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The 11th International Conference on Waste Management and Technology

第十一届固体废物管理与技术国际会议

Proceedings of the Eleventh International Conference on Waste Management and Technology

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Preface

The International Conference on Waste Management and Technoology (ICWMT) has been held 10 times since 2005, with the aim to promote the knowledge and experience exchanges among the international stakeholders, and to enhance the technology cooperation among the countries, which is organized jointly by Tsinghua University, Solid Waste and Chemicals Management Center, Ministry of Environmental Protection of China, United Nations Environment Programme, Stockholm Convention Regional Centre for Capacity-building and the Transfer of Technology in Asia and the Pacific.

The Eleventh International Conference on Waste Management and Technolgy (ICWMT 11) is held on October 21-24, 2016 in Beijing, China. The theme of ICWMT 11 is “Green Low-carbon Circular Development”. Many experts and scholars give excellent speeches about the development trends on waste management and technology. The main topics of the conference include “global partnership on waste management，circular economy & sustainable development，electronic waste policy and management, biomass waste disposal and energy recovery, treatment and reuse of waste from social source, etc.

Outstanding papers from domestic and abroad research institutes and universities are received by the ICWMT 11, representing the latest research trend and innovative ideas of current solid waste treatment filed, and leading the development in this filed for the furture.

Last but not the least, I would like to thank all the reviewers and the authors who devoted a substantial amount of work.

Jinhui Li

Prof. Jinhui Li

Professor/Executive Director

Tsinghua University

Basel Convention Regional Centre for Asia and the Pacific

Proceedings of the Eleventh International Conference on Waste Management and Technology

Contents

Acceptance Letter

Subject: Acceptance of the Full Manuscript Submitted to the Eleventh International Conference on Waste Management and Technology

Dear Ivan Deviatkin, Annika Sormunen, Riina Rantsi, Jouni Havukainen, Mika Horttanainen,

Thank you for submitting the full manuscript to the 11th International Conference on Waste Management and Technology (ICWMT 11). I am pleased to inform you that, after peer review, the manuscript titled "LCA of MSWI Bottom Ash Utilization with Advanced Treatment" has been accepted by the ICWMT 11.

The ICWMT 11 will be held in Beijing, China on October 21-24, 2016. The conference supplies an important international platform for specialists and officials to discuss scientific problems, exchange experiences, and look for innovative solutions. Participants from governments, research institutions, universities, industries will attend this conference.

Please don't hesitate to contact Dr. Shi Xiong if you intend to make oral presentation or have any question about the meeting.

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I look forward to meeting you in Beijing, China.

Yours sincerely,

Jinhui Li

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English Proceedings of the Eleventh International Conference on Waste Management and Technology

The Eleventh International Conference on Waste Management and Technology (ICWMT)

LCA of MSWI Bottom Ash Utilization with Advanced Treatment

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Abstract

In the study, the environmental impact from the recycling of the four mineral fractions obtained during the advanced treatment of municipal solid waste incineration bottom ash by the advanced dry recovery technology was assessed by the means of life cycle assessment (LCA). The mineral fractions technically suitable for the process were recycled in the road construction and the production of garden stones according to the specifications obtained during the real life experiments. The toxic impact associated with the recycling activities was assessed by the inclusion of the leaching data from the bottom ash and its mineral fractions. The two alternative scenarios were compared to the landfilling of untreated bottom ash. The results indicated that the recycling of the mineral fractions in the road construction was beneficial for the environment. The non-toxic impact was reduced in all impact categories with the highest reduction of 19.2% for the freshwater eutrophication potential; the average reduction for the remaining non-toxic impact categories was 3-5%. On contrary, the use of the minerals for the production of garden stones resulted in induced environmental impact across all impact categories. Regardless the scenario studied, the mineral fraction 0-2mm accounts for 58-94% of the total toxic impact caused by all four mineral fractions. Finally, the share of the collected leachate in the landfill was less significant than the presence of a wastewater treatment plant (WWTP) for the removal of heavy metals from the landfill leachate. The highest increase of the environmental impact reached 49% when a WWTP was introduced and only 6.7% when the leachate collection rate reduced to 80% from the ideal 99%.

Keywords: bottom ash, waste management, life cycle assessment, Advanced Dry Recovery

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1. Introduction

The rapid global population growth coupled with the intensive urbanization goes hand in hand with the -increasing generation of municipal solid waste (MSW). Responsible management of MSW is required in order to reduce the negative impact on the environment. Thermal treatment of source-separated MSW is an advantageous management method, since it allows for a significant reduction of waste mass along with the efficient energy recovery achieved in modern municipal solid waste incineration (MSWI) plants, thus, allowing for the substitution of fossil-based energy[1]. Moreover, waste incineration is recognized as the key element of a sustainable waste management strategy[2].

Further reduction of environmental impact could be achieved through the sustainable recycling of solid residues left after the treatment. Special attention is drawn to bottom ash (BA), which is the largest solid waste stream in a MSWI plant equipped with a grate boiler. Several methods to recycle MSWI BA have been identified previously[3].

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The most common methods include the use of BA in road construction[4–7], for cement or concrete production[8–10] and for the landfill construction [4,11]. Moreover, limited research is available on the use of the BA in the agricultural sector[12]. While recycling the BA, the production of natural aggregates or products manufactured from virgin materials is avoided and the negative impact on the environment reduced.

Despite the anticipated reduction of the environmental impact caused by the BA recycling activities, this is not necessarily the case since BA contains significant amounts of toxic substances [13–17], which might eventually leach into the environment while being recycled. To holistically assess the environmental impact from the multifaceted systems, like the waste management systems, the life cycle assessment has been widely recognized by academia and successfully applied by the industry for several decades[18,19]. Multiple assessments have been performed to study the impact from the recycling of BA of different origin by various utilization methods using the approach of LCA[4,7,20–27]. Moreover, an LCA of advanced utilization of BA incorporating the recycling of ferrous and non-ferrous fractions obtained during the ash treatment was performed[28].

However, the use of untreated BA studied in the current paper was impossible since the leaching values of certain heavy metals exceeded the limit values for the use of waste in road construction presented in the Finnish Government Decree concerning the recovery of certain wastes in earth construction 591/2006 [29]. Moreover, the field tests with the BA under the study were performed (results are under preparation) and the results showed technical applicability of the mineral fractions for road construction and the production of concrete-based products, namely garden stones. However, not all size fractions of the minerals can be utilized raising the need to treat the bottom ash and further fractionate the mineral fraction depending on its size.

In the present study, the environmental impact of the BA treatment by a novel technology, called advanced dry recovery, in a mobile treatment plant and further management of the four mineral fractions with different grain sizes was assessed. The applicability of the mineral fractions for the road construction and the production of the garden stones was technically studied. The primary data for the treatment process, as well as the recycling possibilities were gathered in the study. The leaching of the toxic substances from the BA and the four mineral fractions obtained was determined to study the toxic impact related to the recycling activities. The alternatives studied were compared to the landfilling of the untreated BA, as the least preferred management option.

2. Materials and methods

The LCA methodology was applied in the study since this is the most common method applied in the field of waste management[18,19,30]. The ISO 14040/44 standards[31,32], along with the ILCD Handbook guidelines[33], were primarily followed for the methodological choices regarding the LCA.

2.1. Goal and scope definition

The goal of the study was to assess the environmental impact of the MSWI BA treatment in a mobile treatment plant and consequent management of the mineral fractions obtained in the road construction and the production of garden stones, and to compare the impact of BA recycling with the BA landfilling, the least desired management option in waste management. The primary function of the study was to manage the MSWI BA by legally accepted and technologically suitable methods. The secondary functions of the study were determined by the alternative recycling methods included in the study: the construction of roads and the production of garden stones as specified in the present study. The functional unit was 1 000 kg of the BA managed, 0.22 m of roads built, and 0.35 m^3 of garden stones produced. The system boundaries of the product system were expanded to account for the production of materials substituted or affected by the recycling activities.

2.2. Bottom ash characterization

The BA studied originated from a MSWI plant equipped with a grate boiler. The plant is located in Mustasaari, Finland and treats approximately 180 000 t waste (mainly source-separated MSW, but also agricultural and industrial waste) from 50 municipalities with over 400 000 residents. The average annual amount of bottom ash generated is 30 000 t. The detailed information about the BA composition is presented by Sormunen & Rantsi [17].

For the study, the leaching data for each mineral fraction were determined by a column test according to CEN/TS 14405 [34] and it available in the article by Sormunen & Rantsi[17]. The leaching data for the untreated BA were obtained with the two-stage batch leaching test as presented in the standard EN 12457-3 [35]. The leaching of the toxic substances from untreated BA over the range of liquid to solid (L/S) ratios from zero to ten was interpolated based on the release curves of the toxic substances from the mineral fractions of the same BA.

2.3. Scenarios description

In the study, two alternative scenarios for the recycling of the mineral fractions were included, as well as the baseline scenario – landfilling of untreated BA.

2.3.1. Road construction (S1-RC)

In the road construction scenario (S1-RC), the mineral fractions were used for the road construction. The mineral fractions were suitable since the leaching of heavy metals decreased and was within the limit values set by the government. A specific blend of the four mineral fractions (composition is given in the LCI chapter of the study) to be utilized was transported to the utilization site by trucks. The minerals were used in the sub-base layer of a pedestrian road. The remaining mass of the mineral fractions was landfilled. Alternatively, gravel was used for the road construction when the mineral fractions were landfilled or utilized in the garden stones production. Leaching from the minerals or gravel was included in the scenario. No other layers of the road, as well as the road construction process, were affected by the utilization of the minerals, so the impact from these activities was excluded.

2.3.2. Garden stone production (S2-GSP)

In the Garden stone production scenario (S2-GSP), the mineral fraction 2-5 mm was used in the production of the garden stones. The remaining mineral fractions were not technically suitable for this purpose and, thus, were landfilled. Alternatively, sand was used for the garden stones production. Moreover, the recipe for the garden stones production was affected by the minerals utilization: more cement was required when the mineral fraction was utilized as stated in the life cycle inventory (LCI) chapter. The consumption of energy or other raw materials was not affected by the minerals utilization, and thus was not included in the study. After the lifetime of the garden stones of 20 years, the stones were assumed to be crushed and used in the road construction. Leaching from the end-of-life of the garden stones, i.e. utilization in road construction, was included, whereas the leaching from the use phase was omitted due to lack of data. Moreover, Allegrini[36] found that the impact from the end-of-life of concrete with the short lifetime would be dominant compared to its use phase.

2.3.3. Landfilling (S0-LF)

The landfilling scenario (S0-LF) included in the study reflects the situation when no application for either the untreated BA, or some of the mineral fractions was available. The bottom ash was transported to the landfill site and was disposed using specific machinery. The impact from the daily operational activities was included in the study, whereas that of the capital goods was not. According to a recent research paper[37], the majority of the impact from the landfilling originates from the operational activities, namely, spreading of a daily cover, spreading and compacting of waste, and generation of electricity for leachate pumps. The only impact category where the impact from capital goods dominated was the abiotic resources depletion potential and was associated with the acquisition of steel.

Regarding the leachate modelling, two potential situations were modelled in the study to deal with uncertainty. The first scenario considered 99% leachate collection rate and absence of specific leachate treatment from heavy metals. The second scenario was partly modelled according to Birgisdóttir[4] and considered the leachate collection rate of 80% and a specific WWTP for the removal of heavy metals and salt from the landfill leachate.

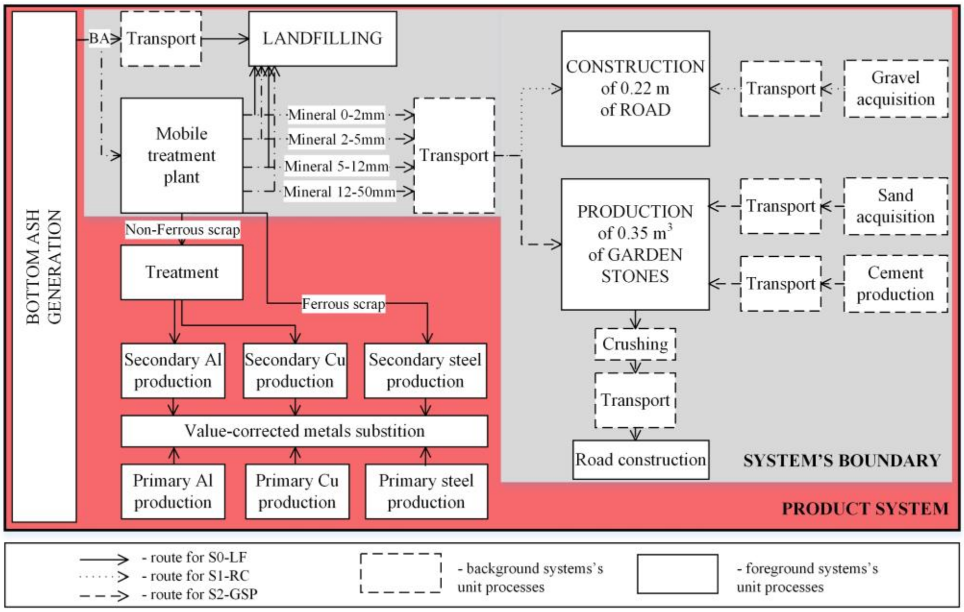

Fig. 1. The product system and the system's boundaries of the present study

2.4. System boundaries

The system boundaries of the product system studied are presented in Figure 1. The solid connectors between the blocks are used for the S0-LF, the connectors with the short dashes for S1-RC, the connectors with the long dashes for S2-GSP. The figure shows that the study begins with the generation of the BA and ends with the incorporation of the BA into a final product within the selected temporal scope of 100 years. Due to the comparative nature of the study, only the unit processes affected by the management of the BA or the mineral fractions were included in the study. The impact from the capital goods was omitted in the study due to the lack of consistent data throughout the product system. Finally, the impact from the recycling of ferrous and non-ferrous fractions was not included in the study due to the lack of reliable and consistent data, while it is known to have significant impact on the results [28].

2.5. Life cycle inventory

During the life cycle inventory (LCI) phase of the LCA study, all unit processes included in the system's boundary are compiled by gathering the information about elementary flows. In the study, all LCI data were compiled based on the affiliation of each unit process to either a background or a foreground system as shown in Figure 1.

2.5.1. Background system

Table 1 lists the background system unit processes of the study, along with their names, functions served in the model, transportation distances and payload capacities, if applicable.

2.5.2. Foreground system

The unit processes directly related to the management of the BA or the four mineral fractions are characterized under the foreground system.

Table 1. Unit processes from the background system.

Location in the model	Name	Function served	Transportation distance, km	Payload capacity full, t	Reference
S0-LF	GLO[a]: Truck	BA transportation	50	18.4	[38]
	FI[b]: Electricity grid mix	Electricity supply	N/A	N/A	[38]
S1-RC	GLO[a]: Truck	Mineral fraction transportation	5	18.4	[38]
		Gravel transportation	50	24.7	
	EU-27[c]: Gravel 2/32	Gravel supply	N/A	N/A	[38]
S2-GSP	GLO[a]: Truck	Mineral fraction transportation	200	18.4	[38]
		Sand transportation	10	24.7	
		Cement transportation	100	9.3	
		Crushed stone transportation	100	9.3	
	EU-27[c]: Sand 0/2	Sand supply	N/A	N/A	[38]
	RER[a]: Portland cement (CEM I) ELCD/CEMBUREAU	Cement supply	N/A	N/A	[38]
	Crushing [d]	Crushing of garden stones	N/A	N/A	[39,40]
All	EU-27[c]: Diesel mix at refinery	On-land vehicles fuelling	N/A	N/A	[38]

[a] – the data set of the unit process is representative globally;
[b] – the data set of the unit process is representative in Finland;
[c] – the data set of the unit process is representative in EU-27 member countries;
[d] – the diesel consumption was taken from [39], while emissions from [40] as for "Other drivable machines, diesel".

2.5.2.1. Landfilling

In general, the landfill was modelled following the approach of Birgosdottir[4]. The landfill had four time periods. The length of the periods was determined for the Finnish conditions and was partly similar to Birgosdottir[4]: I period – 5 years, II period – 2 years, III period – 30 years, IV period – 63 years. The height of the landfill body was set to 10 m. The default scenario had the leachate collection rate of 99% as considered realistic since modern landfills operate with double liners. Also, the mineral layer is usually built in 2-3 layers to prevent any cracks in the system. Finally, possible holes in the geosynthetic layer will also be local, since good contact with the mineral layer prevents horizontal spreading of leachate. Another parameter applied in the default scenario was the absence of a WWTP for specific heavy metals removal. However, the possible removal of heavy metals and salts was assessed in the sensitivity analysis of the study since the mineral sealing layer and geosynthetic layer can remove polar compounds from leachate passing through. Parameters related to the calculation of the L/S ratio, such as infiltration and precipitation, are presented at the end of the chapter.

Regarding the operational impact, 0.55 l diesel and 0.085 kWh electricity per ton of waste disposed and compacted were consumed[37]. The emissions from the machinery were retrieved from LIPASTO[40], a collection of data for emissions from the machinery used in Finland. The type of machinery used from the database was a roller.

2.5.2.2. Mobile treatment plant

The BA was treated with a Dutch technology called advanced dry recovery (ADR). During the treatment, the BA with the dry matter content (DMC) of 84% and the density of 1 700 kg/m^3 was first sieved to remove particles with the size exceeding 50mm. Next, the remaining BA passed through a system of dry screens, magnets, sifters, an eddy current separator, and the ADR[41]. More detailed information about the ADR technology is available from de Vries & Rem[42].

The outcomes of the process are the four mineral fractions: 0-2mm – 35% , 2-5mm – 13%, 5-12mm – 15%, 12-50mm – 14%, and the ferrous and nonferrous fractions, which accounted for the remaining 23% of the input mass [17]. The installation was run on diesel. Moreover, the machinery required to load and unload the materials also consumed diesel, which has been accounted for in the study. The emissions from the diesel combustion by the machinery were retrieved from LIPASTO[40] for an "Excavator, rubber tires", a "Wheel loader" for the drivable machines, and a "Generator sets, diesel" and "Other movable machines, diesel" for the movable equipment.

2.5.2.3. Construction of a road

In the study, a specific blend of the four mineral fractions (35% of 0-2mm, 25% of 2-5mm, 25% of 5-12mm, and 15% of 12-50mm) was used to build a sub-base layer of a pedestrian road. The ratio used in the study was experimentally determined and found to be the most appropriate for that purpose [41]. The width of the layer was 3 m, and the height of the layer 0.7 m. When the road was built with the minerals, around 480 kg of gravel was avoided. The substitution was based on a 1:1 ratio by the volume of the materials.

2.5.2.4. Production of garden stones

In the study, only the mineral fraction 2-5mm was used for the garden stone production process. The use of the minerals affected the consumption of sand and cement. 1 300 kg of sand and 300 kg of cement were required to produce one cubic meter of the conventional garden stones, while only 500 kg of sand and 320 kg of cement were required to produce the same volume of garden stones with the minerals. The substitution was based on a 1:1 ratio by the mass of the materials.

The lifetime of the garden stones was assumed to be 20 years, after which the stones were crushed. The crusher consumed 0.5 l diesel both for the loading and the crushing itself[39]. Finally, the crushed stones were used in the road construction process, similar the one described in sub-chapter 2.5.2.3.

2.5.3. Leaching data

To estimate the release of the toxic substances and salts as a results of leaching, the approach of Kosson[43] was used and the L/S ratio was calculated as follows:

$$ {}^{L}\!/_{S}\,ratio = \frac{P \cdot I \cdot T}{\rho \cdot h}, [\,{}^{l}\!/_{kg}] \qquad (1) $$

where P – annual precipitation, mm·year^{-1} (see Table 2);
I – infiltration rate, % (see Table 2);
T – time horizon, years (see Table 2);
ρ – density of a material, kg·m^{-3} (see Table 2);
h – height of a material layer, m (see Table 2).

Primary leaching data for the mineral fractions were used in the study and were determined by the column percolation test CEN/TS 14405 [34] and the results presented in Sormunen & Rantsi[17]. Primary leaching data for the raw bottom ash and concrete products manufactured analogically to the garden stones were used in the study and were determined by the two-stage batch test EN 12457-3 [35]. The leaching data from gravel and sand were retrieved from Laine-Ylijoki[44]. The following elements were included to study the toxic impact caused by the BA, the mineral fractions and the garden stones: As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn, Co, V, chloride, fluoride, sulphate, and dissolved organic carbon. All elements were assumed to leach into the ground in the road construction process and into the ground from uncollected leachate and into freshwater from collected leachate in the landfilling scenario. Further behavior into the environment was considered in the impact assessment method used in the study. The leaching values below the limit of quantification were accounted for as halves of the limits of quantification.

Table 2. Parameters used to calculate the L/S ratio in the study.

Location in the model	P, mm/year	I, %	T, years	ρ, kg/m^3	*h*, m
S0-LF	515	80% – I period	5	1 700	10
	515	40% – II period	2	1 700	10
	515	30% – III period	30	1 700	10
	515	30% – IV period	63	1 700	10
S1-RC	354 [a]	7%	100	1 720	0.7
S2-GSP	354 [a]	7%	80	1 900	0.7

[a] – the precipitation is given for the period when ambient air temperature is above zero, thus accounting for the clearing of roads in winter.

2.6. Life cycle impact assessment

In the study, the most developed characterization models were used as recommended for the European context[45]. The list of the recommended impact categories named as “Impacts ILCD/PEF recommendation v1.09” in the GaBi software was further narrowed by excluding the “Resource depletion, water” , “Ionizing radiation, humans”, and “Ionizing radiation, ecosystems” impact categories because of inconsistency with the goal of the study. Moreover, the impact on “Respiratory inorganics” was left outside of the study due to lack of consistent data. The following impact categories were included: acidification potential (AP), climate change, or global warming potential, 100 years (GWP), ecotoxicity potential (EP), freshwater eutrophication potential (FEP), marine eutrophication potential (MEP), terrestrial eutrophication potential (TEP), carcinogenic human toxicity potential (HTP_c), non-carcinogenic human toxicity potential ($HTP_{non\text{-}c}$), ozone layer depletion potential (ODP), photochemical ozone formation potential (POFP), and resource depletion potential for mineral, fossil, and renewable materials (RDP).

3. Results and discussion

3.1. Overall environmental impact

The results for the two alternative scenarios are presented in Figure 2. The results are presented as relative changes caused by the recycling activities in S1-RC and S2-GSP in relation to the impact caused by the baseline scenario – S0-LF – for a number of impact categories. The impact categories were divided into a group of non-toxic (top graph) and a group of toxic (bottom graph) impact categories. The results were also grouped into several categories. The “Landfill operation” presents the results associated with the actual disposal of the BA or the mineral fractions not suitable for the recycling. “Landfill leaching”, “Road leaching”, and “Garden stone leaching” present information related to the leaching of the chemical substances into the environment from the BA, the minerals, or the substituted products depending on the scenario. The categories related to transportation include the impact from the transportation activities themselves, as well as from the diesel manufacturing. The impact from the treatment of the BA in the ADR facility is shown in the “Bottom ash treatment” category. Finally, the impact from the avoided or additional production of the materials affected by the recycling activities is shown in the “Affected product acquisition”.

The results clearly indicated the superiority of the road construction process (S1-RC) utilizing 520 kg of the minerals over the garden stone production (S2-GSP) utilizing 130 kg of the minerals for both non-toxic and toxic impact categories. Regarding the non-toxic impact categories, the avoided impact in S1-RC ranged from 0% for the ODP to as high as 19.2% for the FEP. As per the remaining impact categories, the reduction achieved in S1-RC ranged 3-5%. On contrary, the additional impact in S2-GSP ranged 3-9%. Regarding the toxic impact categories, both scenarios performed worse than landfilling for ETP and HTP_c with the additional impact of 4.9% and 29.4% for S1-RC and 48% and 82.7% for S2-GSP. A reduction of the $HTP_{non\text{-}c}$ of 17.5% for S1-RC and 1.2% for S2-GSP was achieved, on the other hand. In the study by Allegrini [28], additional impact for the ETP and HTP_c from the MSWI BA utilization in road or concrete production was stated, while the use of the BA in concrete was beneficial for $HTP_{non\text{-}c}$.

In the study, the prime difference in the results between the two alternative scenarios was the impact associated with the transportation of the residues. Since the product system of the study was only limited to the processes affected by the recycling activities, the baseline impact of the product system was small, causing higher importance of the transportation activities. In S1-RC, the majority of the minerals was sent for the road construction with the transportation distance of only 5 km, whereas in S2-GSP, the transportation distance for the minerals to the production plant was set to 200 km and the distance for the remaining minerals to the landfill – 50 km. All these aspects affected the emissions from the transportation, as well as the diesel consumption. Another reason was the impact from the transportation and acquisition of avoided or affected materials. Avoided gravel was important for the overall positive impact in S1-RC. At the same time, in S2-GSP, sand was only partly replaced by the use of the minerals, whereas additional 20 kg of cement were required. Because the cement production had significantly higher impact on the environment compared to the acquisition of sand, the total impact from the affected materials acquisition was higher in S2-GSP.

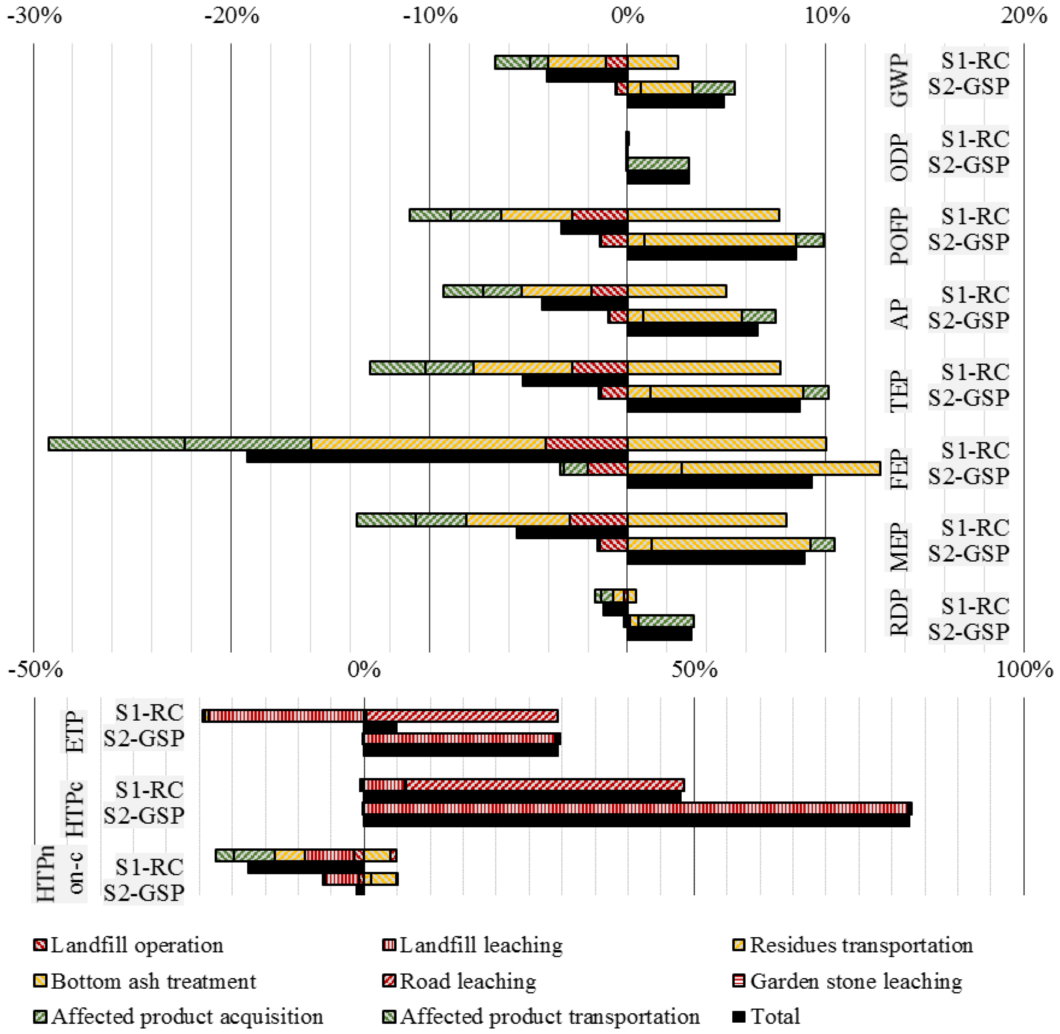

Figure 2. The results of the LCA study over a range of toxic (top) and non-toxic (bottom) impact categories.

Closer analysis of the toxic impact categories showed that several factors affected the differences in the total results. Similar for all toxic impact categories, the L/S ratio for the BA and the mineral fractions was different in the landfill due to the difference in the densities of the materials. The cumulative L/S in the landfill after 100 years was 0.99 for the BA, and 2.47 for the minerals. This was the reason for the increased impact from the landfilling for the HTP_c and ETP in S2-GSP. Moreover, the leaching of different substances strongly depends on the L/S ratio causing the controversial behavior between, e.g. the increased impact from the landfill on HTP_c and decreased impact on HTP_{non-c}.

Finally, the difference was associated with the properties of the different mineral fractions. The mineral fraction 0-2mm was the most toxic fraction causing over than 90% of the overall toxic impact for ETP and HTP_c and more than 50% of the HTP_{non-c} in the system. Therefore, the use of 51% of the mineral fraction 0-2mm in the road construction resulted in the superiority of S1-RC scenario compared to S2-GSP for the toxic impact categories. When the mineral fraction 0-2 mm was used in the S1-RC, the leaching was lower than in the landfill due to lower L/S ratio for the road construction (equals to 2) than for the landfilling.

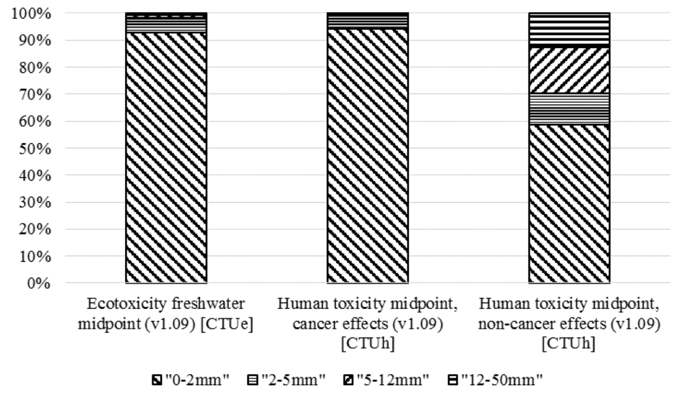

Figure 3. Relative toxic impact of the four mineral fractions accounting for their shares in the total mass at L/S 2.

The impact from the landfill was based on the assumption that the leachate collection rate was 99% and there was no specific WWTP plant for the removal of the heavy metals from leachate. In the sensitivity analysis, the leachate collection rate was lowered to 80% and the WWTP was included with the removal efficiencies as shown in the article by Gianfilippo[26]. The results of the sensitivity analysis are shown in Figure 4 as the total impact over the toxic impact categories; the non-toxic categories were not affected by the analysis.

As can be seen, the WWTP had significant impact on the total toxic impact of the product system. The largest increase of the impact was for ETP in S1-RC by 49%, S2-GSP by 31%, and HTP_c in S1-RC by 28%. The remaining impact categories did not change by more than 5% in both scenarios. At the same time, the impact of the collection rate only had moderate impact on the results with the highest change of around 7% in S1-RC for ETP.

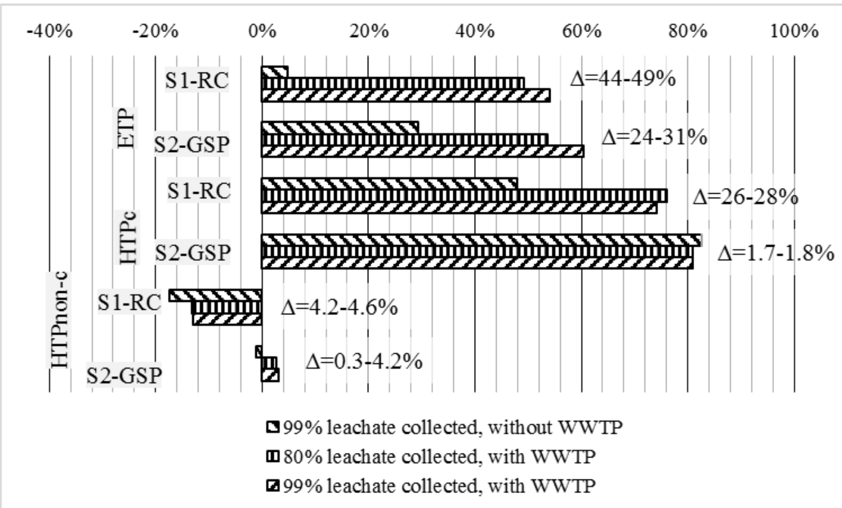

Figure 4. Results of the sensitivity analysis.

4. Conclusions

The results of the study showed that the advance treatment of the MSWI BA in order to recycle the mineral fractions reduced the impact on the non-toxic impact categories when the minerals were used for the road construction. On the other hand, the use of the mineral fraction 2-5mm in the garden stone production resulted in increased impact compared to the reference scenario. The induced impact in S2-GSP primarily originated from the additional use of cement in the process and comparatively high (200km) transportation distance to the final utilization place. In most cases, both scenarios resulted in additional impacts in the toxic impact categories. The impact was primarily due to the increased leaching of toxic elements resulting from higher L/S ratios. Moreover, the increase in the adverse impacts became more evident when the WWTP for leachate treatment was introduced in the landfill scenario, which significantly reduced the baseline impacts from the landfilling.

Acknowledgements

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