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Exploratory research on the adoption of composting for the management of biowaste in the Mediterranean island of Cyprus

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ABSTRACT

Biowaste management is one of the biggest challenges for the European and Commonwealth small state of Cyprus, a Mediterranean island situated in the southeast corner of Europe. On the one hand, it is widely acknowledged that biowaste treatment processes such as composting should be adopted to divert biowaste from landfills, protect the environment, safeguard human health and well-being, and comply with the European environmental policies and legislation; on the other hand, national and local government efforts that promote its implementation appear to be lethargic preventing the move towards a sustainable bioeconomy. Using the political, economic, social, technological, environmental and legal (PESTEL) approach, the study conceptually explores the underlying motives and multitude of reasons that may preclude the adoption of composting for biowaste management. Findings suggest that the lack of a biowaste management infrastructure investment strategy plan has derailed progress on biowaste management, despite the national government's rhetoric to promote sustainable development. Moreover, the lack of waste planning at the local level, public awareness on the consequences of biowaste mismanagement, and the lack of market demand for the compost produced are additional barriers to the adoption of composting. This emphasizes the urgent need for collaboration between the national and local governments to promote the development of a functional, sustainable biowaste management strategy. The study informs on the need of policy and decision-makers to prioritise the development of biowaste management strategy that would be broadly implemented could not only help Cyprus reduce its reliance on landfills and comply with the European legislation, but create environmental, economic and social value via the recovery of resources from biowaste and a sense of responsibility to its public. This is key to supporting the transition towards a circular bioeconomy.

Introduction

Cyprus is one of the top five producers of municipal solid waste (MSW) among the European member states contributing with a staggering per capita generation rate of 0.64 t MSW per year, which is well above the average European rate (i.e. around 0.5 t/capita/year). The Cyprus Statistical Service (2021) reported that in 2019 around 70% of MSW was landfilled, while around 19% of MSW was recycled and 5% was composted (Department of Environment 2021; Eurostat 2018). According to the European Environment Agency (2019), this landfilling rate is 40% higher than the European Union (EU) average landfill rate of 28%, whereas the recycling and composting rates are well below the EU average (i.e., 38% for recycling and composting combined).

The negative environmental impacts caused by the landfilling of MSW, such as greenhouse gas emissions, air pollution, leachate generation, and risk of fires, are well documented in the global literature (Kirkeby et al., 2007; Palmiotto et al., 2014; Di Maria and Mical, 2014; Tsangas et al., 2020). In addition to environmental impacts, social impacts are arising from waste landfilling, including public health and safety risks due to disease spread via pests and animal scavengers that feed on landfilled waste, and water and soil pollution caused by leachate - a toxic cocktail composed of both organic and inorganic compounds - mismanagement, malodours and visual pollution, as well as safety risks for landfill employees, all of which can be quite significant (Arena et al., 2016). These social impacts are often linked to direct financial implications due to increases in health-care costs, land clean-ups and landfill restoration, while the Cyprus government has paid thousands of euros in fines (actual number not provided) due to its non-compliance to the European Union (EU) waste management legislation.

The EU waste management legislation stipulates that member states should develop an effective solid waste management strategy that can protect the natural environment and public health, whilst promoting

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the circularity of resources for as long as it is environmentally, technically, socially and economically feasible and viable (Iacovidou and Hahladakis, 2019). Specifically, the EU Landfill Directive (1999/31/EC) mandated member states to divert biodegradable municipal waste (BMW) disposed of to landfill and set up specific targets to enable the transition; giving member states five years to reduce BMW disposed to landfill to 75%, eight years to reduce BMW to 50% and 15 years to reduce BMW to 35% of the total amount (by weight) of BMW produced in 1995 (Council of the European Union, 1999). Biodegradable waste as in Article 2 of the Landfill Directive is "*any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard*" (Council of the European Union, 1999). States heavily reliant on landfills, such as Cyprus, received an additional 5-year window to meet the targets; meaning that BMW had to be reduced to 35% of the 1995 disposal level by 2020 (Council of the European Union, 1999).

To further tackle the use of landfills as a means of waste management and promote resource efficiency the EU introduced the Waste Framework Directive (2006/12/EC) to define waste and provide a framework for its proper management (Council of the European Union, 2006). In 2008, the revised Waste Framework Directive (2008/98/EC) mandated member states to take measures to encourage the efficient management of their wastes. It proposed a waste management hierarchy (WH) (Article 4) with which member states can develop strategies and measures to prevent the generation of waste and reduce its negative impacts on the environment and human health (Directive 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste and repealing certain directives. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098/98/EC of the European Parliament and the Council). The WH suggests that where possible, waste materials should be reused, recycled or recovered, or used as a source of energy, and only be disposed of safely when there is no other option available for their management.

In the WFD (2008/98/EC) (European Commission 2008), there was a specific provision for the separate collection and management of bio-waste in a way that fulfils a high level of environmental protection. Biowaste in the WFD is defined as *"biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants"* (WFD, 2008/98/EC). Composting and anaerobic digestion (AD) were proposed as highly efficient processes for the management of bio-waste. Both composting and AD are biological treatment processes that can convert organic materials into a nutrient-rich end-product, biogas, and other high added value bio-based products (e.g., phenolic compounds, lignin, cellulose, hemicellulose, etc.) via the activity of microorganisms. Ten years later, in 2018, the revised Waste Framework Directive (2018/851) (rWFD), (European Parliament and of the Council 2018) reinforced those requirements, by setting a target for member states to ensure that by 31 December 2023, biowaste is either recycled at source (via home composting) or is collected separately for treatment via composting and anaerobic digestion (European Parliament and of the Council, Directive 2018/851, 2018). In the rWFD, the term biowaste was replaced with *"biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plant"* to offer further clarity. Composting and AD are increasingly promoted in supporting the implementation of the so-called circular bioeconomy, and yet, their uptake and implementation in Cyprus is stalled.

Circular bioeconomy is a concept that aims to promote the increased use of bio-based resources and the recovery of bio-based products emphasizing the transition to a renewable, bio-based economy, where an industry by-product becomes another industry's input (D'Adamo et al., 2020; Morone et al., 2019; D'Amato et al., 2017). The circular bioeconomy is gaining increased attention in the European policy arena as a way to support and promote the transformation of biowaste into high-value bio-based products that can re-enter the economy and replace non-renewable resources, whilst achieving the 2030 Agenda and its Sustainable Development Goals (D'Adamo et al., 2020). Moreover, a circular bioeconomy represents an opportunity to create new bio clusters, boost productivity, promote competition and, in turn, spur innovation, that can promote regional sustainable development whilst exploring and exploiting locally available natural resources and waste (D'Adamo et al., 2019).

Biowaste makes up around 40% of the MSW generated in Cyprus (Zorpas et al., 2015a; Zorpas et al., 2018). In the Mediterranean islands, this is expected due to an intensive agricultural sector, a booming tourism industry (Violaris and de Heide, 2007), and a household food consumption that *"represents the second-highest share of the Ecological Footprint after transportation"* with Ecological Footprint defined as "the resource provisioning and the regulatory services demanded to provide households with the food they consume" (Galli et al., 2017). A reduction in household food consumption and wastage, and consideration of its proper management via composting and/or AD, represent an important opportunity to recover value in the form of bio-based products; hence, promoting the transition to a circular bioeconomy. It can also divert biowaste from landfills and reduce environmental degradation (Zorpas et al., 2014, 2015b; Lasaridi et al., 2015; Abylkhani et al., 2020; Girón-Rojas et al., 2020), whilst changing consumer food purchasing behaviour, and instigating a preference to bio-based products (e.g., compost and other secondary commodities). In turn, this can generate economic opportunities in the agriculture and landscaping industry that represents 4.4% of gross domestic product (GDP) in Cyprus, whilst it can benefit communities via environmental improvements. Moreovertransition, a transition to a circular bioeconomy couldlower the risk of non-compliance with the European legislation, the Paris Agreement and the targets set by the European Green Deal (COM (2019) 640) for achieving climate neutrality by 2050, creating confidence and trust over authorities (UNFCCC, 2015; European Commission, 2020).

The use of AD can be capital and labour intensive, but has the potential to deliver a return on investment through the biogas and digestate production. However, a market for the digestate and biogas by-products is a prerequisite for unlocking return on investment. At present, there is a lack of suitable markets for biogas and digestate in Cyprus, as well as the required skill set to successfully operate AD plants, which essentially rule out investments in AD. Composting may have its own challenges, but is considered to be a mature, simpler technology to operate, and the lower investment costs compared to AD make it an attractive option in the Cyprus context. According to Loan et al. (2019), the simultaneous adoption of home composting can offer additional benefits, but like centralised composting it has gained very little attention and even less traction as a biowaste management option (Zorpas et al., 2000; Edgerton et al., 2009; Zorpas and Loizidou, 2008).

Composting is a simple and viable way to support the transition to a circular bioeconomy (Morone et al., 2021), and therefore, exploring the factors that currently impede its uptake in Cyprus is of paramount importance. This perspective article aims to unpack the multitude of barriers that prevent the management of biowaste via centralised and decentralised (home) composting processes. To achieve that, it initially provides an overview of the current situation related to biowaste management focusing on political, organizational, economic, social-technical and environmental impacts. Then, it highlights missed opportunities and changes needed to support the development of a viable biowaste management system. The article concludes with recommendations for future actions that should be prioritised for promoting circularity in the waste management sector in Cyprus.

Material and methods

The Political, Economic, Social, Technological, Environmental and Legal (PESTEL) approach is adopted in this study to analyse the external macro-environment to identify and understand the conditions that are likely to influence the adoption and implementation of composting

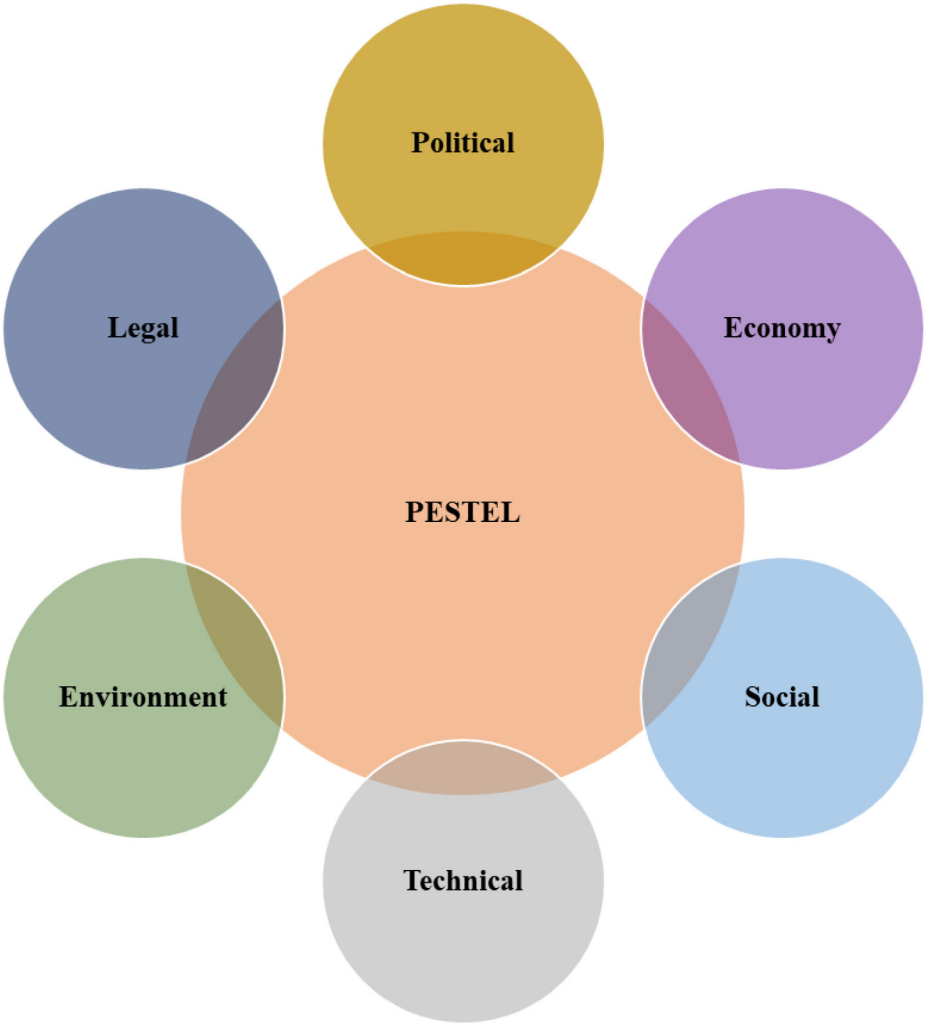

Fig. 1. A depiction of the six domains involved in a PESTEL analysis.

processes in Cyprus. This approach integrates environmental, economic and societal aspects associated with composting, with evidence on infrastructure and technological innovations, and the current and impending legislation and political decisions that affect the waste management industry.

PESTEL has gained increased traction as an assessment tool in the environmental sciences field in supporting decision-making processes (Iacovidou et al., 2017; Symeonides et al., 2019; Tsangas et al., 2019). It has been used to identify metrics for the life cycle sustainability (Daddi et al., 2019) assessment of food waste management options (Iacovidou et al., 2017), to assess the implementation of biofuel and energy management systems (Achinas et al., 2019), to identify risks in construction projects (Kremer and Symmons, 2015), and in the development of waste management infrastructure (Song et al., 2017), to mention a few. It is, however, a conceptual tool, and therefore restricted to the identification and theoretical evaluation of contextual opportunities and barriers that should be subject to more detailed analysis (Iacovidou et al., 2017). It has been successfully applied to conceptually explore renewable energy parks, tire waste management systems, natural resources exploitation, and organic waste management (Zorpas 2020; Srdjevic et al., 2012; Iacovidou et al., 2017).

Fig. 1, presents the PESTEL framework.

For the PESTEL analysis, we carried out a narrative literature review, using appropriate search terms to identify relevant documents that provide an understanding of the main political, economic, social technological, environmental and legal parameters. This is an important step in the conceptualisation of the opportunities and impacts for each of the six PESTEL domains. Due to the lack of data in the Cypriot context we employed a qualitative method for extracting information and supplementing our analysis. We sought to explore the experiences and perceptions of influential stakeholders on the implementation of biowaste management in the Cypriot context, and the importance of this in creating national strategic impact.

We identified the principal and potentially most influential stakeholders in the development and implementation of a biowaste management strategy, based on the following criteria: (i) must be involved in the formulation and development of waste management strategies, i.e., the Ministry of Environment, and the Office of the Commissioner of the Environment; (ii) must be responsible for the implementation of strategies, i.e., local authorities/municipalities; and iii) must be involved in the promotion and decision-making support, i.e. academic institutions and environmental consultancies. We communicated with them directly to gather both objective (data) and subjective information on the use of composting process, their personal experiences and perceptions, and help to unfold particular areas of interest with the right amount of detail.

Results and discussions

To provide some context we found that at present there are only two mechanical-biological treatment (MBT) plants operating in the island for the management of MSW; one in Pentakomo serving the Limassol District, and another in Koshi, serving the Larnaca and Famagusta Districts, which are both under the control of the government. MBT is composed of a mechanical part – for the separation of recyclable waste materials -

and a biological part – for the stabilization and treatment of the biowaste fraction of MSW, and is often been employed as an alternative to landfill (Ng et al., 2021). According to its configuration, MBT can generate several by-products including a compost-like output (CLO), biogas and digestate (depending on the biological treatment method used), recyclable waste materials, and refuse-derived fuel (RDF) / solid recovered fuel (SRF).

According to Chatzipanayiotou (2019), the composting processes incorporated in the MBT plants at Koshi and Pentakomo can treat organic waste (mainly green waste, wooden waste free of chemicals, vegetables and fruits) with a capacity of up to 30,000 t/year. The RDF/SRF produced at the Pentakomo facility is sent to a cement manufacturing industry to replace fossil fuel and reduce its carbon footprint (Chatziaras et al., 2016). There is limited insight on the fate of RDF/SRF produced at the Koshi facility.

Political considerations

Political discussions on waste management in Cyprus are influenced by the EU legislation(s), and the Cypriot government pledged to develop a strategy for promoting sustainable development and leaving the island in a better condition for the next generation. The forefront role of this pledge is the need of moving towards a circular economy to retain materials, components, and products in use for as long as possible while reducing waste Loizia et al., 2018; Zorpas, 2020; Loizia et al., 2021a; Voukali et al., 2021; EllenMacArthurFoundation 2022). Echoing these targets, the Department of Environment developed the 2015–2021 Waste Management Plan for promoting the proper management of MSW. However, the actual implementation of the plan has stalled due to cross-sectoral influences dominated by investments in natural gas exploration in the Cyprus Exclusive Economic Zone (EEZ), and the lack of investment in private and State waste management infrastructure (Department of Environment, 2021).

Whilst the government has developed financing mechanisms for research and development (R&D) activities, such as the Research Promotion Foundation (RPF) established in 1996, renamed to Research and Innovation Foundation in 2018, that supports with millions of euros, financial mechanisms for the actual implementation of sustainable waste management are inexistent. Planning activities, such as identifying the needs of each area in terms of managing biowaste, selecting a biowaste management technology (and its capacity) that would perform efficiently in the medium and long-term, considering the appropriateness of the site where installation would take place (following an environmental impact assessment), considering also, the proximity of the facilities installed and the need for introducing suitable collection schemes and regimes, are essential of any waste strategy development. Moreover, the development of the national waste strategy should be aligned with the Waste Hierarchy and must include considerations around sorting of waste at source, waste prevention, recycling, and energy from waste (EfW) (Zorpas, 2020; Zorpas et al., 2017b; Loizia et al., 2021; Voukkali et al., 2021; Cucchiell et al., 2017); at present these are not well developed, nor implemented in the island. According to Zorpas et al. (2018), the lack of a waste management plan can be an important driver to failure. The Cypriot government delegates the task of waste management to Local Authorities (LAs), which are often ignorant of the legal framework and the duties imposed on them, and/or cannot implement strategies and measures that promote sustainable management of waste. The inability of the national government to actively engage and support LAs in monitoring and controlling the waste management services they deliver, and ways by which these align to the national waste management plan creates systemic failures in the sustainable management of waste, as it allows LAs to deviate for delivering the services needed to meet the national targets. This points also to inefficiencies in tracking information on the actual flows of (bio)waste generated, collected and managed, which in turn prevents coordination of efforts in delivering circular bioeconomy at the local level.

Additionally, the government appears to prioritise the adoption of practices with the lowest cost, which often results in failures in the proper management of waste. A recent example is the operation of the Pentakomo MBT plant. Whilst this MBT facility was built to divert a substantial amount of MSW from landfills, and produce an SRF that would be taken up as fuel by a nearby cement manufacturing plant, it allegedly failed to meet the required technical standards set by the EU (SRF is standardised by CEN/TC 343). As a result, the cement manufacturing plant refused to take the RDF, and anecdotal evidence suggests that this has resulted in the burying of the plant's output in a nearby basin that was set up as a temporary management option. With these political decisions taking precedence, the potential to achieve a circular bioeconomy will fade away.

3.2. Economic considerations

In Cyprus, LAs are not financially independent as they receive their funding from the central government. Nonetheless, according to Section 84Z, of the National Law N(I)111/1985, LAs have the right to charge households within their vicinities for the waste collection services they offer. Usually, the charge is as follows: (i) per households (irrespective of m^2) maximum €171/y; (ii) for any kind of stores as well as, coffee shops and other similar activities they can charge up to €855/y; (iii) for any kind of restaurants as well as nominated tourist apartments up to €6848/y; (iv) regarding the hospitality industry and especially for each Hotel, they can charge maximum €17,100/y and (v) for any manufacturing, clinics or other similar activities a maximum amount of €13,680/y. While these cost revenues could justify investment in separate biowaste collection that could in turn spur innovation in the waste management infrastructure, at present there is no evidence of where these revenues are being allocated; highlighting the lack of transparency in the way LAs operate.

Investments in waste management infrastructure are perceived as a big financial risk for the government and waste management companies, because of the absence of separate collection schemes. Some LAs have claimed that the cost of establishing a separate collection scheme for biowaste collection is an important barrier to introducing this service. Some officials suggest that it is the lack of a good organisational structure that prevents the development of a well-functioning biowaste management system, including investments in the composting infrastructure, biowaste collection bins and liners, and use of appropriate tracks for its collection and transfer to composting facilities.

The lack of confidence in the production of good quality compost and its market uptake appears to be another barrier. Even though, Cyprus has a strong horticulture sector, that could benefit from the compost produced, the widespread misperception over the quality of the compost that would be potentially produced via composting severely impact the take-up of the composting process. The quality of compost depends on the composting technology employed (including pre-treatment steps), and therefore, with the adoption of the appropriate technology (see details on the *technological* domain) the compost quality can be improved, but this will dictate its price (i.e. the more expensive the technology is, the higher the compost price) (Rouse et al., 2008). Price is important in influencing compost demand; the willingness of end-users to initially pay a price that covers its production costs is of paramount importance.

At present, the farmers' ignorance of the environmental and social advantages of using compost instead of artificial fertilisers, and the fact that artificial fertilisers and manures are currently available in the market at a much lower price are stalling the shift of preference to bio-based alternatives. In addition, LAs have used that as an excuse for their growing reluctance to invest in separate biowaste collection and management, also because they are unable to return a profit via the sale of compost. Nonetheless, it must be noted, that awareness of the sustainability benefits offered by the use of compost compared to its cheaper counterparts (i.e. artificial fertilisers), will not necessarily increase the market uptake of compost. As Morone et al. (2021) suggest multiple

factors can influence consumer purchasing behaviour and attitude towards bio-based products such as compost. It is worth mentioning, that even if the intention to purchase compost exists, the lack of standards for the certification of the compost quality, could diminish the chance of increasing its uptake (Morone et al., 2021).

In the case of decentralised (home) composting the relevant cost of the composted bins varies from 30 to 100 € based on its volume (i.e., litres (l) capacity). The successful implementation of this scheme requires personal effort by the householders that includes the preparation of the compost bin and biowaste, careful monitoring of the composting process, and continuous motivation by the LAs. It is estimated that per batch of a 250–350 l compost bin, approximately 200 l of good quality compost can be produced, in a four or 5-month period. Usually, people who are engaged in this process use the compost in their back yards. Any excess is disposed of, to nearby fields, or is given to neighbours. It is very rare for householders to sell their compost, as it cannot fetch a price in the Cypriot market.

3.3. Social considerations

Social considerations related to the implementation of both centralised and decentralised (home) compositing is extremely complex, due to cultural trends and norms, lifestyle, income, diet, social mobility, habits, beliefs, educational level, and access to waste infrastructure (Agapiou et al., 2020; Loizia et al., 2021a; Voukkali et al., 2021). In some LAs fly-tipping of biowaste has been reported, as well as the fact that a large proportion of people find this practice acceptable. Ignorance of the negative impacts caused to the natural environment by the degrading piles of biowaste people throw away (i.e. fly-tipping), indicates that this practice will persevere unless LAs intervene and begin educating people against it.

For centralised composting to succeed, citizen *acceptance* and *participation* in the biowaste separate collection scheme are key prerequisites. Recent studies suggest that the acceptance and participation to separate disposal and collection of biowaste can be extremely challenging to achieve in the Cypriot context, due to a combination of the public's misperception about the separate collection of any waste, and the lack of engagement and communication by the local authorities (Zorpas et al., 2017a; Loizia et al., 2021a; Voukkali et al., 2021). This is in line with Price (2001) and Purcell and Magette (2010), who suggest that the lack of knowledge and awareness can negatively impact the successful implementation of a waste management option (Price, 2001; Purcell and Magette, 2010).

A programme initiated by the Office of the Commissioner of the Environment in Cyprus in 2015 that aimed to explore the uptake of home composting delivered important insights that show that awareness-raising can often result in inaction. The programme involved 200 participants separated into two groups of 100 participants each, and each group agreed to home compost their biowaste for 10 weeks. Participants in group A were provided with continuous information and were monitored and controlled once a week, whereas participants in group B were informed only once at the beginning of the trial. After 10 weeks, 75% of the participants in group A, were successfully home composting their biowaste, contributing to a reduction of 27% biowaste disposed of to landfills. Group B, underperformed with only 7% of the participants participating in the home composting programme. This pilot study, strongly indicated that without continuous stimulation and awareness, the participation rate may decline significantly, which is in line with the findings of Fletcher et al., (2003).

Recognising the importance of breaking down the knowledge barriers and diffusing the misperceptions with regards to biowaste management, and composting in particular, the Office of the Commissioner of the Environment in Cyprus developed a communication strategy and engagement programme on promoting composting. From 2015, until the 1st quarter of 2020, before the break out of the Covid-19 pandemic that brought a halt to the programme, they organised 263 visits in schools (e.g. nursery, primary and secondary schools) reaching out to a total number of 30,123 children, and 3939 teachers, a breakdown is presented in Table 1.

Using visual aids and demonstration kits involving the use of composting bins provided by the Office of the Commissioner of the Environment, scientists involved in the programme showed children and their teachers how to compost. The scientists also organised lectures and created several podcasts to reach out and engage other stakeholders such as public officers representing LAs (Lozia et al., 2021b). The educational campaign delivered some results, with home composting being adopted by >5% of the programme participants outlined in Table 1. In addition, what came out of this campaign, which strengthens also the results of the 2015 composting trial programme, is that monitoring and continuous support is important in building up confidence in home composting.

3.4. Technological considerations

Cyprus is a renowned summer destination, and from April to October every year, large fluxes of tourists visit the island (contributing to 76.5% to Cyprus GDP). As a result, during these months the island faces a great challenge in respect to biowaste management, as it experiences an increase in the amount and type of biowaste generated compared to the rest of the months of the year. Even though, there is a lack of waste audits that can provide evidence on the variations in the types and volumes of waste generated in Cyprus all-year-round, studies in other regions with high tourism suggest that biowaste generated by tourism far exceeded the amount generated by the local population in the off-tourism season (Ranieri et al., 2014; Obersteiner et al., 2021). For example, Ranieri et al. (2014) showed a peak in biowaste generation during the touristic period, and that the largest fraction of biowaste resulting from tourism is food waste, emphasising the urgent need to introduce a sustainable biowaste management system to support efforts to promote resource efficiency and reduce the carbon footprint of tourism (Obersteiner et al., 2021). Following personal communication with officials, this variation is also observed in the tourist regions in Cyprus during the high season. This presents a key technical challenge that must be included in the decision on which type of composting technology should be adopted to justify the capital and operational costs; this has reportedly (personal communication) led to the selection of an MBT facility, also due to the lack of separate biowaste collection infrastructure.

At present, the MBT plants at Pentakomo and Koshi that receive biowaste as part of the MSW, are facing several technical issues as they are unable to operate up to the required standards. The facilities, which are part-funded by the EU and are under a contract between a private company/operator and the Cypriot government, have not been built up to the right specifications; hence, failing to perform well. The quality of the compost-like output (CLO) produced is of questionable quality and there is a lack of evidence on its end-of-life fate. This raised concerns not only for the poor operational performance of the MBT facilities, and of composting in particular, but also, and most importantly, for the loss of value and the environmental, economic and social implications accrued by these inefficiencies.

It is worth noting that there are several well-established composting techniques available in the market, such as open windrow composting, aerated static pile composting, in-vessel composting (IVC) and vermicomposting (VC); the latter is less practised (Hussein et al., 2021). Open windrow and aerated static pile composting can be relatively flexible processes for the management of biowaste containing large amounts of food waste from the hospitality sector, offering space for fluctuations in the amount of biowaste received. However, both techniques require continuous monitoring of the piles' conditions (e.g. humidity, temperature, carbon to nitrogen ratio) and frequent aeration to improve porosity, reduce malodours and retain oxygen levels in the piles to ensure good degradation performance, especially at high ambient temperatures. The main difference between the two techniques is on the aeration process; the aerated static pile is aerated via a pipe that blows air into the pile,

Table 1
Number of students and teachers that participated in the public awareness activities carried out at different educational levels.

Year	Nursery	Primary school	Secondary school	No. Students	No. Teachers	Others	No. Participants
2015–17	36	120	15	17,322	2561	6	180
2018	11	38	2	7299	765	2	96
2019	1	16		2295	255	2	65
2020	2	10	4	2160	237	2	82
2021	1	5	2	1047	121	–	–

whereas in an open windrow the piles are turned. The transformation of biowaste to compost takes numerous weeks (i.e. 12–20 weeks for open windrow composting; 10–13 weeks for aerated static pile composting). IVC can only take a few weeks to complete, and, thus, is faster than open windrow and aerated static pile composting processes. The process occurs in an enclosed environment (hence, in-vessel), where the oxygen, temperature, and moisture are carefully controlled and monitored to ensure efficient composting performance. This technique is particularly beneficial in warm climate countries such as Cyprus as it can prevent malodours, drying piles, and pest attraction, but requires skilled workers to operate the technology, while it's expensive to install. Nonetheless, the IVC can properly handle all biowaste (incl. cooked and uncooked food from different establishments) and ensure good compost quality. It requires limited space and can prevent negative impacts (pest and vermin attraction, malodours, leakages). Further research is required to determine the most suitable composting technique, by weighting environmental, economic, social and technical aspects based on the volume and composition of biowaste, climatic conditions, and variations thereof, and so on, using area-specific characteristics.

Key considerations with regards to the implementation of centralised composting facilities in Cyprus include the land space requirements, and associated land-use change, the procurement of machinery and other equipment, as well as the employment of a skilled workforce to ensure their day-to-day operation. It is worth noting, that all composting techniques will require some pre-treatment to remove impurities, such as plastic bags and containers, metals, and other residues, and to reduce the size of biowaste to ensure a homogenous mixture and an optimal substrate surface area for achieving high microorganism activity. Moreover, all composting techniques require skilled workers that are trained to monitor and control the composting process parameters, as these may change depending on the climatic conditions, and can quickly adopt the right measures to circumvent any failures. This will ensure optimal composting performance, and the production of a quality compost compliant with the specifications set for use in agricultural land Bernal et al., 2009; Lasaridi et al., 2014; Zorpas, 2008, 2012a, 2012b, 2016).

For decentralised (home) composting an important consideration is space to set up the compost bin. Most of the population in Cyprus leaves in private households, and therefore space is not much of an issue. The main barrier in the uptake of home composting is the lack of know-how. Biowaste needs to be properly sorted at home, to eliminate contamination by other materials (e.g. plastics, small metals, and some types of paper), and closely monitor the moisture and heat content to ensure and maintain stable composting conditions and performance (Chanakya et al., 2007; Girón-Rojas et al., 2020). This is key to preventing the production of leachate and low molecular organic acids. When biowaste is excessively wet it may require the addition of dry wastes (e.g., sawdust, leaves, straws) to reduce the moisture, and it may also need the aeration of waste, which can be relatively unpleasant, especially during the warm months. This procedure may create resistance by the householders and impact their participation in the composting process.

3.5. Environmental considerations

The failure of MBT facilities at Koshi and Pentakomo point to the worrisome fact that there are multiple environmental externalities created as a result of underperformance. These facilities not only divert a limited amount of biowaste from landfills (less than 35%), but in doing so they generate a CLO that is of inferior quality that cannot be used and is most likely buried with uncertain environmental impacts. It is worth noting that currently there are no environmental benefits accrued from biowaste management in Cyprus, and all available information points to the fact that there is an urgent need to fully assess the environmental impacts and generate a plan of action.

While centralised composting facilities may be associated with carbon dioxide emissions as a result of aerobic decomposition, these emissions are considered to be of biogenic origin and thus, not currently considered to contribute to the global warming potential (IPCC, 2006). By diverting biowaste from landfills composting not only reduces carbon emissions and volatile organic compounds (Nastev et al., 2001), it prevents the generation of leachate and the pollution of surrounding environmental compartments. The use of different composting techniques can result in some environmental externalities (malodours, pest and vermin attraction, etc.) all of which can be managed with the appropriate monitoring and control measures. It is worth noting, that important environmental benefits can be offered by the use of compost. Compost is rich in nutrients making it particularly attractive as a soil amendment for agriculture and horticulture (Doula et al., 2018, 2019, 2020; Pérez-Gimeno et al., 2019; Vlyssides et al., 1999); hence closing the biowaste loop and promoting circular bioeconomy. Furthermore, using compost instead of artificial chemical fertilizers can lower considerably the negative environmental impacts associated with artificial fertilisers production and use.

In the case of decentralised (home) composting environmental benefits span the reduction in the amount of biowaste collected (separately or commingled), transported (Tanaka 2007), and managed (Smith and Jasim, 2009), and use of compost for the garden and plant care, and for improving soil fertility (Andersen et al., 2012; Bargaoui et al., 2020; Barrena et al., 2014). However, according to Amlinger et al. (2008), home composting has its drawbacks, as gases such as nitrous oxide (N_2O), ammonia (NH_3) and methane (CH_4), may be released (especially when the process fails) impacting negatively the environment and human health. Also, meat, fish, fats, cooking and salad oils, may create problems with flies, rodent attraction and malodours that may, in turn, represent safety risks.

3.6. Legal considerations

Cyprus is a European member state and therefore, has the legal obligation to comply with the EU legislation and develop a strategy for sustainable waste management by the Sustainable Development Goals (SDGs) UNDP (2019), Circular Economy and European Green Deal targets. The Department of Environment must develop a Waste Management Plan to make sure they comply with the obligations arising from the European directives, including (a) 40% separate collection of total MSW by the year 2021, and 50% by 2027 (from 20% in 2012); (b) 50% of recyclable waste materials (e.g., paper, plastic, metal, glass) as part of MSW to be prepared for reuse by 2020; (c) 15% of biowaste to be collected separately by 2021; (e) meet the objectives of the European directives on packaging waste, electrical and electronic equipment waste generated from the residential sector and other sources that are simi-

lar in type to those of the domestic sector and waste from household batteries and accumulators (Department of Environment, 2021).

Despite the 2015–2021 Waste Management Plan development, the government failed to deliver the targets set in the European legislation. Relatively recently (in the year 2012) Cyprus has been referred to the Court of Justice of the EU (EU 2012) over its failure to ensure the protection of the environment (Directive 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste and repealing certain directives. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098/99/EC), and the operation of illegal landfills (Institute for European Environmental Policy, 2012). This had severe implications to the legal and financial stability of the nation, and penalties had to be paid (a daily penalty payment of € 5909 until the adoption of all the necessary national measures for a complete transposition); money that could have been spent to develop a sound waste management infrastructure. It is interesting to see that since then a recycling facility, an EfW plant, and two Mechanical Biological Treatment (MBT) facilities have been built to manage waste, but there was no investment in composting or AD. What's more, the specifications under which the MBT facilities have been built are not up to the right standards. This bears the question of whether Cyprus is meeting its legally binding targets.

Discussion

In Cyprus, biowaste management is almost inexistent raising the alarm in terms of non-compliance with the EU waste management regulations, putting at stake the state of the environment and the safety of public health. While the Cypriot government has developed a national (bio)waste management strategy to achieve the targets set by the EU, its implementation appears to be hindered by convoluted political, economic and social aspects. The absence of tenacity and financial support from the national to the local government, and the lack of a mechanism that monitors and controls policies implementation at the regional and local level, could be important underlying reasons for the failure of Cyprus in meeting the EU waste management targets and securing a better environment for its people.

The lack of waste audits and robust data on the amount of biowaste produced seem to exacerbate the problem as there is no insight into the amount and flows of biowaste generated and thus the magnitude of the biowaste mismanagement issue, which in turn leads to inaction. This inaction is also fuelled by the uncertainty and risk over the investment in biowaste management infrastructure, rendering the separate collection of biowaste and the installation of centralised composting facilities a potentially uneconomical venture. Notwithstanding, the public's ignorance on the deleterious impacts of biowaste mismanagement (via its fly-tipping and disposal to landfills) is used as an impetus to delay the adoption of a separate biowaste collection scheme. It is thus imperative that LAs raise awareness and educate the public on the importance of managing biowaste for recovering multi-dimensional value (i.e. environmental, economic, social and technical) (Iacovidou et al., 2017) from this waste stream rather than allowing it to give rise to negative environmental, economic and social impacts that would in the long-term create several negative externalities. This knowledge could empower public participation even before new measures, such as separate biowaste collection, are being implemented; safeguarding their efficiency.

Moreover, educational campaigns could be used as a means to collect the views and needs of communities, and design engagement strategies that avoid unnecessary concerns and negative attitudes towards separate collections. Offering people, the opportunity to express their views can be important in ensuring their participation. Whilst some form of decentralized (home) composting seems to occur, its uptake remains low because of the inconvenience caused, malodours and pest attraction and time needed to properly operate the composter. For considerable progress to be made towards the increased uptake of home composting in Cyprus, there should be at least at the beginning, a continuous engagement, communication and monitoring process (Zorpas et al., 2018).

All PESTEL domains revealed areas where interventions are needed (Table 2) to break the vicious cycle of inaction that is fuelling the current perverse political and organisational decision-making structures. The priority level assignment is based on the authors understanding of their relevance and impact of inaction on the resource recovery system in the Cypriot context. There are no low hanging fruits with regards to biowaste management on the island. Given the continuous and increasing downgrading of the environment due to the disposal of biowaste to landfills, there is a pressing need for change. Key interventions that can promote this transition include: (i) educational campaigns and awareness-raising activities on the integration of production, consumption and management systems and public participation and engagement in waste management activities (including segregation at source, home composting, monitoring diet, and purchasing decisions), (ii) investment in composting facilities, or other technologies should these be deemed more appropriate, and communicate the benefits of replacing artificial fertilisers with compost, (iii) stringent regulatory measures and policies that are monitored and properly enforced to ensure quality standards are met; (iv) financial and technical support of the local government in employing the right infrastructure and building community-based facilities to promote biowaste management locally, which could motivate citizens and enterprises to contribute.

Zorpas et al. (2014) and (2018) suggested that research projects that are co-created with the local and national Government in Cyprus, appear to infuse confidence in developing and implementing new waste management measures. For example, the Municipality of Limassol (Hadjioannou, 2019c) participates in the Autonomous Composting Units for Urban Areas (ACUA) program (Interreg V-A Greece Cyprus 2014–2020) to develop within the urban network a system for the collection of biowaste and their processing (partially or fully) in the same site, without triggering any nuisance. Additionally, the European Union LIFE+ programme LIFE10 ENV/GR/622 project "Development and Demonstration of a Waste Prevention Support Tool for Local Authorities – WASP Tool", which was co-funded by the Municipality of Paralimni (located in the Eastern region of Cyprus) had implemented a waste prevention strategy, targeting the reduction of food waste, green waste, plastics, as well as the establishment of a decentralised (home) composting strategy. Although these are important attempts, supported by the government, transformational change and transition to a biowaste management economy remain low.

Finally, it is worth noting that a sustainable biowaste management system is constructed based on a good understanding of its interlinkages with production and consumption systems; as productivity and efficiency across all stages of a system are needed to reduce environmental, economic, social and technical impacts and promote recovery of value. One key limitation of this study is that it focused on composting as the solution for biowaste management on the island, due to anecdotal evidence that other technologies are rejected due to their investment costs. Moreover, our analysis is based on scant data and information collected by the public databases and officials on the flows of biowaste and the conditions under which its management fails. This severe lack of transparency and the unwillingness of local governments to disclose information on waste planning activities, etc., is an important barrier to any attempt to promote change.

While we may have emphasized unpacking the reasons behind the lack of biowaste management infrastructure and composting in particular, it is important to also note that biowaste, and particularly food production and consumption stages need to be scrutinized in making sense of the needs of the island and developing the biowaste management investment infrastructure strategy. This entails an understanding of agricultural practices, purchase patterns, preparation and management of food in the household and hospitality sector, as well as storage, display and management of food in the retail sector. In regards to the latter, Marrucci et al. (2020) showed that a large fraction of waste gener-

Table 2
Key areas of intervention uncovered by the PESTEL analysis of composting uptake and implementation in Cyprus. The table indicates the priority level for the interventions propose using a traffic light system (RED: high, ORANGE: medium, GREEN: low).

DOMAIN	INTRVENTION	PRIORITY
Political	Pol 1	Development and implementation of a roadmap to achieving circular bioeconomy
	Pol 2	Enforcement of planning activities in accordance with EU legislation
	Pol 3	Development of fiscal instruments to promote sustainable waste management
	Pol 4	Control and monitoring of LAs compliance with the Roadmap of action
	Pol 5	Regulate LAs budgetary spent
Economic	Eco 1	Public and private investment in waste management infrastructure
	Eco 2	Development of a market outlet of compost - subsidising also composting facilities
	Eco 3	Financial support of households interested in participating in home composting
	Eco 4	Revenue creation mechanisms for LAs / waste management companies and their proper implementation
Social	Soc 1	Educational campaigns to help individuals and communities understand why and how to properly sort their waste at source
	Soc 2	Development of communication tools to support the better management of food at households, catering and hospitality sectors and prevent its wastage
	Soc 3	(Bio)waste management introduced to the education system
	Soc 5	Creation of new local jobs and skills training in composting infrastructure
Technical	Tech 1	Monitoring the performance of composting processes in MBT facilities
	Tech 2	Waste audits in all LAs to get a picture of the type of biowaste produced
	Tech 3	Quality assurance (QA)/ quality control (QC) schemes for compost
	Tech 4	Development of the necessary skill set to support composting operations
	Env 1	Relief of waste-driven stress of ecosystems/land due to landfills expansion, and temporary burying of waste
Environmental		
	Env 2	Promotion of the value recovery from biowaste and the return of nutrients back to the environment
	Env 3	Encouragement of the use of compost in agriculture and landscaping
	Env 4	Promotion of pro-environmental behaviour to help communities understand that this can have an impact on sustainable development
Legal	Leg 1	Regulatory relief measures
	Leg 2	Compliance with existing directives, regulations, decisions
	Leg 3	Close monitoring of the implementation of targets by the EU

ated by this sector is organic waste, and its proper segregation at source and management via composting can lead to considerable carbon emissions savings (‘000 of CO2-eq.) compared to landfilling (Bennici et al., 2018; Marrucci et al., 2020).

Therefore, policy and decision-makers must become aware of the missed opportunities of recovering value from biowaste. They must realise that on the one hand food production and landscaping consume a vast number of natural resources (land, water, chemicals), contributing to environmental pollution, and on the other hand, they augment these negative impacts by allowing the continuous mismanagement of the biowaste produced. This results in a severe negation of multi-dimensional value. Introducing mechanisms that monitor the amount of food and food waste produced, and developing a well-informed and sustainable waste management framework that caters to the need of each area and sector can aid the sustainable management of (bio)waste. These efforts can be completed by the tourism industry and the public via moderating food consumption (via calorie intake and portion control) and promoting innovation in food waste collection and management. Hence, the coordination of efforts across all sectors and the effective communication among all stakeholders involved is key to making the transition to a circular bioeconomy.

Conclusions

Biowaste management in Cyprus is a complex, multi-dimensional challenge. Nonetheless, this should not stall progress in bring up change. Composting is considered one of the most established, promising, cost-effective and sustainable methods to manage biowaste at centralized (local /regional level) and decentralised (household level), and yet, it is not currently practised in Cyprus. This is due to the severe lack of a viable plan of action for sustainable waste management practices, accompanied by a lack of monitoring and control measures across the national and local government. The associated environmental, economic and social impacts of this failure to manage biowaste are manifold, including environmental pollution and degradation, increase in fossil fuel consumption by the reliant cement manufacturing industry, fines for non-compliance with the European legislation, costs for clean-up and mitigation measures for the pollution caused, human health impacts, etc.

A new approach to biowaste management infrastructure investment and framework development is necessary to promote the sustainable management of (bio)waste in insular communities, such that promotes the recovery of value and reduces environmental, economic and social impacts. The fragmentation between production, consumption and management systems points to a missed opportunity in extracting value from the biowaste produced. The island’s geographical position lends itself to the adoption of sustainable biowaste management options that could valorise waste and generate value. These options require the strong participation of the many stakeholders including the householders, industry and policy and decision-makers as there are multiple pathways of leveraging multi-dimensional benefits from such development. Further research that looks into the production-consumption-management systems holistically, and provides an in-depth evaluation of the multi-dimensional value created and lost in the system would foster transparency and illuminate key blind spots, where interventions are needed to bring change.

Declaration of Competing Interest

None.

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