processes

MDPI

Article

Industrial Symbiosis for Optimal Bio-Waste Management and Production of a Higher Value-Added Product

Edgaras Stunžėnas *, Irina Kliopova, Daina Kliaugaitė and Rimas Pranas Budrys

Institute of Environmental Engineering, Kaunas University of Technology, Gedimino St. 50, LT-44239 Kaunas, Lithuania; irina.kliopova@ktu.lt (I.K.); daina.kliaugaite@ktu.lt (D.K.); rimas.budrys@ktu.edu (R.P.B.)
* Correspondence: edgaras.stunzenas@ktu.edu; Tel.: +370-626-88384

Abstract: A considerable amount of food waste ends up in centralized treatment plants due to the lack of preventive measures, resulting in significant environmental impacts. Hospitality food waste management is even more resource-intensive because of animal by-products regulation. According to this regulation, companies must store and then consign waste to specific waste managers. The extensive need for transportation of high-moisture-content materials is the leading cause of the impact. Moreover, the management of category III animal by-products is costly for companies. A previous study has shown the economic benefits of decentralized animal by-product treatment by intensive composting in catering companies. Although the produced compost was characterized by exceptional quality parameters, it was phytotoxic. The investigation of hospitality waste management is scarcely discussed among scholars, and waste management on a regional scale is nearly absent. This study examines the regional management of hospitality food waste by exploiting the municipal waste management infrastructure and intensive composting at the source. The co-maturation experiment with animal by-products and municipal green waste primary composts showed that the phytotoxicity parameters of the cured compost were in the optimal range or below the thresholds (conductivity (1.1 mS cm^{-1}), dissolved organic carbon (82 mg kg^{-1}), and NH_4^+/NO_3^- ratio (0.0027)). Additionally, the amounts of total nitrogen, water-soluble nitrogen, and water-soluble phosphorus in the compost were rated as very high. Finally, inventory and environmental impact analysis of the current and planned management approaches showed a reduction in 12 of 18 impact categories.

Keywords: animal by-products; intensive composting; industrial symbiosis; catering; compost quality parameters; hospitality; life cycle assessment; life cycle inventory

check for updates

Citation: Stunžėnas, E.; Kliopova, I.; Kliaugaitė, D.; Budrys, R.P. Industrial Symbiosis for Optimal Bio-Waste Management and Production of a Higher Value-Added Product. *Processes* **2021**, *9*, 2228. https://doi.org/10.3390/pr9122228

Academic Editor: Antoni Sánchez

Received: 22 November 2021
Accepted: 8 December 2021
Published: 10 December 2021

1. Introduction

Food waste (FW) is a major concern, and its quantity will most likely increase in parallel with population growth. The Food and Agricultural Organization of the United Nations (FAO) has forecasted that by 2050, food production will increase by over 70 % to feed 9.1 billion people [1]. This growth would definitely result in a substantial generation of FW, considering that nearly one-third of food is currently wasted [2]. Additionally, as the Boston Consulting Group states, this wastage could increase from 1.6 to 2.1 billion tons by 2030 if the current tendency does not change [3]. Although FW prevention is most preferable, only avoidable FW streams can be addressed, which represents 64% of the total FW [4]. Therefore, there is a need for conventional but sustainable end-of-pipe treatment methods.

In this regard, the hospitality sector has the potential for more sustainable management of unavoidable FW. For instance, in the European Union (EU), hotels, restaurants, cafeterias, and other examples in the hospitality sector generate approximately 12 million tonnes of FW annually [5]. However, kitchen waste of catering companies is no longer referred to as FW; instead, according to Regulation (EC) No. 1069/2009 (Animal By-products regulation) [6], the waste is now entitled as Category III animal by-products (ABPs).

Because Category III ABPs can increase the spread of contagious diseases, this waste must be managed in accordance with the health rules presented in Commission Regulation (EU) No 142/2011 [7]. According to these rules, catering companies must separate and store FW in refrigerators under specific conditions before the ABP manager transfers them for further treatment. This ABP management causes increased environmental impact due to electricity consumption for refrigerating and the frequent transportation of ABPs that contain considerable moisture content and is also expensive for a catering company [8].

Kliopova et al. (2019) indicated that costly ABP management could be avoided by adopting intensive composting equipment. Such an approach would avoid costly ABP management services and significantly reduce the environmental impact. Additionally, the resulting product was characterized by outstanding quality parameters (e.g., organic matter (OM) [85% of dry matter (DM)], water-soluble N (840 ppm), P (2089 ppm), and K (15,875 ppm)), trace amounts of heavy metals, and practically no microbiological contamination [8]. However, the primary compost contained an abundance of SO_4^{2-} (2800 ppm as received) and Cl^- (11,300 ppm as received) anions, which are toxic to plants at high concentrations (>300 ppm) [9]. These anions are a part of the total conductivity (5.89 mS cm^{-1}), which was significantly higher than the threshold limit of 4 mS cm^{-1} [10]. Furthermore, the primary compost stability, expressed as the concentration of dissolved organic carbon (DOC, 87,264 mg kg^{-1}), was far from that of mature compost (<4000 mg kg^{-1}) [11]. Moreover, the sole maturation of the primary FW compost for one month did not help to stabilize the parameters (Kliopova et al., 2019). The compliance of SO_4^{2-},Cl^-, conductivity, and biodegradability values with corresponding thresholds is crucial for safe agricultural application; therefore, additional measures to control these parameters are needed [12].

As the produced primary ABP compost is characterized by outstanding nutritive properties, it can be considered as an amendment for low-quality green waste compost (GWC). The GWC often contains minor quantities of N (0.5–1.5% DM), P (0.1–0.2% DM), K (0.4–0.8% DM) [13], and OM (between 8.5 and 28.6% DM) [9]. Poor compost quality is a problem because the majority of countries have established limits for quality compost, and if the produced compost does not comply with the limits, it is considered a waste. For instance, in Lithuania, compost produced from GW and FW must contain more than 25% DM of OM, and the sum of total N (TN), P_2O_5, and K_2O must be over 2.5%. Similarly, the Canadian standard for certification requires compost to contain more than 0.7, 0.5, 0.75, and 20% of N, P, K, and OM, respectively, to be classified as quality compost [14]. For this reason, it is important to meet requirements to utilize products in the market.

This study investigates the possibility of improving the environmental and economic performance of catering Category III ABP management in a region by applying industrial symbiosis compared to conventional ABP management. The industrial symbiosis approach was chosen because the municipal GW stream can be incorporated into the system to optimize compost quality and increase the amount of higher value compost production. Interestingly, in this study, the GW was not exploited as a co-substrate, as typically found in other studies [15]; however, the authors suggest the use of already produced GW primary compost, which is an abundant material in municipal GW composting sites [16]. The addition of ABPs primary compost to GW primary compost would increase the concentration of important nutrients and OM in the maturated mixture, thus increasing the price of the final product. As poor nutrient concentration is considered one of the reasons for reduced compost usage, the addition would promote a more extensive application of compost in agriculture, reducing environmental impacts [17].

In general, researchers agree that FW management in the hospitality sector is scarcely documented in the scientific literature [18]. Moreover, most of the studies are focused on the management of avoidable FW [18]; these studies mostly consider preventative measures [19]. To the authors' knowledge, the combination of the management of unavoidable hospitality FW following ABP regulation, the principle of industrial symbiosis, and exploitation of existing municipal GW management systems has not been addressed by other researchers.

The main objectives of this study are as follows:

1. Conduct primary ABP compost production experiments in three catering companies, investigate quality parameters, and select one for further analysis;
2. Perform maturation experiments of selected ABPs and GW primary composts and analyze quality parameters of the produced compost;
3. Run the life cycle inventory of the currently employed ABP composting plant in the region and analyze the quality of the compost produced;
4. Compare the environmental performance of conventional management and suggest catering ABP management approaches by applying the life cycle assessment (LCA) method;
5. Run an economic assessment of the suggested alternative.

2. Materials and Methods

2.1. Experimental Conditions and Equipment

The experiment was performed at three Lithuanian catering companies that generated between 25 and 35 kg d^{-1} (approx. 10 t y^{-1}) of Category III ABPs (FW referred to as ABPs according to Regulation (EC) No. 1069/2009). Two of them were kindergartens, which had a consistent menu such as a typical restaurant; thus, at the end of a day, leftovers and preparation waste were quite uniform because of very few different dishes. As kindergartens have a very strict diet, vegetables and grains were the prevailing ingredients for the dishes, accompanied by main entrees (meat-based) and also dairy products and fruits. Consequently, preparation and unavoidable residues (peelings of potatoes, beets, and carrots, banana skins, apples, etc.), and unconsumed meals comprise very homogeneous FW streams. Conversely, the third catering company had heterogeneous FW because meals were prepared according to the changing demands of customers. Due to differences in FW composition and its potential impact on final product parameters, the three catering companies were considered.

Across the catering companies, two different technologies for closed-loop intensive aerobic treatment were utilized: the Oklin GreenGood 10s [8] and the Green Service Bioreactor Bio-10 [20]. The three intensive automatic composting machines were installed in each company in accordance with the requirements presented in the manuals. Oklin equipment for exhaust air treatment uses an activated carbon filter, whereas Green Service applies a nano-filter deodorization unit before removing the generated gas through a ventilation system.

Both intensive composting machines are designed to treat a batch of FW in a 24-h cycle. After the cycle was completed, the primary compost produced was removed, leaving approximately 10% of the compost as an inoculum for the successive cycle. The Oklin technology incorporates a specific microorganism strain under the brand name ACIDULO^{TM}, whereas Green Service uses the Ecibulo brand, which is composed of halophilic, eosinophilic, and thermophilic germs [21]. Green Service also emphasizes the need for the inoculum and even replenishment of microorganisms every year. Microorganisms, intensive aeration, agitation, and temperature regimes are the main factors influencing rapid FW degradation, moisture evaporation, and mass reduction of up to 50–90%. During composting, Oklin equipment maintains temperatures above 55 °C, but for 1 h, the temperature is increased to 70 °C to eliminate pathogens [8]. Green Service technology follows the same pattern; during processing, the temperature is maintained in the range of 54–56 °C, but at the end of the composting, the temperature is increased to 70 °C for 1 h.

The experiment was divided into two parts. The first part was the production of primary composts in the three catering companies. The experiment started in June 2018, during which 20 cycles (one cycle duration was one working day or 24 h) were conducted in the catering companies. The first catering company transformed approximately 28 kg per cycle (total 560 kg of ABPs per 20 cycles) to 6.72 kg (total 134.3 kg of ABPs). The second catering company composted 14.63 kg per cycle (total 292.6 kg) of ABPs to 3.18 kg (total 63.5 kg). The third catering company composted 9.83 kg per cycle (total 196.5 kg) of ABPs to 2.39 kg (total 47.8 kg) of the primary compost. In each catering company, each batch (produced per cycle) was poured into a clean polypropylene bag and mixed with the other simultaneously gathered batches. After completion of the 20 cycles, the sampling procedure was performed. Three samples from the primary compost of ABPs1 were collected. Sampling was performed by taking 10 specimens from the top, middle, and bottom locations of the collected ABPs1 primary compost in random order and then uniformly mixing these 10 specimens to form one sample. The second and third samples of ABPs1 were prepared in the same manner. The same sampling procedure was applied to the primary compost of ABPs2 and ABPs3.

GW primary compost was prepared at a municipal GW composting site. The GW primary compost production started in the first week of April 2018 and ended at the end of July 2018. The waste available at the municipal GW composting site was used as a substrate. After composting was completed, three samples were taken from the pile of the primary GW compost. The samples were prepared in the same manner as the ABPs1, ABPs2, and ABPs3 samples.

The second part of the experiment was the co-maturation of the selected ABPs and GW primary composts in the municipal GW composting site. The experiment started at the beginning of August 2018. The ABPs2 primary compost was selected for the second part of the experiment because it contained higher concentrations of TN and total P (TP), and had a more attractive visual appearance than ABPs1 and ABPs3. A total of 15% of ABPs2 and 85% of GW primary composts were mixed (by mass) and loaded into a standard open home composting bin (V-approx. 700 L) for co-maturation. During maturation, the substrate was thoroughly mixed at least once a week. Finally, the samples were collected after 60 days (in October 2018) and 90 days (in November 2018) of co-maturation. All these ABPs and GW (including the compost produced in the conventional ABP treatment plant) samples were delivered to the agrochemical research and joint-stock company "Jurby Water Tech" laboratories to analyze the quality parameters.

2.2. Evaluation of Mass Balance during Composting Processes

The Utena municipality (Lithuania) was chosen to assess current catering ABP management and compare it to the new approach. The most important features of the region were the number and location of municipal GW composting sites, distance from a catering company to ABP managers, and technology used for ABP management. The average distance from the catering company to the municipal GW site was 15 km, whereas the distance between the companies and ABPs managers was 50 km.

The N balance was calculated according to the study by Yang et al. (2019) [22]. These authors found that the N loss via N_2O was 0.07%, N loss via NH_3 was 9.88%, N loss via leachate was 0.38%, unaccounted N was 2.81%, and TN loss was 13.13% from the initial N content for forced aeration systems. Similarly, N balance was assessed for passive aeration systems [22]. In this case, the N loss via N_2O was 0.09%, N loss via NH_3 was 8.10%, N loss via leachate was 5.17%, unaccounted N was 2.62%, and TN loss was 15.98% of the initial N content.

The P balance was evaluated using the study of Iqbal et al. (2015). These authors found that the TP loss with filtrate during composting was approximately 3% from initial P [23]. Similarly, based on the study of Sommer (2001), the loss of total K (TK) with filtrate was 12% from initial K [24]. CO emissions were assessed according to EMEP/CORINAIR, whereas CH_4 emissions for open (3.4 kg t^{-1} of waste) and closed (0.9 kg t^{-1} of waste) composting were taken from the study of Boldrin et al. (2009) [25]. The heavy metal loss was calculated considering that 2% of the heavy metals present in compost will be washed with leachate [26].

2.3. Life Cycle Assessment Methodology

The environmental impacts of the conventional and suggested catering ABP management scenarios were calculated and compared using the LCA method. The ReCiPe method at the midpoint level was used to perform the impact assessment based on ReCiPe2008 by Goedkoop et al. (2008) [27] and an updated version ReCiPe2016 by the National Institute for Public Health and the Environment [28]. In terms of the environmental impact categories at the midpoint, all 18 impact categories were calculated. The LCA Ecoinvent Database v3.6. (2019) was applied as the background source for life cycle impact analysis [29]. The potential environmental impacts of management scenarios were calculated using the LCA software SimaPro 9.1 [30]. The functional unit used was 10 t y^{-1} of the ABPs.

3. Results and Discussion

3.1. Parameters of Primary Composts

The analysis of the primary composts obtained and produced during the first part of the experiment showed expected yet variable quality parameters (see Table 1). The analysis of the produced ABPs1, ABPs2, and ABPs3 primary composts confirmed that the quality parameters rely heavily on the input FW. For instance, ABPs2 and ABPs3 from kindergartens had relatively similar menus; hence, the produced primary composts were similar as well. However, noticeable differences in NPK values between ABPs2 and ABPs3 kindergarten primary composts were observed. Regarding TN, the ABPs2 primary compost contained 2.38% DM, whereas ABPs3 had slightly less (1.92% DM), showing that ABPs2 had more N-rich waste such as fish or meat meal residues. The ammonification rate difference between the primary compost of the ABPs1 (518 ppm NH_4^+) and ABPs2 (1534 ppm NH_4^+) was notable, but these two catering companies utilized separate intensive composting technologies with diverse microbial communities. However, it is possible that the inoculation procedure was disrupted, resulting in highly fluctuating (518–1534 ppm) NH_4^+ concentrations in the primary composts analyzed. Regarding the inoculum, technology applied for the ABPs2 and ABPs3 treatments used halophiles, which are effective under extreme conditions such as low pH (<4), high conductivity (>5 mS cm^{-1}), and temperature (>55 °C), potentially influencing the swift mineralization of biomass [31].

Because these extreme conditions are detrimental to typical composting microflora, these microbes can easily dominate. Moreover, when the temperature was increased to 70 °C, pathogens and potentially the most typical composting microbes were eliminated. For this reason, when processed, ABPs were removed from the automatic composting machine and left at ambient temperature, and the microbial activity was significantly reduced. As a result, the ammonification process was impeded, leading to the preservation of NH_4^+ in the compost. In addition to high temperature, forced air supply for 24 h of batch processing also influenced the N behavior. Most of the time, the temperature was in the range of 40–60 °C, which is optimum for conversion or organic N to ammonium and inhibitory for nitrifying bacteria [32]. Therefore, NH_4^+ dominated NO_3^- in the primary compost. The forced air supply may have also contributed to the NH_4^+ concentration. According to de Guardia et al. (2010), the aeration rate can considerably increase the ammonification rate, for example, from 36.7 to 43.1% for household waste or from 52.0 to 71.4% for pig slaughterhouse sludge [33].

The pH of ABPs1, ABPs2, and ABPs3 primary composts was correlated with NH_4^+ concentration. Because NH_4^+ increases the pH, the highest pH was found in the specimen containing the largest amount of NH_4^+ (1534 ppm). As NH_4^+ concentrations decreased in ABPs3 (970 ppm) and ABPs1 (518 ppm) specimens, the pH decreased to 5.0 and 4.7, respectively.

Table 1. Major agronomical parameters of primary GW and ABPs composts.

Quality Indicators *	Primary GW Compost	Primary ABPs1 Compost	Primary ABPs2 Compost	Primary ABPs3 Compost
E. coli **, cfu g^{-1}	$\leq 1 \times 10^3$	$\leq 1 \times 10^3$	$\leq 1 \times 10^3$	$\leq 1 \times 10^3$
Conductivity, mS cm^{-1}	**1.04** (1.02–1.08)	**5.77** (5.70–5.81)	**5.40** (5.37–5.42)	**5.51** (5.47–5.55)
pH_{KCl}	**7.4** (7.3–7.5)	**4.70** (4.6–4.8)	**7.1** (7.0–7.1)	**5.0** (4.9–5.1)
DM %	**66.18** (64.13–67.21)	**88.92** (86.97–91.20)	**84.21** (82.08–87.04)	**75.77** (72.16–78.21)
OM, % DM	**18.31** (16.94–19.23)	**83.22** (82.14–84.63)	**88.34** (87.48–89.35)	**92.89** (91.94–93.85)
TN, % DM	**0.72** (0.69–0.75)	**1.81** (1.79–1.84)	**2.38** (2.35–2.41)	**1.92** (1.86–1.98)
TP, % DM	**0.71** (0.69–0.75)	**0.39** (0.38–0.40)	**0.65** (0.60–0.67)	**0.54** (0.49–0.53)
TK, % DM	**0.62** (0.59–0.64)	**1.44** (1.40–1.51)	**1.26** (1.23–1.28)	**1.02** (1.01–1.04)
Water-soluble N, ppm	**189** (182–195)	**546** (520–566)	**1534** (1501–1563)	**1015** (967–1045)
Water-soluble NO_3^- + NO_2^-, ppm	**159** (153–164)	**27.82** (25.03–31.15)	**52.89** (48.21–58.01)	**45.05** (40.14–47.67)
Water-soluble NH_4^+, ppm	**30.39** (26.71–35.54)	**518** (489–524)	**1481** (1453–1505)	**970** (919–998)
Water-soluble P, ppm	**53.6** (51.0–55.2)	**1321** (1302–1349)	**1898** (1845–1915)	**1917** (1851–1966)
Water-soluble K, ppm	**854** (812–887)	**10,319** (10,204–10,495)	**10,745** (10,406–11,008)	**11,054** (10,524–11,386)
Cl, ppm	**471** (428–511)	**7155** (7120–7230)	**9240** (9028–9484)	**9797** (9715–9887)
SO_4, ppm	**628** (598–662)	**1820** (1773–1858)	**1089** (1026–1184)	**987** (976–1003)
DOC, mg kg^{-1}	**486** (446–517)	**80,892** (80,506–81,508)	**42,970** (42,397–43,394)	**41,190** (41,024–41,386)
Bulk density, g L^{-1}	795	688	776	

Notes: * Data are reported as mean with n = 3 and the largest and lowest values in parentheses. **—Contamination by *E. coli* was measured only once per sample.

The conductivity among the primary composts varied from 5.4 to 5.77 mS cm^{-1}, possibly contributing to extreme conditions. For example, Setia et al. (2010) stated that at a conductivity above 5.0 mS cm^{-1}, soil respiration declined over 50% [34], whereas other researchers reported that the inhibitory value for microbial activity during composting was 8 mS cm^{-1} [35]. In addition to inhibitory effects, the high conductivity of the primary composts illustrates the effective release of NH_4^+, P, and K from organic compounds. These conductivity values were far from those of composts used in agriculture; for instance, Turan (2008) stated that 2 mS cm^{-1} is the ideal value [36], whereas Staugaitis et al. (2016) referred to 1.1–1.5 mS cm^{-1} as optimum values for stable products.

The unfinished degradation process is clearly illustrated by the abundance of DOC, also referred to as biodegradability (compost stability). The ABPs2 (42,970 mg kg^{-1}) and ABPs3 (41,190 mg kg^{-1}) primary composts had nearly identical concentrations of DOC, whereas that of ABPs1 was twice as high (80,892 mg kg^{-1}). All of these primary composts exceeded the stable compost threshold of <4000 mg kg^{-1} by 10 to 20 times [11]. Although the primary compost was not stable, high concentrations of DOC indicated microbial activity [37]. In addition, Kliopova et al. (2019) reported that primary compost produced in an intensive composting machine had relatively high concentrations of fulvic and humic acids, which indicates that the composting process was not simple evaporation of water [8].

Water-soluble P solubilization during the treatment period was comparatively high. The soluble P-concentration ranged from 1321 to 1917 ppm (1920–2477 mg kg^{-1} according to the bulk density). The high solubilization rate may be due to low molecular weight acids in the total pool of DOC and the activity of P-solubilizing microorganisms [38].

The concentration of water-soluble K accumulated for 24 h was extremely high. The water-soluble P was nearly identical in samples from the catering companies and varied from 10,319 to 11,054 mg kg−1. K is not incorporated in organic compounds such as N or P; instead, it is concentrated in cells in the form of salts [39]. For this reason, when cells collapse during composting, K salts are released into the media, resulting in a high K concentration.

In the analyzed samples, contamination by *E. coli* was below the limit value (see Table 1). These results are consistent with those of a previous study by Kliopova et al. (2019) and Pandey et al. (2016), who also indicated that closed-loop composting equipment can produce compost without any pathogenic microorganisms [40].

The GW primary compost had typical values found across Lithuania municipal GW composting sites [9]. Generally, the primary compost had low quantities of TN, TP, and TK, as well as their soluble forms. In contrast to catering companies, in primary GWC, the nitrates were dominant over NH_4^+, indicating the prevalence of nitrifying bacteria.

3.2. Parameters of Cured Compost

The co-maturation of ABPs2 and GW primary composts resulted in a product with no phytotoxic qualities (see Table 2). The conductivity (1.1 mS cm^{-1}) was in the optimum range, excluding the possibility of osmotic imbalance (dehydration) of a plant cell. The pH after 60 days of maturation was 6.63, but reached 7.0 after 90 days. This is the optimal pH because N, K, Ca, Mg, and S are more available in the pH range of 6.5–8.0, whereas P is more available in a pH between 5.5 and 7.5 [41]. The DOC (82 mg kg^{-1}) was significantly lower than the threshold (<4000 mg kg^{-1}), resulting in a very stable product. In fact, even if the co-maturation duration was shortened, the compost stability would have met the requirement. Cl^- concentration (298 ppm), which is another parameter associated with toxicity in plants, was also below the limit value of > 300 ppm. The SO_4^{2-} concentration (808 ppm) remained high, and concentrations above 300 may be detrimental for susceptible plants [9]. However-, the concentration of sulfate (128 ppm) was reduced significantly after 90 days.

Table 2. Results of co-maturation of GW and ABPs primary composts.

Parameters for Quality Indication	**** Values for Quality Indication**	*** Maturated Composts ABPs2 + GW**		**Quality Assessment of Compost (After 2 Months)**
		After 2 Months	**After 3 Months**	
Conductivity, mS cm^{-1}	<0.6 → > 2	**1.1** (1.07–1.14)	**0.9** (0.98–0.92)	Medium
pH_{KCl}	<5.6 → 8.5	**6.63** (6.56–6.71)	**7.0** (6.9–7.1)	Medium
DM, %	<21 →>50	**58.18** (56.89–59.6)	**60.35** (60.05–60.60)	Very high
OM, % DM	<16 → >45	**20.32** (19.81–21.17)	**17.30** (17.01–17.82)	Low
N, % DM	<0.5 → >2.0	**1.36** (1.28–1.42)	**0.97** (0.89–1.08)	Medium
P, % DM	<0.21 → >0.8	**0.93** (0.80–1.01)	**0.76** (0.69–0.82)	Very high
K, % DM	<0.6 → >2.5	**0.76** (0.70–0.82)	**0.45** (0.42–0.47)	Low
Water-soluble N, ppm	<51 → >200	**388** (372.0–406.1)	**344** (341–348)	Very high
Water-soluble NO_3^- + NO_2^-, ppm	<51 → >200	**387** (371–405)	**344** (341–348)	Very high

Table 2. *Cont.*

Parameters for Quality Indication	** Values for Quality Indication	* Maturated Composts ABPs2 + GW		Quality Assessment of Compost (After 2 Months)
		After 2 Months	After 3 Months	
Water-soluble NH_4^+, ppm	-	**1.06** (1.03–1.10)	**0.013** (0.010–0.018)	-
Water-soluble P, ppm	<26 → >100	**214** (236–250)	**190** (188–192)	Very high
Water-soluble K, ppm	<91 → >300	**832** (809–862)	**700** (697–703)	Very high
Water-soluble Ca, ppm	<101 → >500	**318** (311–325)	**201** (196–205)	High
Water-soluble Mg, ppm	<31 → >120	**105** (95–114)	**81** (80–83)	High
Cl, ppm	<51 → > 300	**298** (271–328)	**248** (241–258)	High
SO_4, ppm	<51 → > 200	**808** (788–832)	**123** (119–128)	Very high
DOC, mg kg^{-1}	< 4000	82	0	Stable compost
E. coli, cfu g^{-1}	$\leq 1\times10^3$	6.4×10^4	2.3×10^3	Polluted

Notes: * Data are reported as mean with n = 3 and the largest and lowest values in parentheses. **—Maturated compost quality was assessed according to Staugaitis et al. (2016). The first and second values refer to the lower (very low quality) and upper (very high quality) limits of the parameter in question.

Another parameter for compost stability determination is the NH_4^+ to NO_3^- ratio. Many researchers claim that the NH_4^+ to NO_3^- ratio should be less than 1. In the experiment, the NH_4^+:NO_3^- ratio was only 0.0027, suggesting excellent stability. Moreover, due to effective NH_4^+ oxidation, the maturation period could be considerably reduced, maintaining the NH_4^+ to NO_3^- ratio lower than one.

Many parameters associated with the fertility of the product exceeded the value, which was determined to be valuable according to a study conducted by Staugaitis et al. (2016). The compost produced in the experiment had several parameters that surpassed a very high rating, such as TP (0.93%; very high > 0.8%); water-soluble N (388 ppm; very high > 200 ppm); water-soluble P (214 ppm; very high > 100 ppm); water-soluble K (808 ppm; very high > 300 ppm); DM (58.18%; very high > 50%) (see Table 2). However, the most important agronomical parameter of OM was considerably low because of the prevalence of low OM containing GW primary compost and degradation of organic material during maturation. Nevertheless, if the ABPs2 portion in the mixture was increased by 20 to 30%, the OM percentage would notably increase.

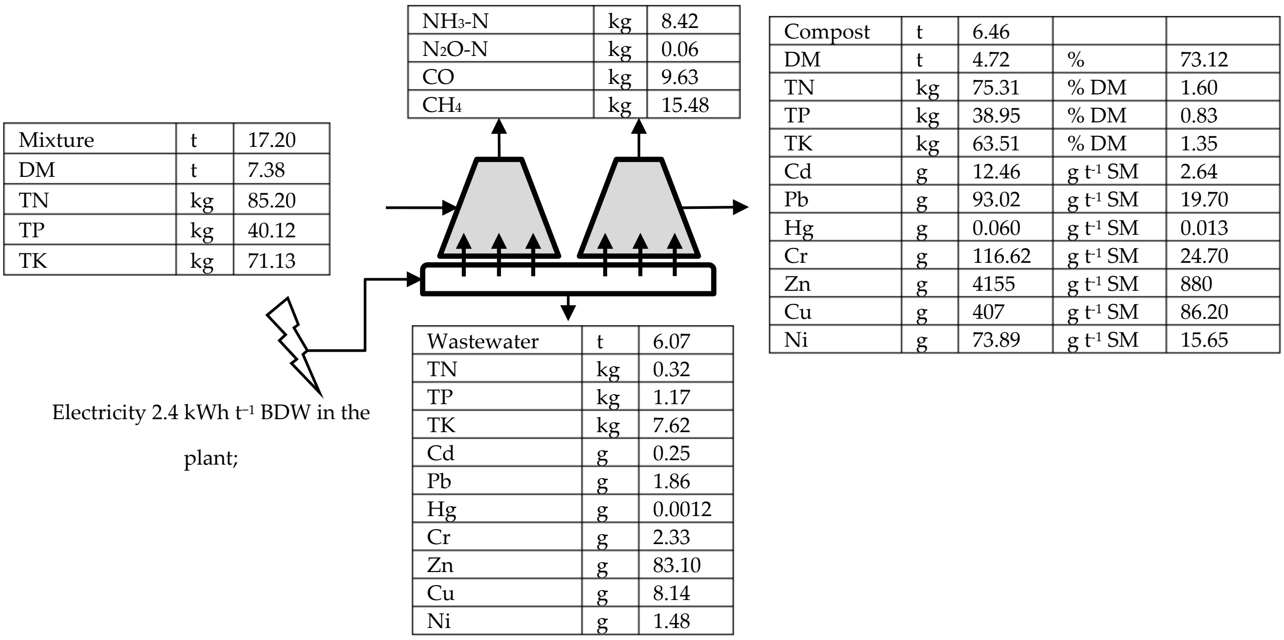
Although the parameters associated with phytotoxicity and compost fertility exhibited excellent values, during the experiment, *E. coli* (6.4×10^4) exceeded the limit value of 1×10^3 cfu g^{-1}, and the microbial count of the GW and ABPs primary composts was below the threshold value. The increase in *E. coli* colony count could be due to uncontrolled disturbances and low temperatures during maturation.

As a solution for emerging *E. coli* problems, specific microorganism mixtures can be introduced during co-maturation. After the analysis conducted in the Department of Veterinary Medicine, Jelgava University of Agriculture, the specifically developed probiotic mixture (microbiological preparations) showed that *E. coli* (strain No. ATCC25922) colony numbers were significantly reduced in only 24 h [42]. The comparison of both produced composts revealed that composting with the probiotics completely eliminated *E. coli* and Salmonella as well as other types of pathogens (e.g., *Enterobacter cloacae*) [43].

3.3. Current and Planned Hospitality ABPs Management Approach

To reveal the environmental benefits of catering ABP management, a comparison of existing and suggested approaches to treat 10 tons of ABPs was performed. First, a field study of the current ABP plant was conducted. During the study, the researchers found that the technology used was composting under fabric cover with forced aeration (air supply through perforated tubes under the piles) to minimize the need for pile turning (a windrow turner was used only two times per composting cycle) and accelerate the composting process. However, compost turning was applied for mixing catering ABPs (55%), GW (35%), and biomass combustion ash (10%) to adjust the moisture content and C/N ratio. After surveying the plant's staff, it was assumed that the substrate mass was reduced by approximately 62%, whereas the dry material reduction was approximately 36%. Composting with forced aeration generated 6.07 t y^{-1} of leachate.

After the plant staff survey and analysis of the produced compost quality and contamination parameters (average value n = 3), and analysis of scientific literature, the mass balance was calculated (see Figure 1). According to the compost quality analysis and loss of material during composting (see Section 2.2), the NPK in the input material was calculated.



Mixture	t	17.20
DM	t	7.38
TN	kg	85.20
TP	kg	40.12
TK	kg	71.13

NH_3-N	kg	8.42
N_2O-N	kg	0.06
CO	kg	9.63
CH_4	kg	15.48

Compost	t	6.46		
DM	t	4.72	%	73.12
TN	kg	75.31	% DM	1.60
TP	kg	38.95	% DM	0.83
TK	kg	63.51	% DM	1.35
Cd	g	12.46	g t^{-1} SM	2.64
Pb	g	93.02	g t^{-1} SM	19.70
Hg	g	0.060	g t^{-1} SM	0.013
Cr	g	116.62	g t^{-1} SM	24.70
Zn	g	4155	g t^{-1} SM	880
Cu	g	407	g t^{-1} SM	86.20
Ni	g	73.89	g t^{-1} SM	15.65

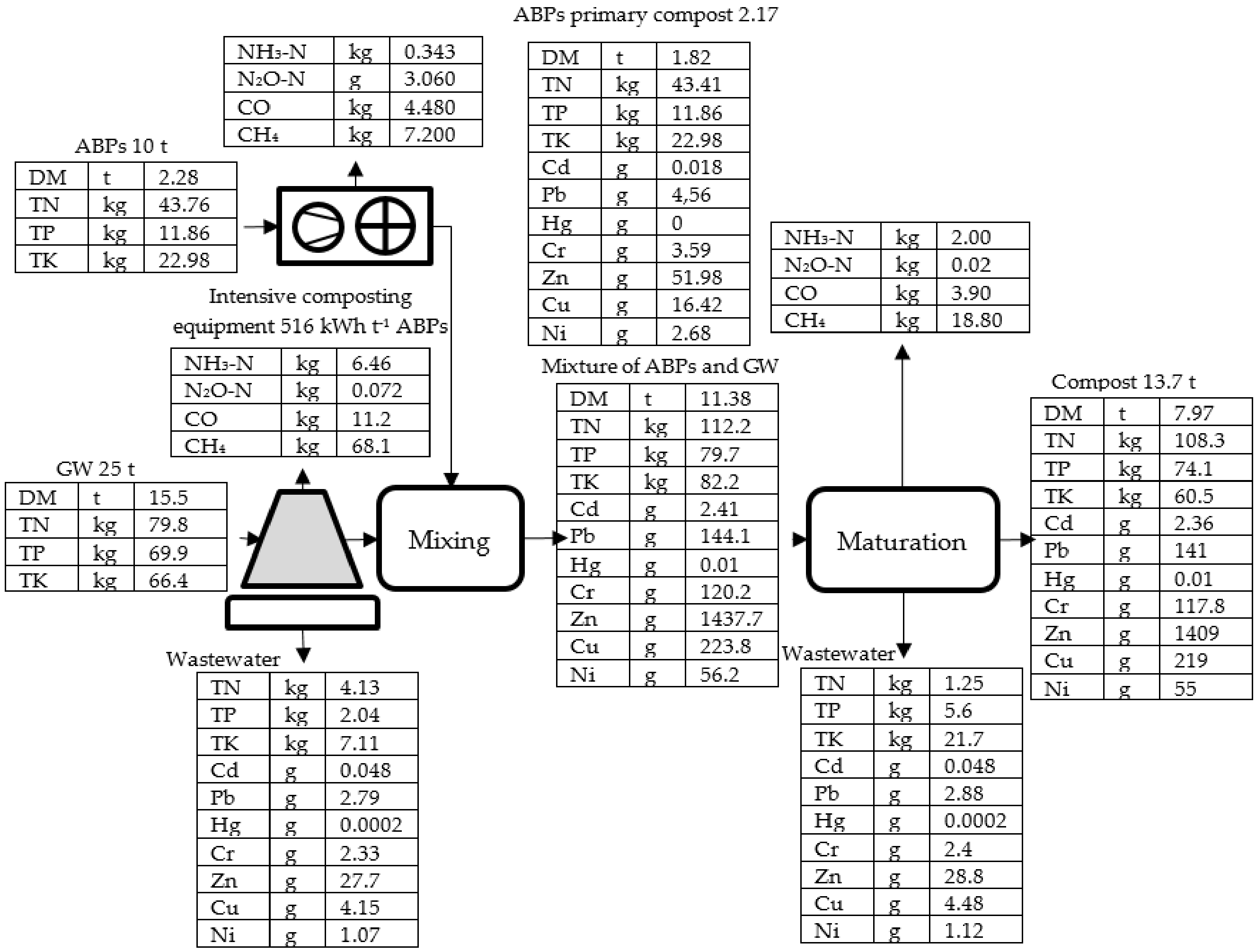
Wastewater	t	6.07
TN	kg	0.32
TP	kg	1.17
TK	kg	7.62
Cd	g	0.25
Pb	g	1.86
Hg	g	0.0012
Cr	g	2.33
Zn	g	83.10
Cu	g	8.14
Ni	g	1.48

Figure 1. Existing hospitality ABPs management in the selected region.

After material flow analysis, the energy demand data for the composting operations were gathered. Electricity consumption in the plant was 2.4 kW h t^{-1} of biodegradable waste (BDW), amounting to a total of 41.29 kWh for 17.2 t y^{-1} of the substrate. Regarding diesel consumption, the staff reported that all the machinery consumed 1.26 kg t y^{-1} BDW, resulting in a total 21.68 kg of fuel for the composting operation.

Conventional catering ABP management in the selected region requires considerable energy for transportation. In the case of the catering company, which generates 10 t y^{-1} ABPs, it is assumed that the ABPs will be collected every week (52 picks per year), consisting of 192.3 kg per pick. Because the average distance between the catering company and the ABP manager is 50 km, the need for transportation is 26,000 tkm y−1. Moreover, the transportation of the product (6.46 t y^{-1}) to agricultural fields in the region would also amount to 50 km, amounting to a total of 306.74 tkm.

The suggested management approach is shown in Figure 2. The flowchart presents the management of one catering company's ABPs by applying intensive composting at the source of generation, followed by co-maturation of GW and ABPs primary composts in the closest municipal GW composting sites.



ABPs 10 t

DM	t	2.28
TN	kg	43.76
TP	kg	11.86
TK	kg	22.98

Intensive composting emissions

NH_3-N	kg	0.343
N_2O-N	g	3.060
CO	kg	4.480
CH_4	kg	7.200

ABPs primary compost 2.17

DM	t	1.82
TN	kg	43.41
TP	kg	11.86
TK	kg	22.98
Cd	g	0.018
Pb	g	4,56
Hg	g	0
Cr	g	3.59
Zn	g	51.98
Cu	g	16.42
Ni	g	2.68

GW 25 t

DM	t	15.5
TN	kg	79.8
TP	kg	69.9
TK	kg	66.4

GW composting emissions

NH_3-N	kg	6.46
N_2O-N	kg	0.072
CO	kg	11.2
CH_4	kg	68.1

Wastewater

TN	kg	4.13
TP	kg	2.04
TK	kg	7.11
Cd	g	0.048
Pb	g	2.79
Hg	g	0.0002
Cr	g	2.33
Zn	g	27.7
Cu	g	4.15
Ni	g	1.07

Mixture of ABPs and GW

DM	t	11.38
TN	kg	112.2
TP	kg	79.7
TK	kg	82.2
Cd	g	2.41
Pb	g	144.1
Hg	g	0.01
Cr	g	120.2
Zn	g	1437.7
Cu	g	223.8
Ni	g	56.2

Maturation emissions

NH_3-N	kg	2.00
N_2O-N	kg	0.02
CO	kg	3.90
CH_4	kg	18.80

Wastewater

TN	kg	1.25
TP	kg	5.6
TK	kg	21.7
Cd	g	0.048
Pb	g	2.88
Hg	g	0.0002
Cr	g	2.4
Zn	g	28.8
Cu	g	4.48
Ni	g	1.12

Compost 13.7 t

DM	t	7.97
TN	kg	108.3
TP	kg	74.1
TK	kg	60.5
Cd	g	2.36
Pb	g	141
Hg	g	0.01
Cr	g	117.8
Zn	g	1409
Cu	g	219
Ni	g	55

Figure 2. Existing hospitality ABPs management in the selected region.

The scheme in Figure 2 presents the flow of nutrients and materials during the application of the novel management approach. The box with an air blower and agitator presets intensive composting on the premises of a catering company, and the gray pile depicts typical municipal GW composting.

During the intensive composting of catering ABPs, no wastewater was generated due to external heating and evaporation. For this reason, the quantities of K and P remained the same in the lower-mass material. In a previous study, Kliopova et al. (2019) reported that 0.0416 kg of NH_3 was generated per ton of catering ABPs. These findings were used to evaluate the loss of TN in the form of NH_3 (0.343 kg) from the system. As N_2O emissions were not measured, the emissions factor for aerated compost was taken from Yang et al. (2019). The N balance was calculated in accordance with N emissions.

Concentrations of heavy metals were also taken from the study of Kliopova et al. (2019), as additional laboratory analysis would be redundant due to the nature of source segregated FW, which is nearly heavy metals-absent. Heavy metal concentrations of GWC were taken from Staugaitis et al. (2016) as a more reliable source of data. The authors analyzed composts of multiple GW composting sites and showed average heavy metal concentrations across Lithuania. The heavy metal concentrations in both primary composts were used to assess the amount of heavy metals in the mixture before maturation.

CH_4 and CO emissions were distributed across the composting and maturation processes. A total of 80% of CH_4 and CO were assigned to composting and 20% to maturation.

During the novel ABP management, the majority of diesel is consumed during municipal GW composting. The staff of the GW composting plant of the region reported 0.756 kg per ton of GW, representing 18.9 kg per 25.0 t for GW composting. In the case of the suggested management approach, diesel is used to mix ABPs and GW primary composts before maturation by using the plant compost-turning machine (capacity 2800 m^3 h^{-1}) with diesel consumption of 16 L h^{-1} or 0.016 L per ton of BDW (one cycle). It is assessed that two cycles would be sufficient to ensure proper mixing of the primary composts, amounting to 0.23 kg of diesel for 16.6 tons of primary composts.

Most importantly, the novel ABP management approach proposed can substantially reduce transportation needs. As the production of primary compost in a catering company is no longer waste, ABP regulation does not apply to this subproduct. Therefore, the transport of the primary compost to the closest municipal GW composting sites is suggested. In the case of the selected region, 10 t y^{-1} of ABPs would be transformed into 2.17 t y^{-1} of the primary compost and transported for 15 km (empty return) to the closest municipal GW composting site (32.49 tkm) every two weeks or 26 times per year (83.3 kg). Moreover, the delivery of the produced compost to the surrounding agricultural fields would be less intensive compared to the current management approach. Six GW composting sites with a radius of 15 km cover 85% of the region's territory. For this reason, the delivery of the product (10.29 t y^{-1}) for field application would amount to 154.16 tkm.

3.4. Current and Planned Hospitality ABPs Management Environmental Impact Assessment

To highlight the environmental benefits, current and planned catering ABP management approaches were interpreted by applying the LCA method. After the analysis (characterization) of both approaches, a reduction was observed in 12 environmental impact categories from a total of 18. For instance, the environmental impact in the climate change category was reduced by 48%, ozone formation by 107%, fossil resource scarcity by 83%, etc. (see Figure 3). The same impact categories with their corresponding units were depicted in Table 3.

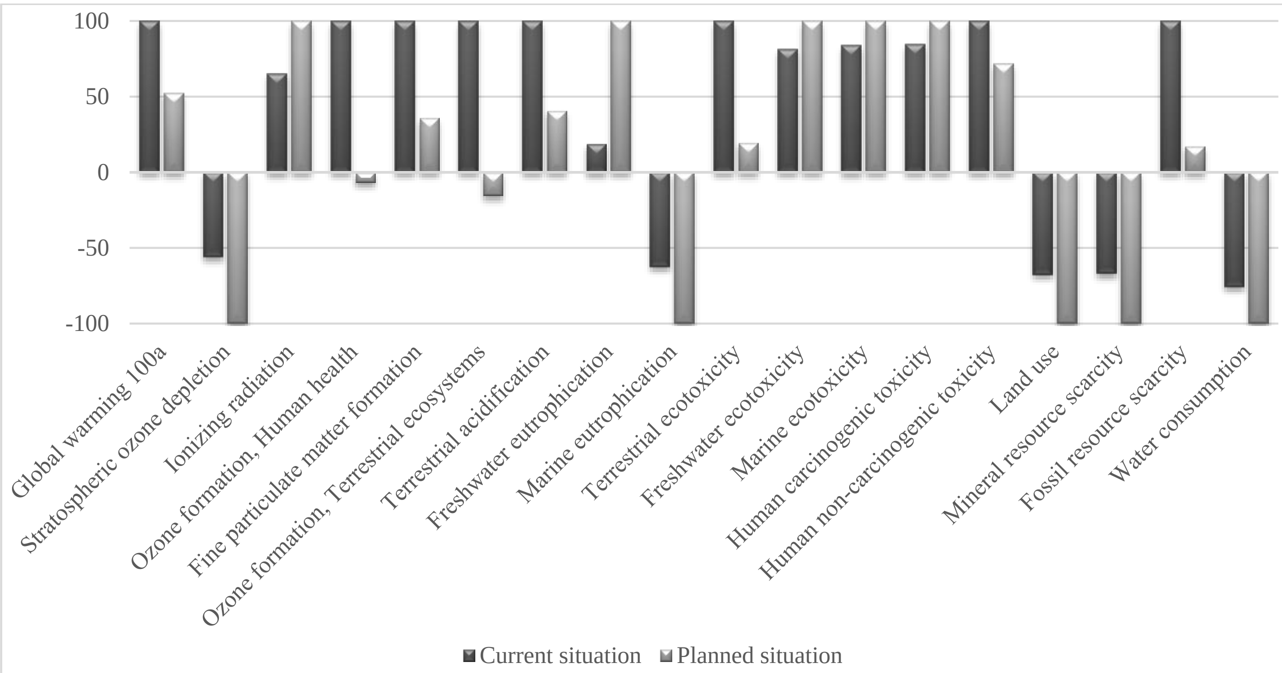


Figure 3. Comparison of environmental impacts according to the LCA method for current and planned catering ABP management approaches.

Table 3. Comparison of current and planned situations in 18 environmental impact categories.

	Impact Category	Unit	Current Situation	Planned Situation
1	Global warming 100a	kg CO_2 eq	7935	4141
2	Stratospheric ozone depletion	kg CFC11 eq	−0.0087	−0.0156
3	Ionizing radiation	kBq Co-60 eq	646	988
4	Ozone formation, Human health	kg NOx eq	80.9	−5.48
5	Fine particulate matter formation	kg PM2.5 eq	14.8	5.32
6	Ozone formation, Terrestrial ecosystems	kg NOx eq	77.0	−11.8
7	Terrestrial acidification	kg SO_2 eq	57.7	23.6
8	Freshwater eutrophication	kg P eq	1.57	8.28
9	Marine eutrophication	kg N eq	−0.40	−0.64
10	Terrestrial ecotoxicity	kg 1,4-DCB	18,236	3572
11	Freshwater ecotoxicity	kg 1,4-DCB	173	212
12	Marine ecotoxicity	kg 1,4-DCB	221	263
13	Human carcinogenic toxicity	kg 1,4-DCB	63.7	75.2
14	Human non-carcinogenic toxicity	kg 1,4-DCB	2969	2129
15	Land use	m^2a crop eq	−4,567,849	−6,760,311
16	Mineral resource scarcity	kg Cu eq	−7.16	−10.7
17	Fossil resource scarcity	kg oil eq	2364	413
18	Water consumption	m^3	−34.9	−46.2

3.5. Economic Assessment of the Proposed Management Approach

The savings for a catering company were evaluated in a previous study (Kliopova et al., 2019), amounting to 4203 EUR per year, when the produced compost is used in the catering company premises. However, when the primary compost cannot be matured and used for the needs of the company, it is suggested to divert the primary compost to GW composting sites, as it was analyzed in the present study. In this case, system boundaries are enlarged, encompassing municipal GW composting sites, which also receive extra earnings. The pay-pack period of implementation of an intensive composter will be approximately 2.1 years (see Table 4).

Table 4. Economic evaluation (savings) due to installation of an intensive composter at the catering company.

Analyzed Parameters	Units	Price	Situation before Implementation (Conventional ABPs Management)	Situation after Implantation of Intensive Composter	Savings	
		EUR unit^{-1}	Units y^{-1}	Units y^{-1}	Unites y^{-1}	EUR y^{-1}
ABPs	t	446.11	10	0	10	4461.1
PC	t	-	0	2.17	−2.17	0
* Electricity	kWh	0.15	3300	5160	−1860	−279.00
** Diesel fuel	L	1.00	0	54.6	−54.6	−54.6
			Total savings:			4127.5

Notes: * Animal by-products in a catering company are stored in a separate freezer with an installed power of 0.35 kW); electricity consumption of intensive composter: 5160 kWh t^{-1} of raw ABPs. ** Diesel fuel consumption for ABPs primary compost transportation to GW composting site: 32.49 tkm (diesel consumption 7 L km^{-1}).

As it was suggested that ABP management increases the nutritive properties of GW compost, the price of the improved compost is assumed to increase from 7–13 to 20 EUR t^{-1}. For this reason, established symbiotic relationships between catering and municipal GW composting sites would allow them to double the income as GW compost producers. In the case of our example, 13.7 t of higher quality compost can be produced using 2.17 t of ABPs primary compost as an amendment; expected incomes were 274 EUR or on average 137 EUR more in comparison to the current situation per catering company.

4. Conclusions

The analysis of ABP primary compost produced by the three catering companies has shown outstanding nutritive properties, such as the amount of OM (75–89% DM), TN content (1.5–1.38% DM), and water-soluble P concentration (1321–1917 ppm). However, the primary composts were phytotoxic, containing large concentrations of SO_4^{2-} (987–1820 ppm), Cl^- (7155–9797 ppm), high conductivity (5.40–5.77 mS cm^{-1}), and biodegradability (41,190–80,892 mg kg^{-1}).

The co-maturation experiment with ABPs2 and GW primary compost resulted in the stabilization of parameters associated with phytotoxicity. The cured compost conductivity was in the optimal range (1.1 mS cm^{-1}), biodegradability (82 mg kg^{-1}) in a stable range, Cl^- (298 ppm) below the limit considered detrimental for the susceptible plant; however, SO_4^{2-} remained high 808 ppm. According to the selected quality assessment method, the quality of the cured compost was exceptional. Parameters such as DM, TP, and soluble forms of NPK in the produced compost ranged from high to very high values.

The analysis of the current ABP management approach in the analyzed region showed that these catering wastes were composted by centralized intensive composting under forced aeration and fabric cover. In the plant, ABPs (55%) were mixed with GW (35%) and biomass combustion ash (10 %) to adjust the moisture content and C/N ratio. In addition, to treat 10 t y^{-1} of ABPs, 21.68 kg of diesel was needed. In contrast, the transportation need for the current approach amounts to 26,000 km. Although the nutritive properties of the compost were high, the compost contained large amounts of heavy metals (e.g., 880 g Zn t^{-1} DM).

The analysis of the environmental impacts of current and suggested ABP management approaches has revealed that in the case of implementation of the novel method, environmental performance can be increased in 12 impact categories from a total of 18. Marked reductions were achieved in climate change (48%), ozone formation (107%), and fossil resource scarcity (83%) impact categories.

The economic assessment proved that the symbiotic relationship between catering companies and GW composting sites results in economic benefits for the involved parties. Production of primary compost from 10 t of ABPs and delivery to the closest GW composting site would allow savings of EUR 4.1 thousand per year for a catering company. Additionally, co-maturation of GW and ABPs primary compost would allow a production of 13.7 tons of higher value compost in the composting site, which is two times higher than typical GW compost in the Lithuanian market because of better nutritional properties.

Author Contributions: Conceptualization, E.S. and I.K.; methodology, E.S. and D.K.; software, D.K.; validation, E.S., I.K. and R.P.B.; formal analysis, E.S.; investigation, E.S. and I.K; resources, E.S.; data curation, E.S.; writing—original draft preparation, E.S., I.K. and R.P.B.; writing—review and editing, I.K. and D.K; visualization, E.S.; supervision, I.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAO. *How to Feed the World in 2050*; High-Level Expert Forum; FAO: Rome, Italy, 2009.
2. Gustavsson, J.; Cederberg, C.; Sonesson, U. *Global Food Losses and Food Waste*; Save Food Interpack Düsseldorf Ger: Quebec City, QC, Canada, 2011.
3. Hegnsholt, E.; Unnikrishnan, S.; Pollmann-Larsen, M.; Askelsdottir, B.; Gerard, M. Tackling the 1.6-Billion-Ton Food Loss and Waste Crisis. Available online: https://www.bcg.com/publications/2018/tackling-1.6-billion-ton-food-loss-and-waste-crisis.aspx (accessed on 17 December 2018).
4. Kelleher, M.; Robins, J. What Is Waste Food? *Biocycle* **2013**, *54*, 36.

5. Oliveira, B.; De Moura, A.P.; Cunha, L.M. Reducing Food Waste in the Food Service Sector as a Way to Promote Public Health and Environmental Sustainability. In *Climate Change And Health: Improving Resilience And Reducing Risks*; Filho, L., Azeiteiro, W., Alves, U.M., Sud, F., Eds.; Springer International Publishing: Cham, Germany, 2016; pp. 117–132. [CrossRef]
6. Regulation (EC) No. 1069/2009. Regulation Ec No 1069/2009 of the European Parliament and of the Council of 21 October 2009 Laying Down Health Rules as Regards Animal by-Products and Derived Products not Intended for Human Consumption and Repealing Regulation (Ec) No 1774/2002. Available online: https://eur-lex.europa.eu/eli/reg/2009/1069/oj (accessed on 7 December 2018).
7. Commission Regulation (Eu) No 142/2011. Commission Regulation (Eu) No 142/2011 of 25 February 2011 Implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32011R0142 (accessed on 7 December 2018).
8. Kliopova, I.; Staniškis, J.K.; Stunžėnas, E.; Jurovickaja, E. Bio-nutrient recycling with a novel integrated biodegradable waste management system for catering companies. *J. Clean. Prod.* **2018**, *209*, 116–125. [CrossRef]
9. Staugaitis, G.; Kliopova, I.; Mažeika, R.; Gvildienė, K.; Jurovickaja, E. Arrangement of Requirements (Criterions) for Products Made of Biodegradable Waste. Unpublished work. 2016.
10. Meharg, A. Marschner's Mineral Nutrition of Higher Plants. 3rd Edition. Edited by P. Marschner. Amsterdam, Netherlands: Elsevier/Academic Press (2011), pp. 684 ISBN 978-0-12-384905-2. *Exp. Agric.* **2012**, *48*, 305. [CrossRef]
11. Zmora-Nahum, S.; Markovitch, O.; Tarchitzky, J.; Chen, Y. Dissolved organic carbon (doc) as a parameter of compost maturity. *Soil Biol. Biochem.* **2005**, *37*, 2109–2116. [CrossRef]
12. Zhang, L.; Sun, X. Evaluation of maifanite and silage as amendments for green waste composting. *Waste Manag.* **2018**, *77*, 435–446. [CrossRef]
13. Reyes-Torres, M.; Oviedo-Ocaña, E.R.; Dominguez, I.; Komilis, D.; Sánchez, A. A systematic review on the composting of green waste: Feedstock quality and optimization strategies. *Waste Manag.* **2018**, *77*, 486–499. [CrossRef]
14. Langenberg, W.J. A "Fresh" Look at Manure-"Compost"-an Iimportant "Added-Value Horticultural Product" Setting the Standards for Certification. Available online: http://www.compost.org/pdf/certifica.pdf (accessed on 4 November 2018).
15. Neugebauer, M.; Sołowiej, P. The use of green waste to overcome the difficulty in small-scale composting of organic household waste. *J. Clean. Prod.* **2017**, *156*, 865–875. [CrossRef]
16. Cao, L.; Luo, G.; Tsang, D.C.; Chen, H.; Zhang, S.; Chen, J. A novel process for obtaining high quality cellulose acetate from green landscaping waste. *J. Clean. Prod.* **2018**, *176*, 338–347. [CrossRef]
17. Ayilara, M.S.; Olanrewaju, O.S.; Babalola, O.O.; Odeyemi, O. Waste management through composting: Challenges and potentials. *Sustainability* **2020**, *12*, 4456. [CrossRef]
18. Pirani, S.I.; Arafat, H.A. Solid waste management in the hospitality industry: A review. *J. Environ. Manag.* **2014**, *146*, 320–336. [CrossRef]
19. Filimonau, V.; Todorova, E.; Mzembe, A.; Sauer, L.; Yankholmes, A. A comparative study of food waste management in full service restaurants of the united kingdom and the netherlands. *J. Clean. Prod.* **2020**, *258*, 120775. [CrossRef]
20. Green Service. Available online: http://Www.Greenservice.Lt/En/Bioreactor-Bio-10 (accessed on 5 November 2018).
21. Bio-10 Manual. Available online: http://Www.Greenservice.Lt/Images/Documents/Bio-10-Manual.Pdf (accessed on 5 November 2018).
22. Yang, X.; Liu, E.; Zhu, X.; Wang, H.; Dong, W.; Liu, H.; Liu, X. Impact of composting methods on nitrogen retention and losses during dairy manure composting. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3324. [CrossRef]
23. Iqbal, H.; Garcia-Perez, M.; Flury, M. Effect of biochar on leaching of organic carbon, nitrogen, and phosphorus from compost in bioretention systems. *Sci. Total. Environ.* **2015**, *521–522*, 37–45. [CrossRef]
24. Sommer, S. Effect of composting on nutrient loss and nitrogen availability of cattle deep litter. *Eur. J. Agron.* **2001**, *14*, 123–133. [CrossRef]
25. Boldrin, A.; Andersen, J.K.; Møller, J.; Christensen, T.H.; Favoino, E. Composting and compost utilization: Accounting of greenhouse gases and global warming contributions. *Waste Manag. Res.* **2009**, *27*, 800–812. [CrossRef]
26. Ulén, B. Leaching of plant nutrients and heavy metals during the composting of household wastes and chemical characterization of the final product. *Acta Agric. Scand. Sect. B-Plant Soil Sci.* **1997**, *47*, 142–148. [CrossRef]
27. Goedkoop, M.; Heijungs, R.; Huijbregts, M.; Schryver, A.; Struijs, J.; Zelm, R. Recipe 2008: A Life Cycle Impact Assessment Method Which Comprises Harmonised Category Indicators at the Midpoint and the Endpoint Level; 2008. Available online: https://www.leidenuniv.nl/cml/ssp/publications/recipe_characterisation.pdf (accessed on 8 December 2021).
28. Huijbregts, M.A.J.; Steinmann, Z.J.N.; Elshout, P.M.F.; Stam, G.; Verones, F.; Vieira, M.; Zijp, M.; Hollander, A.; Van Zelm, R. Recipe2016: A harmonised life cycle impact assessment method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* **2017**, *22*, 138–147. [CrossRef]
29. Ecoinvent Database V3.6. Swiss Centre for Life Cycle Inventories. 2019. Available online: https://ecoinvent.org/the-ecoinvent-database/ (accessed on 8 December 2021).
30. Présustainabili Ty. Simapro-Lca Software For Fact-Based Sustainability. Available online: Https://Simapro.Com/ (accessed on 6 March 2019).
31. Kumar, S.; Karan, R.; Kapoor, S.; Singh, S.P.; Khare, S.K. Screening and isolation of halophilic bacteria producing industrially important enzymes. *Braz. J. Microbiol.* **2012**, *43*, 1595–1603. [CrossRef]

32. Gao, M.; Li, B.; Yu, A.; Liang, F.; Yang, L.; Sun, Y. The effect of aeration rate on forced-aeration composting of chicken manure and sawdust. *Bioresour. Technol.* **2010**, *101*, 1899–1903. [CrossRef]
33. Dde Guardia, A.; Mallard, P.; Teglia, C.; Marin, A.; Le Pape, C.; Launay, M.; Benoist, J.; Petiot, C. Comparison of five organic wastes regarding their behaviour during composting: Part 2, nitrogen dynamic. *Waste Manag.* **2010**, *30*, 415–425. [CrossRef]
34. Setia, R.; Marschner, P.; Baldock, J.; Chittleborough, D. Is Co2 evolution in saline soils affected by an osmotic effect and calcium carbonate? *Biol. Fertil. Soils* **2010**, *46*, 781–792. [CrossRef]
35. Haroun, M.; Idris, A.; Omer, S. Composting of Tannery Sludge With Chicken Manure and Rice Bran. *Sci. Technol.* **2004**, *11*, 300–307.
36. Turan, N.G. The effects of natural zeolite on salinity level of poultry litter compost. *Bioresour. Technol.* **2008**, *99*, 2097–2101. [CrossRef] [PubMed]
37. Straathof, A.L.; Comans, R.N. Input materials and processing conditions control compost dissolved organic carbon quality. *Bioresour. Technol.* **2015**, *179*, 619–623. [CrossRef]
38. Gul, S.; Whalen, J.K. Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. *Soil Biol. Biochem.* **2016**, *103*, 1–15. [CrossRef]
39. Li, J.; Shi, W.; Jiang, C.; Bai, L.; Wang, T.; Yu, J.; Ruan, W. Evaluation of potassium as promoter on anaerobic digestion of saline organic wastewater. *Bioresour. Technol.* **2018**, *266*, 68–74. [CrossRef]
40. Pandey, P.K.; Cao, W.; Biswas, S.; Vaddella, V. A new closed loop heating system for composting of green and food wastes. *J. Clean. Prod.* **2016**, *133*, 1252–1259. [CrossRef]
41. Mccauley, A.; Jones, C.; Jacobsen, J. Soil pH and organic matter. *Nutr. Manag. Modul.* **2017**, *8*, 1–16.
42. Valdovska, A.; Vasermane, S. Bioperspektīva mastīta profilaksei govju ganāmpulkā. *Agrotops* **2019**, *11*, 60–62.
43. Rigobelo, E.C.; Cardozo, M.V.; De Avila, F.A.; Blackall, P.J. An evaluation of the use of probiotics and manure composting as strategies to reduce levels of Shiga toxin-producing Escherichia coli in sheep. *Afr. J. Microbiol. Res.* **2016**, *10*, 1011–1017.