the other three compounds are plant protection products.

Table 1.3 Concentrations of compounds detected in green waste and FOGO derived composts from Scotland (from: SEPA 2019)

Determinand	Units	Green waste compost (4 samples)	FOGO derived compost (2 samples)
		Mean concentrations (and standard deviation)	
Bis(2-Ethylhexyl)phthalate (DEHP)	mg kg^{-1}	0.34 (0.19)	0.20 (0.01)
2,6-Dichlorobenzonitrile	µg kg^{-1}	2.17 (1.70)	1.59 (1.65
Endrin	µg kg^{-1}	1932 (2727)	1842 (2183)
Triadimefon	µg kg^{-1}	6.00 (5.67)	ND*

*Not detected.

In 2011, Waste & Resources Action Programme (WRAP) commissioned a technical report focussed upon developing an evidence-base to support the use of green waste and green waste and food waste derived composts in Welsh agriculture. The work was driven by a perceived increase in scrutiny around compost quality compared to other sources of organic materials destined for land application. This was largely because compared to other materials, such as sewage sludge, FOGO compost was relatively new to market. The study sampled seven composts on two occasions and compared the characteristics of these to the characteristics of digestates derived from food wastes and animal manures.

In addition to assessing the physical and biological characteristics, the WRAP study also reviewed the chemical quality of the composts, including trace metals and an extensive suite of organic chemicals including polychlorinated biphenyls (PCBs), dioxins and furans (PCDD/Fs), polybrominated diphenyl ethers (PBDEs) and polycyclic aromatic hydrocarbons (PAHs). Most of the chemical analytes targeted were not present at a detectable concentration.

The risk to environmental and human health from persistent organic chemicals in composts is generally assessed by regulators to be low. This is justified on the basis that there are no obvious sources of such contaminants, and because testing has indicated that they are rarely found at elevated levels. As such, many jurisdictions do not require routine monitoring of organic chemicals[10].

The relatively recent arrival of FOGO derived composts to market compared to other types of widely used organics inevitably means that data on compost characteristics are not as widely available or as comprehensive in terms of physical, biological and chemical coverage as for other similar materials. Much of the regulatory and academic focus on FOGO derived composts has, reasonably enough, been upon nutrient (e.g. Kadir et al. 2017) and trace element content (e.g. Whittle and Dyson 2002) or source related challenges influencing quality (e.g. Favoino 2003; Kawai and Huong 2017; Rupani et al. 2019). The academic studies can also be compromised by a lack of objectivity or clear hypothesis testing in experimentation leading to considerable difficulty in establishing exactly what type of organic material has been used and if any of the results are significant or applicable beyond the laboratory where the testing has been carried out (e.g. El-Nagerabi et al. 2012; Fernández-Delgado Juárez et al. 2015).

What is clear is that in order to facilitate decision making, with regard to long term environmental and agronomic benefit, robust data are needed on the characteristics of composts derived from specific organic source materials.

1.3 Report structure

After this brief introduction we define the key terms to be used in this report. In Section 2 we outline the searching strategy used for the information and literature review and provide results of those searches. The survey of compost processors is discussed in Section 3 along with a summary of their responses. The data on the characteristics of the FOGO derived composts collated from the literature sources and also from the processors are summarised in Section 4. A comparison of the data for FOGO composts put together from the global searching undertaken in this report and assessed against characteristics for MWOO is given in Section 5, with conclusions provided in Section 6.

[10] E.g. https://www.ccme.ca/files/Resources/waste/organics/compostgdlns_1340_e.pdf

1.4 Terms and definitions

Terms and definitions used in different jurisdictions and across the open literature can differ in meaning. Unfortunately, this makes data collection and comparison exercises fraught with the challenge of misidentification of material (e.g. biowastes[11], bio-compost, compost-like, etc.; JRC 2014).

In this report we have focussed our searches and subsequent comparison exercise on composts produced aerobically from food and garden organics (so called FOGO) only. Compost derived from other sources, and indeed organics derived from FOGO anaerobically, have NOT been considered (although the potential of anaerobic digestion of FOGO is likely to be considerable, e.g. Fricke et al. 2017). Where the source information is not clear or does not specifically mention segregation, as in some of the academic papers, we have not considered this as FOGO derived material.

MWOO can be 'broadly' described as biowaste and is generally produced from municipal solid waste. In Europe the process to produce these organic outputs is termed mechanical biological treatment (MBT) and a schematic is provided below of a 'typical' process (Figure 1.2). In the UK the organic material produced is rather generously termed "compost-like output" (CLO).

The physical and chemical characteristics of MWOO has been shown to be highly variable, irrespective of the country in which it is produced (e.g. Wei et al. 2017). This variability is due to many factors, including the inevitable heterogeneity of the inputs (e.g. Donovan et al. 2010; Environment Agency 2010; Di Lonardo et al. 2012). Several regulatory jurisdictions do not permit the application of organic material from MBT to agricultural land, or indeed any land, even for use as landfill cap material or in restoration of heavily degraded sites (e.g. UK, The Netherlands).

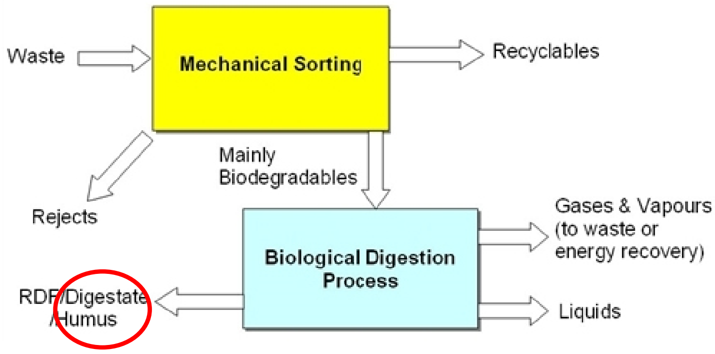

Figure 1.2 A generalised schematic of the steps and outputs from an MBT process (from CIWM[12])

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[11] E.g. biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants (Article 3(4) of the EU Waste Framework Directive, 2008/98/EC).
[12] https://www.ciwm.co.uk/ciwm/knowledge/mechanical-biological-treatment.aspx?WebsiteKey=4a155547-1b67-492b-91d6-2f034eab56ba

2 LITERATURE AND INFORMATION SEARCH

In this section we outline the strategy we have used to identify information sources specifically aimed at identifying the characteristics of FOGO derived compost.

2.1 Searching strategy

Searches of published scientific literature were conducted to identify sources that contain details of the contaminant profile and characteristics of FOGO derived compost. The search range covered all years included in the relevant databases.

Searches of the open scientific literature were conducted using the following:

- Derwent Innovation[13] – A bibliographic database covering scientific literature from products including Web of Science, Current Contents, Conference Proceedings and Inspec.
- TOXLINE[14] - A bibliographic database providing comprehensive coverage of the biochemical, pharmacological, physiological and toxicological effects of drugs and other chemicals from 1900 to present. TOXLINE covers three million citations, almost all with abstracts and/or index terms and CAS registry numbers.

Each database was searched with terms relating to FOGO derived compost and a relevant search string. The resulting hits from the searches were downloaded into an Excel spreadsheet as a record of the searches, and the titles and abstracts were then screened for potentially relevant papers relating to the contaminant profile and characteristics of FOGO derived compost. The search strings which were used for the literature search and the number of hits obtained from each database are shown in Table 2.1.

Table 2.1 Search strings and results from literature searches

Search term	TOXLINE	Derwent Innovation
("food waste compost" OR "garden waste compost" OR FOGO OR "green waste compost" OR "biowaste compost" OR "VFG compost" OR "biomix compost" OR "source separated organics") AND (contamin* OR composition OR regulat* OR hazard OR physical OR chemical OR biological OR pathogen)	611	340

After removing of the duplicate references from the initial searches, 895 publications remained. Initially, the relevance of these papers was screened by title, then by abstract. The screening process was targeted to identify those papers that may include information on the contaminant profile and characteristics of FOGO derived compost.

[13] https://www.derwentinnovation.com/login/
[14] http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?TOXLINE

2.2 Search results

From the published literature, 20 papers were identified that contained information on the contaminant profile and characteristics of FOGO derived compost. These papers were obtained and reviewed in detail. Relevant details were extracted on the composition and physical, biological and chemical characteristics of the FOGO derived compost.

Grey and regulatory sources were also identified from online searches for the key words or through advice received from wca's network and experience from previous projects.

3 PROCESSOR CONSULTATION

The NSW EPA require information on the quality of FOGO derived compost produced internationally and requested the undertaking of a short consultation to obtain information from individual operators processing FOGO to compost worldwide. This task had the primary objective of obtaining available data on composition and compost quality issues. Efforts were focussed on producers in Europe, the USA and Canada.

3.1 Contact strategy

The initial objective of this exercise was to identify relevant companies and organisations and the most appropriate contact within them. This was achieved by consulting existing reports and websites of producers and trade associations (e.g. European Compost Network[15] and the US Composting Council[16]). Most companies and organisations were also phoned to introduce the project and what it is working to achieve and to confirm the most appropriate person to send a short questionnaire to.

A short questionnaire was compiled to capture the following types of information:

- Details of company/organisation;
- Feedstocks, screening methods and technical processes used in compost production;
- Type of contaminants and concentrations found in FOGO compost;
- Additional information on composition and potential contaminants.

The questionnaire was sent to the identified contact via e-mail with a brief introductory letter from NSW EPA outlining the objective of this work. FOGO compost producers were invited to respond by completing the questionnaire and/or having a short phone call to discuss data and issues with FOGO production and use. Producers were given 10 days to respond from receipt of the e-mail and a follow-up email was sent on Day 10 to encourage participation.

3.2 Outcomes of consultation

Forty-two compost producing companies and trade associations were identified as being relevant to contact; e-mail addresses were obtained for 36 of these and questionnaires sent to them via e-mail. Ten producers/associations replied with seven providing useful information; four of the seven respondents were trade associations who provided useful links to reports and quality standards for compost and anaerobic digestate. Four completed questionnaires were returned by commercial compost producers although for two of these, the data related to pre-screened FOGO input rather than the compost produced from it. Relevant data provided by the respondents are detailed in the accompanying spreadsheet and summarised in Table 4.2.

[15] https://www.compostnetwork.info/
[16] https://www.compostingcouncil.org/

3.2.1 Responses from Trade Associations

UK advocates for recycling and composting (WRAP[17] and Renewable Energy Association (REA)[18]) indicated that the main problem for FOGO compost in the UK is plastic contamination in their incoming feedstocks from householders and specifically within the garden waste fraction. WRAP provided a number of technical reports detailing UK compost standards (e.g. PAS 100) and good practice guidelines for processing of anaerobic digestate and use of compost in agriculture (WRAP 2011). REA stated that PAS 100 stipulates a limit level of 0.12% by weight of plastics within the feedstock but this is still very high and many local authorities who are responsible for collecting this feedstock from householders make little effort to reduce the plastic volumes collected. Composters use wind sifters and air screens to take out the plastics, but this is difficult to achieve. In an attempt to tackle this issue UK regulators are making an effort to put greater responsibility on the householder rather than the compost producer who bears all the cost of removing contaminants to an acceptable level.

The European Compost Network provided a report detailing a comprehensive study of compost and digestate with different input materials, contaminants and quality assurance across Europe (JRC 2014). In Europe the main feedstocks are separately collected bio-waste from households, commercial and industry; this is mainly door to door collection via bio-bin or biobags for food waste, separate collection of green waste and collection points for green waste operated by local authorities. A member of the Composting Association of Ireland Teo (Cré) provided a report that included a comprehensive database detailing the characteristics and contaminant levels for FOGO-type compost produced in Ireland (Irish EPA 2009).

The Canadian Compost Council operate the Compost Quality Alliance program, which is a voluntary initiative amongst compost producers regarding end-product testing and usage recommendation. Approximately 25% of overall tonnage of compost produced in Canada is part of this program. Testing for foreign matter such as plastic is a fundamental component of their mandatory compost testing program with regulatory enforcement.

3.2.2 Responses from Compost Producers

Two compost producers in the UK (one in England and one in Scotland) responded providing summary data on compost composition and contaminants. The English plant accepts separately separated green waste from Household Waste Recycling Centres, doorstep collection and a negligible amount of commercial green waste as feedstock. This material is shredded to 180 mm before composting for 12 weeks in an open window system under PAS100 certification rules. The final product is trommel screened to 10 mm for horticultural use and bagging and 20 mm for agricultural use. The main contaminants are plastic bags used for the transport of green waste by householders to the Recycling Centre along with garden related plastics such as flowerpots and compost bags. Balls and garden tools are often in the deliveries. The plant does not use wind sifters to remove plastics but has a magnet belt on screener to remove metals. The data provided by this producer was not suitable for inclusion in the final dataset as it was based on pre-screened material (e.g. 3% plastic, which would

[17] http://www.wrap.org.uk/
[18] https://www.r-e-a.net/

need reducing to <0.5% to meet UK PAS100 guidelines for compost) and did not include food waste.

The Scottish producer reported that there has been much debate in Scotland regarding the economics and ethics of separate collections of food waste and collections co-mingled with green garden waste. The main issue with collecting co-mingled waste is ensuring that it lacks plastic contamination as this is proving extremely difficult to remove to a level which is commensurate with the requirements of the end users of the compost – namely agriculture. All compost produced from municipal sources in the UK must be manufactured to the accredited PAS standard otherwise it cannot be claimed as recycled. Meeting the high standards of PAS, or Scottish standards which are higher still, has created significant and costly issues. Producers highlighted that it is important to not consider the economics of co-mingled collections as a standalone entity but to also include the costs of meeting the requirements of the end user of the compost produced.

A compost producer from the Netherlands provided a full dataset on compost composition and contaminants. The feedstock is source separated biowaste from households, which, in Holland, is co-mingled garden waste and food waste (kitchen waste), considered to be about 80% garden waste and 20% kitchen waste. In the Netherlands the collection of source separated biowaste is mandatory and the amount collected annually is about 87 kg per inhabitant (1,500,000 tonnes in total). The producer stated that they operate several compost-producing facilities that utilise a range of different treatment technologies. All plants include pre- and post-treatment of impurities and the compost is screened to a small size of a 10 mm. Plants use slow rotating shredders, wind shifters and ballistic technics to remove impurities such as plastic and stone. The average composting time is only 18 days. The amount of impurities in the biowaste inputs in the Netherlands is about 4%. After treatment, the amount of impurities in compost is about 0.11% dry weight for glass and 0.09% for plastics and other impurities (these are 90th percentile values so should be treated as 'reasonable worst case'). In the Netherlands the maximum allowable concentration for impurities is 0.5% dry weight and all the compost is certified with all the acceptable values specified in a certification scheme[19].

A large multinational waste treatment company provided a response covering their operations in Europe, Canada and Australia. They stated that, depending on the country, a typical FOGO composting plant would start with a slow speed double shaft shredder, followed by an intensive in-vessel composting phase for pasteurization purposes, then by a second phase in vessels or maturation phase in/outdoors. Final compost manufacturing focuses on size reduction by star screens and / or trommel screen, with optional metal removal, optional lights removal (wind sifting) and finally inert (glass and stone) removal, with clean over-sized product being recirculated to the start of the process. Compost contaminant levels comply with the relevant compost standard of the applicable country. Data on contaminant levels were provided for a typical FOGO input sample at an Italian reference facility receiving input with a very high percentage of FO and low GO. This material contained high levels of plastic (>5%) but the data are not relevant for consideration in this exercise as they are for pre-

[19] http://keurcompost.nl/

screened input material and do not relate to a compost derived from FOGO; the producer confirmed that compost output would conform to Italian standards.

The analysis undertaken by European compost producers is almost entirely driven by the requirements of national certification schemes. These schemes specify standards for physical, chemical and biological parameters, with the chemical parameters being primarily inorganic. There is therefore an absence of data from the producers for organic contaminants such as PAHs, per- and polyfluoroalkyl substances (PFAS) compounds and polybrominated diphenyl ethers (PBDEs); it should be noted, though, that there are no obvious sources for these compounds in food and garden organic waste. All producers and composting trade associations confirmed plastics to be the main contaminant of concern in FOGO derived compost.

4 DATA REVIEW

In this section we provide summaries of the characteristics of FOGO derived composts from the open and grey literature sources and also from surveys returned by compost processors. The characteristics of the FOGO derived composts have been separated based on physical, biological and chemical parameters.

It is important to recognise that while every effort has been made to ensure that the composts being summarised here are produced using the same source material and in the same way this may not always be the case, simply because many of the academic reports give scant detail in regard to process. Where we have had doubts, we have not included these data (e.g. Som et al. 2009; Paradelo et al. 2011; Oviedo-Ocaña et al. 2015).

4.1 Literature-sourced data

Data for FOGO derived, and green waste composts were identified from at least 10 countries around the world. These were mostly European, but this is perhaps reflective of the status of the regulatory landscape with regard to focus upon the sustainable use of materials, formerly identified as wastes, being recycled to land.

Physical contaminant characteristics, such as the quantity of impurities, plastics, stones, metals and glass are less well reported in the open academic literature than chemical characteristics. Nevertheless, grey sources, such as regulatory reports with a specific 'use' related focus do include these. As noted in Section 1, the study undertaken by WRAP (2011) on Welsh green waste and FOGO derived composts (and digestates) provides an excellent dataset of biological, chemical and physical determinands from which to assess quality. One of the 12 compost samples from this study exceeded UK certification limits for total contaminants (>2 mm) of 0.5%. The authors of the WRAP (2011) report conclude that for those composts failing certification standards there is a need for process improvements in regard to assessment of feedstock input quality, as well as the screening of compost outputs to reduce the presence of physical contaminants. This is the fundamental challenge to ensuring the sustainable use of composts or digestates from FOGO. Indeed, regulators are looking to make the 'end of waste' requirements more stringent in the future[20].

Challenges also exist in the consistency of assessment of the physical contaminants present in green waste and FOGO derived composts (Echavarri-Bravo et al. 2017). The authors of that study spiked subsamples of three composts with physical contaminants and then sent these samples for testing at commercial laboratories apparently certified to undertake the assessment (JRC 2014). Unfortunately, for many of the categories, under reporting (especially for paper and cardboard and materials like solid foams) and misreporting of final percentages were common. It is widely recognised across the compost industry that physical contaminant analysis across batches (and laboratories) can be highly variable. Nevertheless, general trends with food waste derived composts tend to suggest plastic contamination is a key issue,

[20] E.g. https://www.sepa.org.uk/media/219843/wst-g-050-regulation-of-outputs-from-composting-processes.pdf

although it is lower when compared to FOGO derived, and just green waste, composts (Jeremy Jacobs, REA, pers. comm.).

Common microbiological metrics for the assessment of FOGO derived or green waste composts are mean *E. coli* numbers (with a limit in the UK of 1000 CFU g^{-1} fw) and the presence or absence of *Salmonella* spp (JRC 2014). Generally, these are a close reflection of the effectiveness of the composting process.

Wastes with high salt content can adversely impact plant growth and soil structure when applied to land, and this is a particular concern regarding food wastes (Cerda et al. 2018, and references therein). The chemical characteristics of green waste and FOGO derived composts shows the range of total phosphorus between 0.94 and 10 kg t^{-1} fw, with the highest being from FOGO derived composts. Total potassium varied over two orders of magnitude but did not seem to be entirely reflective of the source materials. The FOGO derived composts show higher relative total nitrogen contents than green waste compost, which is intuitive in the context of green waste being a common additive to food waste to balance the C:N ratio during composting. Food waste proportions range from 6.5 kg FO t^{-1} GO in a green waste compost, to 26 kg FO t^{-1} GO in a FOGO derived compost, both from Lithuania.

In a study on urban source-separated composts derived from household waste[21] from the city of Abeokuta, Nigeria, Adekunle et al. (2011) noted the increasing nutrient content (N, P and K) over the composting period in the wastes. Metals concentrations from this source material were relatively low compared to others identified from the literature searching, with minor increases in concentrations during composting in part due to the reduction in material volumes. In a study of 39 composts from urban and sub-urban processors in Hamburg over four seasons, Krogmann (1999) noted seasonal trends in trace metal concentrations. Specifically, they noted winter highs of copper and lead, thought potentially due to a reduced dilution by garden waste, and higher concentrations of copper, mercury and zinc in urban compared to suburban composts. The author suggested that elevated levels of metals in composts from garden wastes may be reflective of geogenic sources, i.e. natural ambient background concentrations in soils. Importantly, the metal concentrations determined in this study were 30-90% lower than those identified in non-source separated composts.

Despite some academic studies suggesting that trace metals are one of the main problems linked to the quality of composts (e.g. Paradelo et al. 2011), for source separated composts and digestates (especially food waste composts, e.g. Višniauskė et al. 2018) this is generally not the case, with only poorly managed local issues arising from long-term applications (e.g. Kupper et al. 2014). The range of trace element concentrations in source separated FOGO (BW) and green waste (GW) derived composts from countries across Europe (Table 4.1) support this, indicating that trace element concentrations are unlikely to be limiting in terms of sustainable agricultural application rates. Most composts are within the range of ambient background concentrations in soils and well below limit values or triggers associated with potential ecological or human health risks (e.g. ECN 2010).

[21] Defined by the authors as kitchen waste, food remnants, and vegetable matter

With improvements in analytical chemistry methods and procedures for dealing with complex environmental matrices, organic chemicals can now be readily determined at nanogram per kilogram concentrations or less. This has led to an academic surge in publications identifying concentrations of organic chemicals in waters, soils, sediments, wastes and biota (e.g. Carmona et al. 2014; Donnachie et al. 2016).

Beníšek et al. (2015) analysed 88 samples of composts and digestates from 16 European countries for persistent organic chemicals, including PAHs and dioxins. The authors noted that the concentration of the sum of PAHs[22] and median toxic equivalent of 2, 3, 7, 8 TCDD (median 0.57 µg kg^{-1}) are low compared to national and EU limit values, and are in line with other published data on FOGO and green waste composts (e.g. Višniauskė et al. 2018). Indeed, the main potential sources of PCBs in source-separated urban and rural FOGO derived composts were considered by Brändli et al. (2007) to be related to aerial deposition onto composting material. This study also noted relatively high concentrations of PAHs in over 70 samples of Swiss composts and digestates. The likely sources of this contamination were attributed to liquid fossil fuel combustion, asphalt abrasion and ash from household fireplaces (JRC 2014). The season, maturity, particle size and process methods of compost size all significantly influenced the concentrations determined.

The sum of the 16 US EPA priority pollutant PAHs range from 850 to 3010 µg kg^{-1} for composts from Switzerland and Lithuania. Composts from Wales gave the PAH benzo-[*a*]-pyrene (BaP) concentrations at about 300 µg kg^{-1}. These values are similar (e.g. WRAP 2011) compared to those from sewage sludges in Europe with mean BaP concentrations of about 370 µg kg^{-1} and a maximum of 1476 µg kg^{-1} (JRC 2012).

PFAS compounds have been widely used as coatings on household and industrial products including fabrics, carpets and cooking utensils and have been studied in two composts. In a Welsh compost derived from FOGO and green waste PFAS compounds were identified as individual congeners, whereas for a Swiss compost the sum of 21 congeners was reported. For two of the 18 FOGO derived and green waste Welsh composts perfluorooctanoic acid (PFOA) was identified above the limit of detection with a mean concentration of 5.5 µg kg^{-1} (WRAP 2011), but other congeners were below the limit of detection. In the JRC (2014) review of European compost data it was concluded that while most composts did contain PFAS, the concentrations in source separated bio-waste and green waste (FOGO) and source separated green waste (garden organic waste) composts are at trace levels and well below any existing national limit or guideline value.

PBDEs are persistent organic pollutants that were used as flame retardants in foams, fabrics and electrical equipment[23]. Significant quantities of these compounds have therefore entered commercial and domestic waste streams. WRAP (2011) did not find detectable concentrations of these substances in Welsh compost (i.e. <0.1 µg kg^{-1}) and Brandli et al. (2006, 2007) measured a concentration of 0.2 µg kg^{-1} for 'total PBDEs' in green waste compost in Switzerland. Rigby et al. (2015) measured PBDE congeners in a range of materials that are

[22] 16 US-EPA PAHs
[23] PentaBDE and octaBDE were banned from 2004 in the European Union and decaBDE is subject to restrictions on its use. PBDEs are listed under the Stockholm Convention on Persistent Organic Pollutants.

applied to agricultural land, including MBT CLO; mean concentrations in MBT CLO were 30 µg kg^{-1} for penta-BDEs, 13 µg kg^{-1} for octa-BDE and 1690 µg kg^{-1} for deca-BDE. Concentrations of total PBDEs were therefore over 1000 times higher in MBT CLO measured by Rigby et al. compared to the green waste analysed by Brandli et al.

Table 4.1 Mean or median concentrations of trace elements in composts and from source separated collection (mg kg^{-1}) where BW is source separated FOGO compost and GW source separated green waste compost (from Kupper et al. 2014, and references therein)

Type	n	Year	Country*		Cd	Co	Cr	Cu	Ni	Pb	Zn
BW	12	2006	DE	Median	0.5	-	22	60	14	37	191
GW	12	2006	DE	Median	0.4	-	20	39	12	27	147
BW	11	2009	DE	Median	0.4	-	<25	60	12	26	146
GW	11	2009	DE	Median	0.4	-	<25	37	13	29	136
BW	161	2009-2011	FR	Mean	0.6	-	26	66	17	57	230
BW	15	2007-2008	FR	Median	0.8	-	23	57	15	75	191
BW,GW	1437	2009-2012	UK	Median	0.5	-	19	58	13	95	206
BW,GW	164	2010-2012	AT	Median	0.4	-	26	44	18	25	155
BW,GW	135	2008-2012	ES	Median	0.2	-	22	89	15	43	243
BW,GW	114	2008-2010	BE	Median	1.0	-	31	49	15	64	238
BW,GW	10	2011-2012	PT	Mean	1.7	-	20	105	15	17	372
GW	237	2008-2010	BE	Median	1.0	-	25	34	11	49	168
GW	45	2007-2008	FR	Median	0.5	-	19	49	12	59	136
BW,GW	21	2011	CH	Mean	0.3	6.5	53	46	23	38	150

*DE – Germany, FR – France, UK – United Kingdom, AT – Austria, ES – Spain, BE – Belgium, PT – Portugal & CH – Switzerland

Pesticides, especially those used commercially in parks, green spaces and gardens could potentially be present in FOGO derived composts. Persistent organo-chlorine compounds have been found in some FOGO derived materials (e.g. Wågman et al. 2018), but generally this is not that common, and usually composts contain low or undetectable concentrations (Kawata et al. 2005).

As mentioned in Section 1, and shown in Tables 1.1 and 1.2, many countries across the world have certification schemes for composts that give prescriptive details on the processes to be followed (such as source segregation) in addition to numerical and qualitative limits that must be met. This is driven, in part, by the consumers, who only want a product that meets a prescribed standard. The type and frequency of monitoring of the characteristics of the compost are prescribed in the certification scheme. The European Compost Network specifies quality criteria for certain compost (and digestate) end uses, such as horticultural growing media (ECN 2018). These criteria are often more stringent compared to general compost use, and more detailed in terms of the permissible inputs and physical, chemical and biological limits than for general composts[24]. Plant bioassays with endpoints such as root elongation, biomass and germination are also common in European certification schemes.

[24] https://www.compostnetwork.info/ecn-qas/ecn-qas-manual/

A final, but salient part of the certification jigsaw is the availability of laboratories that can undertake the required tests on a highly organic media such as compost, using the prescribed method, and to an appropriate level of competence. This level of service hasn't always been available or financially practicable (JRC 2014).

If composts are to present low levels of environmental risk and to deliver sustainable benefit when applied to land, then input sources must be controlled. For many countries this is already happening (ECN 2010), but variations in national laws may mean some countries (e.g. Greece) allow the use of non-source separated materials to be used in composts, and this is reflected in compost quality.

4.2 Processor data on compost composition and contaminants

During the consultation exercise, data on FOGO derived compost were provided for the UK, Ireland and the Netherlands. Data from two compost producers were excluded on the basis that they tested pre-screened material rather than the final compost product. Data are focused on establishing compliance with the relevant certification scheme required in the specific country to market the compost for application to agricultural and horticultural soil. Parameters assessed for the certification schemes are physical contaminants (i.e. stones, plastic and solid metal), the standard metals suite and biological determinands such as weed seeds and the indicative pathogens *E. coli* and *Salmonella*. There is generally no requirement for assessment of organic contaminants so data for these determinands are lacking in the processor data. The exception is the dataset for Irish FOGO compost which contained a limited number of measurements: median values were 3.2 $mg.kg^{-1}$ for 'total PAHs' and <120 µg.kg-1 for 'total PCBs'. Table 4.2 contains the data provided by the compost producers in the three countries.

Table 4.2 Data on compost composition and contaminants provided by compost producers from three countries

Determinand	Units	Netherlands (mean)	Scotland (single value)	Ireland (median)
Total impurities	% DW	0.11	-	0.3 (90P[25])
Stone >5 mm	% DW	0.51	3.7	0.12
Glass 2-20 mm	% DW	0.07	0.07	0
Plastic > 2 mm	% DW		0.01	0
Metal	% DW	-	-	0
DM	%	66.5	44.4	-
OM	$g\ kg^{-1}$	332	631	563.5
Total N	$kg\ t^{-1}$ FW	12.4	16.3	20.4
Total P (P_2O5)	$kg\ t^{-1}$ FW	6.80	2.63	4.2
Total K (K_2O)	$kg\ t^{-1}$ FW	10.30	7.62	11.6
MgO	$kg\ t^{-1}$ FW	5.80		-
S	$mg\ kg^{-1}$	2200	2147	-
Cl	$mg\ kg^{-1}$	2900	2424	-

[25] 90th percentile value

EC	water extract – 1:5 ratio, µS cm^{-1}	3400	1500	5145
$CaCO_3$	kg t^{-1} FW	2.50	-	-
Cd	mg kg^{-1}	0.40	<0.1	0.5
Cr	mg kg^{-1}	24.2	6.5	26.5
Cu	mg kg^{-1}	39.0	26	64.2
Hg	mg kg^{-1}	0.10	<0.1	0.08
Ni	mg kg^{-1}	12.3	12	19
Pb	mg kg^{-1}	43.5	51	45.1
Zn	mg kg^{-1}	170.6	143	173
Al	mg kg^{-1}	-	-	-
Mn	mg kg^{-1}	-	-	-
As	mg kg^{-1}	4.40	-	4.7
pH		7.30	5.5	7.98
∑PAHs (EPA 16)	mg kg^{-1}	-	-	3.2
∑PCBs	µg kg^{-1}	-	-	<120
Weed seeds	% DW	0.02	0	-
E. coli	CFU g^{-1} fw	-	400	112
Salmonella spp.	Presence/Absence	-	Absent	Absent

- = no value was available

4.3 Data selected for comparison exercise

This section details the data that will be used subsequently in Section 5 to compare the characteristics of the FOGO derived composts with those of MWOO. Data have been collected from a range of sources, and while it is possible to make comparisons literature-sourced data and processor-sourced data have been intentionally kept separate. The latter is likely to reflect the current nature of FOGO and MWOO outputs, and the processing techniques are well understood. Conversely, the literature-sourced data represents several processing techniques that were not always well described, and reflect data collected over a substantial time period. The selection of determinands was largely driven by data availability, which in turn driven by the certification scheme relevant to the jurisdiction in which the data were obtained.

4.3.1 FOGO derived compost

Table 4.3 shows the ranges of values for determinands in green waste and FOGO derived composts from the literature for six countries. Data from FOGO derived compost from processors in three countries are also included.

PCBs are not included in the table as all the composts gave less than the limit of detection where these data had been collected, aside from those collected by WRAP (2011). It is inevitable that some determinands are missing because either data could not be readily found in the project timeframe, or because source information was ambiguous, or the material was not considered comparable to the materials under consideration in this review.

4.3.2 MWOO data

The MWOO data that are used in the comparison exercise in Section 5 were provided by NSW EPA to the wca Project Team. These data were collated and summarised by the NSW EPA from the outputs of NSW AWT facilities that have land applied MWOO. Mean and the range of values (i.e. minimum – maximum) for measured concentrations are shown in the final column of Table 4.3.

Table 4.3 Range, median and mean values of FOGO derived and green waste composts and MWOO data supplied by NSW EPA

Determinand	Unit	FOGO derived compost range from processors**	FOGO derived compost range from literature*	Green waste compost range from literature*	MWOO data from NSW EPA$^{\Delta}$	
					Mean‡	Range (Min-Max)
DM	%	44 - 67	74	48	-	-
OM	g kg^{-1}	332 - 631	310 - 460	200 – 480	-	-
Total N	kg t^{-1} FW	12.4 – 20.4	10 - 26	7 – 11	16.7	8.8 - 26†
Total P (P_2O_5)	kg t^{-1} FW	2.6 – 6.8	2.1 - 10	0.94 – 4.2	4.1	2.7 - 7.5†
Total K (K_2O)	kg t^{-1} FW	7.6 – 11.6	0.12 - 16	4.7 – 10	6.7	3.7 - 14†
MgO	kg t^{-1} FW	5.8	2.3 – 6.2	2.4 – 8.4	2.4	1.5 - 4.5†
Total S	kg t^{-1} FW	2.1 – 2.2	2.5 – 7.1	2.3 – 3.5	3.4	2.4 - 8.4†
Cl	mg L^{-1}	242 - 290	2250	905	-	-
EC	water extract – µS cm^{-1}	1500 - 5145	1157 – 2730	1530 – 2470	8400	5200-14000
$CaCO_3$	kg t^{-1} FW	2.5	-	55	-	-
Cd	mg kg^{-1}	<0.1 – 0.5	0.1 – 0.63	0.32 - 1.40	1.92	<0.3 - 53
Cr	mg kg^{-1}	6.5 – 26.5	6.5 – 23.4	12.7 – 27	33.5	3.4 - 180
Cu	mg kg^{-1}	26 - 64	0.82 – 79	14 – 122	277	12 - 65000
Hg	mg kg^{-1}	0.08 – 0.1	0 – 0.08	0.10 – 0.64	0.31	0.04 - 4.5
Ni	mg kg^{-1}	12 - 19	4.2 – 16	7.7 – 16	26.4	5.3 - 258
Pb	mg kg^{-1}	44 - 51	4.3 – 68	34 – 163	173	<5 - 5740
Zn	mg kg^{-1}	143 - 173	2.8 – 257	35 – 492	544	77 - 35000
Al	mg kg^{-1}	-	-	-	6110	4100 - 21000
Mn	mg kg^{-1}	-	-	-	266	2 - 1500
As	mg kg^{-1}	4.4 – 4.7	8.2	16	4.4	1.4 - 30
pH		5.5 – 8.0	7.1 – 8.9	7.9 – 8.4	6.7	5.7 - 8.7
Benzo(*a*)pyrene	µg kg^{-1}	-	301	<300	520$^{\diamond}$	50 - 8000$^{\diamond}$
∑PAHs (EPA 16)	µg kg^{-1}	3200	1900	850 - 3010	1430	<50 - 50100
Perfluorodecanoic acid	µg kg^{-1}	-	<5	<6	3.1	<1 - 9.3
Perfluorododecanoic acid	µg kg^{-1}	-	<5	<6	<5	<5
Perfluoroheptanoic acid	µg kg^{-1}	-	<5	<6	2.1	<1 - <5
Perfluorohexanoic acid	µg kg^{-1}	-	<5	<6	5.5	1.3 - 35
Perfluorononanoic acid	µg kg^{-1}	-	<5	<6	2.3	<1 - <5
Perfluorooctanoic acid (PFOA)	µg kg^{-1}	-	5.49	<6	2.6	<1 - 8.5

Determinand	Unit	FOGO derived compost range from processors**	FOGO derived compost range from literature*	Green waste compost range from literature*	MWOO data from NSW EPA^Δ^	
					Mean‡	Range (Min-Max)
Perfluorooctylsulphonate anion (PFOS)	µg kg^{-1}	-	<5	<6	3.8	2.1 - 10
Perfluoropentanoic acid	µg kg^{-1}	-	<20	<20	2.2	<2 - 5.3
Perfluorotetradecanoic acid	µg kg^{-1}	-	<5	<6	<5	<5
∑PFAS	µg kg^{-1}	-	-	6.30#	51.3##	<45 - 549##
Diethylhexyl phthalate	mg kg^{-1}	-	0.2 - 1.25	0.28 – 2.21	194	2.3 - 2600¥
∑PBDEs	µg kg^{-1}	-	<0.1	<0.1 – 0.20	18030	97 - 718000
Triclosan	mg kg^{-1}	-	<0.2	<0.2	-	-
Tributyl tin (TBT)	µg kg^{-1}	-	<20	< 20	1.14	<0.5 - 5.8
Bisphenol A	mg kg^{-1}	-	<1	<1	26.4	4 - 100
Total impurities	% DW	0.1 – 0.3	-	-	-	-
Impurities > 2 mm	% DW	0.04	0.21 – 0.77	0.24 – 0.41	-	-
Stone >5 mm	% DW	0.12 – 3.7	2.16 – 5.52	0.74 – 12	-	-
Glass 2-20 mm	% DW	0 – 0.07	0.14 – 0.17	0.03 – 0.08	-	-
Plastic > 2 mm	% DW	0 – 0.09	0.03 – 0.21	0.06 – 0.22	-	-
Glass, metal and rigid plastics >2 mm (%)	%DW	-	-	-	1.43	0 - 11.8
Plastics – light, flexible or film >5 mm (%)	%DW	-	-	-	0.047	0 - 0.91
E. coli	CFU g^{-1} fw	112 – 400	595 – 720	425	9.2^	<3 - 9.2^
Faecal coliforms	MPN g^{-1} fw	-	-	-	6.4^^	<3 - 9.2^
Salmonella spp.	Presence /Absence	Absent	Present	Absent	Absent	Absent

* Where only one value is given, only one source of information was available.
** range of data (including single value, mean and median values as provided) from Table 4.2
Δ NSW MWOO data was sourced from facility data where this was available. Data for analytes not required to be tested under NSW regulations were sourced from the NSW EPA co-ordinated AWT research program.
‡ Measurements at less than limit of detection (<LoD) are taken as half of LoD in calculation of mean values
† Units and/or determinands are different to those in second column: TKN in mg/kg, not Total N in kg/t/FW, P in mg/kg, not P_2O_5 in kg/t/FW, K in mg/kg, not K_2O in kg/t/FW, Mg in mg/kg, not MgO in kg/t/FW,
◊ B(a)P data only reflects 26 detected values (<LOD data was not available)
¥Total of diethylhexyl phthalate (DEHP) + dibutyl phthalate (DBP), the data (660 samples) comprised >97.5% of DEHP.
∑PFAS - fluorotelomer sulfonate, four fluorotelomer carboxylates, four perfluorinated sulfonates, seven perfluorocarboxylates, three fluorooctane sulfonamides and two fluorooctane sulfonamidoethanols ## ∑PFAS – Sum of PFBS, PFHxS, PFBA, PFOS, PFPeA, PFHxA, PFHpA, PFOA (using 0.5 x LoD where measurement is below limit of detection)
\- = no value was available ^ = MPN g^{-1} fw ^^ mean derived from 2 detected values from 15 samples

5 INDICATIVE COMPARISON OF FOGO DERIVED COMPOST AND MWOO

In this section we briefly compare the characteristics of the FOGO derived composts and MWOO, primarily from NSW. In addition to the data collected from the literature and processors we have included data from a European compost comparison exercise that included both types of material and also green waste composts (JRC 2014).

For the comparison, we have focussed less upon the macronutrient beneficial content and more upon the determinands and characteristics commonly included in certification schemes and quality criteria for declaration of 'end of waste'. Tables 4.2 and 4.3 are used here as the sources of data for this indicative comparison. Due to the inevitable variability in the data from multiple sources it is considered that the assessment presented below is proportionate and reasonable.

5.1 Physical comparison

The literature data for the values of the physical contaminants present in the FOGO derived and green waste compost are all lower than those for the European MWOO data. For plastics, the green waste compost shows greater percentages than FOGO derived, but lower than for the MWOO. Glass content of the FOGO and green waste composts are considerably lower than the MWOO value.

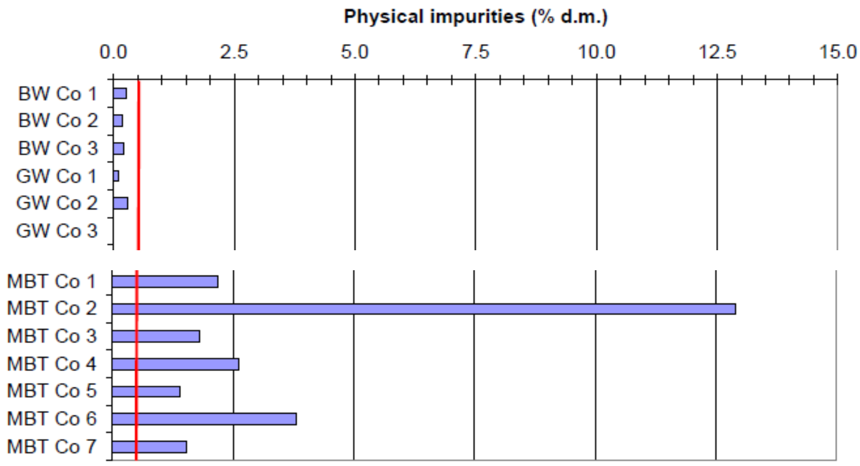

Figure 5.1 Edited figure showing total percentage of physical impurities (glass, plastic and metal >2mm) in FOGO derived composts (BW Co), green waste composts (GW Co) and MWOO (MBT Co) from a European sampling exercise of processor plants (from: JRC 2014). The red line is the limit of 0.5%, which is the proposed EU EoW product quality criteria

The greater level of physical impurities and contaminants in MWOO compared to green waste and FOGO derived composts observed here is supported by findings from a European wide survey undertaken by the Joint Research Centre (Figure 5.1; JRC 2014). The data shown in this figure indicate the high levels of physical impurities in MWOO, such as plastic, glass and cardboard in MWOO, as well as the variability between MWOO produced by different facilities. None of the MWOO would meet the proposed EU End of Waste (EoW) criteria for certification of <0.5% physical impurities.

The measured levels of the physical contaminants present in the FOGO derived compost provided by processors during the consultation exercise are all lower than those for MWOO. These consistently low concentrations are required to meet national certification schemes and ensure that the compost is fit for its end use of application to land. Concentrations of 'total impurities' are an order of magnitude lower in these FOGO samples compared to MWOO.

5.2 Chemical comparison

For the organic chemicals, contaminant concentrations measured in FOGO derived and green waste composts are generally very low. Most of the PFAS compounds were below the limit of detection, with just perfluorooctanoic acid (PFOA) detected at 5.5 µg kg^{-1} in FOGO derived compost (WRAP 2011), and up to 10 µg kg^{-1} for PFOS in MWOO (NSW EPA 2018). PBDE concentrations in FOGO derived compost and green waste are low with a maximum of 0.2 µg kg^{-1} for 'total PBDEs' (Brandli et al. 2006, 2007). The concentrations of total PBDEs are significantly higher in NSW MWOO with measured concentrations ranging from 0.01 to 718 mg kg^{-1} with a mean value of 18 mg kg^{-1} (see Table 4.3). The plasticiser DEHP is also much elevated in NSW MWOO (2.3 – 2600 mg kg^{-1} with an average of 194 mg kg^{-1}) compared to literature values for FOGO derived compost and green waste (maximum value of 2.21 mg kg^{-1}).

More explicit and direct comparison of the concentrations of organic chemicals determined in FOGO and green waste compost and MWOO is not possible with the data available. This is because these data are from multiple studies, processes, and sources and to attempt to derive a single summary metric for comparison purposes would be statistically inappropriate. Furthermore, the scientific validity of such a comparison is likely to lead to the drawing of conclusions that inevitably cannot be supported by the datasets presented here.

More data are available for metal contaminants, and without exception, the concentrations measured in FOGO derived composts and green wastes are far lower than those measured in MWOO. This trend is supported by the study undertaken by the JRC on European compost quality (2014; Table 5.2). The review and analysis of compost data in this study showed that the concentrations of metals are higher for MWOO (MBT CLO) than almost all the source separated materials. Indeed, from the French samples 8.0%, 12.4% and 19.4% of the samples exceeded the Cu, Cd and Pb limits and all the Spanish samples exceeded the criteria for these metals.

For aluminium and manganese there are few data sources for FOGO or green waste composts making comparisons difficult. Ecological assessment of potential risk from these metals is also especially difficult with few, if any, regulatory jurisdictions having developed robust biological metrics for harm in soils.

Table 5.2 Concentrations of metals in food waste compost (BW Co), FOGO derived composts (BW + GW Co), green waste composts (GW Co) and MWOO (MBT Co) from a European sampling exercise of processor plants (from: JRC 2014)

							Median/Average							90 Percentile (From distribution/Calculated)							
Material type	Quality label received?	Data source	Year(s)	MS	Number of samples	Median or Average?	Cd	Cr	Cu	Hg	Ni	Pb	Zn	From Distribution or Calculated?	Cd	Cr	Cu	Hg	Ni	Pb	Zn
"Raw": analytical results from materials that have NOT received a quality label																					
BW Co	No	Ineris	2009-2011	FR	161	A	0.6	26	66	0.19	17	57	230	C	0.9	39	107	0.38	25	92	332
BW Co	No	Cré (IMD)	2000-2006	IE	82	M	0.5	27	64	0.08	19	45	173	D	0.8	65	100	0.30	39	100	266
BW Co	No	ADEME	2007-2008	FR	15	M	0.8	23	57	0.16	15	75	191	D	0.9	38	137	0.45	24	99	255
BW + GW Co	No	DWMA	1994-2009	NL	1728	M	0.4	20	35	0.08	10	56	175	D	0.6	27	55	0.15	13	79	217
BW + GW Co	No	REA	2009-2012	UK	1437	M	0.5	19	58	0.14	13	95	206	D	0.9	37	99	0.24	22	164	282
BW + GW Co	No	ARGE	2010-2012	AT	164	M	0.4	26	44	0.13	18	25	155	D	0.8	40	88	0.28	27	41	324
BW + GW Co	No	MS ES	2008-2012	ES	135	M	0.2	22	89	0.20	15	43	243	D	0.6	57	169	0.60	31	83	359
BW + GW Co	No	VLACO	2008-2010	BE	114	M	1.0	31	49	0.10	15	64	238	D	1.3	46	59	0.20	18	103	317
BW + GW Co	NN	MS PT	2011-2012	PT	10	A	1.7	20	105	0.24	15	17	372	C	2.2	34	111	0.30	18	21	404
GW Co	No	VLACO	2008-2010	BE	237	M	1.0	25	34	0.20	11	49	168	D	1.2	30	41	0.20	14	54	187
GW Co	No	ADEME	2007-2008	FR	45	M	0.5	19	49	0.18	12	59	136	D	0.7	23	60	0.47	14	88	196
GW Co	No	Cré (IMD)	2000-2006	IE	38	M	0.5	40	61	0.10	32	74	182	D	1.0	57	82	0.15	38	114	253
MBT Co	No	Ineris	2009-2011	FR	247	A	1.1	43	128	0.51	26	93	356	C	1.9	64	196	0.93	37	136	497
MBT Co	No	MS ES	2011-2012	ES	12	M	1.0	63	202	0.45	45	118	416	D	1.3	192	449	1.06	129	210	609

Colour coding: Red = above European 'end of waste' limit, Orange = above 90th percentile of European 'end of waste' limit and Green = below 50th percentile of European 'end of waste' limit. Where FR – France, UK – United Kingdom, AT – Austria, ES – Spain, BE – Belgium, PT – Portugal NL – Netherlands IE- Ireland.

The only data on organic contaminants in FOGO derived compost provided by the processors were for concentrations of total PAHs and PCBs in Irish FOGO derived compost; there are little comparable data in MWOO[26] and these persistent organic chemicals were not detected in FOGO at concentrations that would present a risk to human health or the environment.

For metals, the concentrations determined in FOGO derived composts are all lower than those identified in MWOO. The highest concentrations of two of the most hazardous metals (Cd and Pb) in the FOGO compost data provided by processors are three to four times lower compared to the MWOO samples assessed by NSW EPA.

5.3 Biological comparison

For the MWOO data from NSW EPA, the processing removes the presence of *Salmonella spp*, which is present in the FOGO derived compost reported in the literature (Table 4.3). Concentrations of *Escherichia coli* (*E.coli)* in MWOO data from NSW EPA were lower than that reported in the literature for FOGO or GO derived compost (Table 4.3). However, a caveat for this comparison is that different analytical methods were used in the literature to that used in

[26] Total PAHS were measured at 3.2 mg kg-1 in Irish FOGO-derived compost. In NSW MWOO there is an average concentration of 1.43 mg kg^{-1} and a maximum of 50.1 mg kg^{-1}.

the NSW data (colony forming units (CFU g^{-1}) and Most Probable Number (MPN g^{-1})). This review did not find data to compare to the thermotolerant coliform data from NSW.

Generally, these biological indicators are a reflection of the composting process itself, but unfortunately only very limited data were available for E. *coli* or *Salmonella spp* in the literature and the corresponding metrics used for FOGO and green waste compost supplied by processors.

Data on biological determinands provided by FOGO compost processors show low levels of the pathogenic bacteria assessed for certification. *Salmonella spp* were absent in all samples analysed by processors.

6 CONCLUSIONS

The information gathered for this review demonstrates that removal of physical contaminants, and specifically plastics, is the main concern in the production of FOGO derived compost that is suitable for application to land. In Europe acceptable levels of these contaminants are ensured by the regulatory requirement for compliance with certification schemes that also specify acceptable levels of pathogenic bacteria and a range of trace metals. Concentrations of physical, and chemical contaminants in FOGO derived compost generated from source separated food and garden waste are consistently lower than those measured in MWOO.

The data and characteristics comparison that we have detailed in this report is indicative and provides a relatively high-level view of the different organic materials. There are many factors that can influence compost quality and it has not been possible to detail all of these in the data sets we have collated. From this review and comparison exercise we can draw the following conclusions:

- Concentrations of physical and chemical contaminants in FOGO derived compost generated from source separated food and garden waste are consistently lower than those measured in MWOO.
- The biological characteristics of composts are strongly related to the effectiveness of the compost process and perhaps less to the specifics of the feedstock.
- The greatest challenge reported by the producers of FOGO derived composts in regard to meeting the certification limits is compliance with criteria related to physical contamination and specifically plastic content.
- A key difference between FOGO derived and green waste composts and MWOO is related to the consistency of the characteristics. The literature shows that MWOO, as a non-source separated material, remains highly heterogeneous between plants and over time.
- The chemical comparison indicates that metal concentrations in MWOO are routinely much higher than those of FOGO derived composts. Organic chemicals, where they have been determined in FOGO, present consistently low levels of potential risk. This is reflected in the general lack of the requirement to measure organic chemicals in certification schemes, as these substances are unlikely to be found in source separated FOGO.
- The plasticiser DEHP is much higher in MWOO compared to FOGO derived compost and green waste. The persistent organic pollutants PBDEs are also significantly elevated in MWOO (and MBT CLO). High PBDE levels are due to the presence of these brominated flame retardants in plastics, fabrics and electronic equipment that are components of commercial and domestic waste streams.
- In the limited number of studies assessing PFAS compounds in FOGO derived compost concentrations of these substances were below the limit of detection, with just perfluorooctanoic acid (PFOA) detected in a single study at a mean concentration of 5.5 µg/kg. In other studies, reported here, most composts had PFAS at trace levels and well below any existing national limit or guideline value.
- It is clear, from both the certification scheme descriptions and from the characteristic data we obtained, that FOGO derived composts contain low levels of contaminants and present consistently low environmental and human health risks when applied to land appropriately, i.e. following 'good practice'.

REFERENCES

Adekunle IM, Adekunle AA, Akintokun AK, Akintokun PO, Arowolo TA. 2011. Recycling of organic wastes through composting for land applications: a Nigerian experience. Waste Manag. Res., 29: 582-593.

Alvarenga P, Palma P, Gonçalves AP, Fernandes RM, Cunha-Queda AC, Duarte E, Vallini G. 2007. Evaluation of chemical and ecotoxicological characteristics of biodegradable organic residues for application to agricultural land. Environ Int., 33: 505-513.

Beníšek M, Kukučka P, Mariani G, Suurkuusk G, Gawlik BM, Locoro G, Giesy JP, Bláha L. 2015. Dioxins and dioxin-like compounds in composts and digestates from European countries as determined by the in vitro bioassay and chemical analysis. Chemosphere. 122: 168-175.

Bijlsma PB, de Wit DH, Duindam JW, Elsinga GJ, Elsinga W. 2013. Spot test analysis of microbial contents during composting of kitchen- and garden biowaste: sampling procedures, bacterial reductions, time-temperature relationships, and their relevance for EU-regulations concerning animal by-products. J Environ Manage. 115: 198-205.

Bloem E, Albihn A, Elving J, Hermann L, Lehmann L, Sarvi M, Schaaf T, Schicka J, Turtola E, Ylivainio K. 2017. Contamination of organic nutrient sources with potentially toxic elements, antibiotics and pathogen microorganisms in relation to P fertilizer potential and treatment options for the production of sustainable fertilizers: A review. Science of the Total Environment, 607–608: 225–242.

Brändli RC, Kupper T, Bucheli TD, Zennegg M, Huber S, Ortelli D, Müller J, Schaffner C, Iozza S, Schmid P, Berger U, Edder P, Oehme M, Stadelmann FX, Tarradellas J. 2006. Organic pollutants in compost and digestate. Part 2. Polychlorinated dibenzo-p-dioxins, and -furans, dioxin-like polychlorinated biphenyls, brominated flame retardants, perfluorinated alkyl substances, pesticides, and other compounds. Journal of Environmental Monitoring. DOI: 10.1039/b617103f

Brändli RC, Bucheli TD, Kupper T, Zennegg M, Berger U, Edder P, Oehme M, Müller J, Schaffner C, Furrer R, Schmid P, Huber S, Ortelli, D, Iozza, S, Stadelmann FX, Tarradellas J. 2006. Organic pollutants in source- separated compost. Organohalogen Compounds, 68: 863-866.

Brändli RC, Bucheli TD, Kupper T, Furrer R, Stahel WA, Stadelmann FX, Tarradellas J. 2007. Organic pollutants in compost and digestate. Part 1. Polychlorinated biphenyls, polycyclic aromatic hydrocarbons and molecular markers. J Environ Monit., 9: 456-464.

Carmona E, Andreu V, Picó Y. 2014. Occurrence of acidic pharmaceuticals and personal care products in Turia River Basin: from waste to drinking water. Sci Total Environ. 484: 53-63.

Cerda A, Artola A, Font X, Barrena R, Gea T, Sánchez A. 2018. Composting of food wastes: Status and challenges. Bioresource Technology, 248: 57-67.

Comesaña IV, Alves D, Mato S, Romero XM, Varela B. 2017. Decentralized Composting of Organic Waste in a European Rural Region: A Case Study in Allariz (Galicia, Spain). DOI: 10.5772/intechopen.69555.

Di Lonardo MC, Lombardi F, Gavasci R. 2012. Characterization of MBT plants input and outputs: a review. Reviews in Environmental Science and Bio/Technology. 11: 353–363.

Donnachie RL, Johnson AC, Sumpter JP. 2016. A rational approach to selecting and ranking some pharmaceuticals of concern for the aquatic environment and their relative importance compared with other chemicals. Environ Toxicol Chem., 35:1021-1027.

Donovan SM, Bateson T, Gronow JR, Voulvoulis N. 2010. Characterization of compost-like outputs from mechanical biological treatment of municipal solid waste. J Air Waste Manag. Assoc., 60: 694-701.

Echavarri-Bravo V, Thygesen HH, Aspray TJ. 2017. Variability in physical contamination assessment of source segregated biodegradable municipal waste derived composts. Waste Manag. 59: 30-36.

El-Nagerabi SAF, Elshafie AE, AlRawahi HS. 2012. Physico-chemical and microbial quality of locally composted and imported green waste composts in Oman. American Journal of Plant Sciences, 2: 660-668.

Environment Agency. 2009. A review of human health and environmental risks associated with the land application of mechanical-biological treatment outputs. Science report: SC030144/SR2. Environment Agency, Bristol, UK.

Environment Agency. 2010. Assessment of MBT input and output quality. Report: SC030144/R4. Environment Agency, Bristol, UK.

European Compost Network. 2010. Sustainable compost application in agriculture. ECN INFO PAPER 02/2010. European Compost Network. ECN e.v. pp38.

European Compost Network. 2018. Specification for the use of compost as a growing media. European Quality Assurance Scheme, Part D. European Compost Network. ECN e.v. pp16.

Favoino E. 2003. Source segregation of biowaste in Italy. ECN/ORBIT e.V. Source Separation Workshop 2003, Pres. No. 07. Pp12.

Fernández-Delgado Juárez M, Prähauser B, Walter A, Insam H, Franke-Whittle IH. 2015. Co-composting of biowaste and wood ash, influence on a microbially driven-process. Waste Manag., 46: 155-164.

Fricke K, Heußner C, Hüttner A, Turk T. 2017. Recycling of Biowaste: Experience with Collection, Digestion, and Quality in Germany. In: Maletz R, Dornack C, Ziyang L. (eds) Source Separation and Recycling. The Handbook of Environmental Chemistry, vol 63. Springer, Cham.

Irish Environmental Protection Agency. 2009. Development of an Industry-Led Quality Standard for Source-Separated Biodegradable Material Derived Compost (2006-WRM-DS-26 Strive Report). Prepared for the Environmental Protection Agency by Cré – Composting Association of Ireland Teo.

JRC (Joint Research Centre). 2012. Occurrence and levels of selected compounds in European Sewage Sludge Samples: Results of a Pan-European Screening Exercise (FATE SEES). Report EUR 25598 EN. JRC, Ispra, Italy.

JRC (Joint Research Centre). 2014. End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals. Report EUR 26425 EN. JRC, Ispra, Italy.

Kadir AA, Ismail SNM, Jamaludin SN. 2017. Study on composition and generation of food waste in Makanan Ringan Mas Industry. IOP Conf. Ser.: Mater. Sci. Eng., 136: 012057.

Kawai K, Huong LT. 2017. Key parameters for behaviour related to source separation of household organic waste: A case study in Hanoi, Vietnam. Waste Manag Res., 35: 246-252.

Kawata K, Asada T, Oikawa K. 2005. Determination of pesticides in compost by pressurized liquid extraction and gas chromatography-mass spectrometry. J Chromatogr A., 1090: 10-15.

Krogmann U. 1999. Effects of season and population density on source-separated waste composts. Waste Management and Research, 17: 109-123.

Kupper T, Bürge D, Bachmann HJ, Güsewell S, Mayer J. 2014. Heavy metals in source-separated compost and digestates. Waste Manag., 34: 867-874.

Longhurst PJ, Tompkins D, Pollard SJT, Hough RL, Chambers B, Gale P, Tyrrel S, Villa R, Taylor M, Wu S, Sakrabani R, Litterick A, Snary E, Leinster P, Sweet N. 2019. Risk assessments for quality-assured, source-segregated composts and anaerobic digestates for a circular bioeconomy in the UK. Environment International, 127: 253-266.

NSW EPA (Environment Protection Authority). 2018. Alternative Waste Treatment - Mixed Waste Derived Organics Technical Advisory Committee report to the NSW Environment Protection Authority. Report – April 2018 (24 May 2018 (final report)). https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/recycling/mixed-waste-technical-committee-report.pdf

Oviedo-Ocaña ER, Torres-Lozada P, Marmolejo-Rebellon LF, Hoyos LV, Gonzales S, Barrena R, Komilis D;Sanchez A. 2015. Stability and maturity of biowaste composts derived by small municipalities: Correlation among physical, chemical and biological indices. Waste Manag. 44: 63-71.

Paradelo R, Villada A, vesa-Rey R, Moldes AB, Domínguez M, Patiño J, Barral MT. 2011. Distribution and availability of trace elements in municipal solid waste composts. J. Environ. Monit., 13: 201-211.

Rigby H, Dowding A, Fernandes A, Humphries D, Petch RG, Reynolds CK, Rose M, Smith SR. 2015. Organic contaminant content and physico-chemical characteristics of waste materials recycled in agriculture. Agriculture, 5: 1289 – 1328.

Rupani PF, Maleki Delarestaghi R, Asadi H, Rezania S, Park J, Abbaspour M, Shao W. 2019. Current scenario of the Tehran municipal solid waste handling rules towards green technology. Int J Environ Res Public Health. 19:16.

Scottish Environmental Protection Agency. 2014. Assessment of risks to soil quality and human health from organic contaminants in materials commonly spread on land in Scotland. Available online at https://www.sepa.org.uk/media/138585/ep1302-sepa-organic-chemicals-nc.pdf

Scottish Environmental Protection Agency. 2019. The assessment of organic contaminants in materials spread on land. Available online at https://www.sepa.org.uk/media/413269/organic_contaminants_materials_to_land.pdf

Som MP, Lemée L, Amblès A. 2009. Stability and maturity of a green waste and biowaste compost assessed on the basis of a molecular study using spectroscopy, thermal analysis, thermodesorption and thermochemolysis. Bioresour. Technol., 100: 4404-4416.

Višniauskė I, Barčauskaitė K, Bakšienė E, Mažeika R. 2018. Evaluation of contamination levels of different types of composts and their suitability for usage in agriculture. Zemdirbyste-Agriculture, 105: 211-220.

Wågman N, Strandberg B, van Bavel B, Bergqvist PA, Öberg L, Rappe C. 2018. Organochlorine pesticides and polychlorinated biphenyls in household composts and earthworms (*Eisenia foetida*). Environ Toxicology and Chemistry, 18: 1157-1163.

Waste & Resources Action Programme (WRAP). 2011. Compost and anaerobic digestate quality for Welsh agriculture. Project code: OAV032-004. Banbury, UK. Pp135.

Wei Y, Li J, Shi D, Liu G, Zhao Y, Shimaoka T. 2017. Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. Resources, Conservation and Recycling 122: 51–65.

Whittle AJ, Dyson AJ. 2002. The fate of heavy metals in green waste composting. Environmentalist, 22: 13–21.

Zhang H, Luo Y, Wu L, Huang Y, Christie P. 2014. Residues and potential ecological risks of veterinary antibiotics in manures and composts associated with protected vegetable farming. Environmental Science and Pollution Research International, 8: 5908-18.