5-2019

Soil-less Soil Study - A Sustainable Solution for Green Infrastructure Soil Media - Part 1, Life Cycle Assessment

Anqi Zhang
University of Pennsylvania

Zhang, Anqi, "Soil-less Soil Study - A Sustainable Solution for Green Infrastructure Soil Media - Part 1, Life Cycle Assessment" (2019). *Master of Environmental Studies Capstone Projects*. 78.
https://repository.upenn.edu/mes_capstones/78

Soil-less Soil Study - A Sustainable Solution for Green Infrastructure Soil Media - Part 1, Life Cycle Assessment

Abstract

The management of waste glass is of great concern worldwide due to its non-combustible and non-putrescible nature. Additionally, there is an urgent need for more sustainable alternatives and sources for aggregate, as the world is running out of quarried sand for use in construction. The Soil-less Soils Project, which is currently being run by the Philadelphia-based landscape architecture firm, OLIN, in partnership with the University of Pennsylvania and Temple University, is located at the nexus of two pressing environmental issues associated with urban development: a scarcity of sand and an overabundance of post-consumer glass. To solve these problems, the research initiative aims to develop and test a low-carbon footprint, rapidly renewable manufactured soil mix for use in green infrastructure and urban planting applications. The principle components of the mix are Class A biosolids and fine-ground recycled glass cullet. While the primary goals of the Soil-less Soils Project are environmental, the use of glass, an inert material, in place of mineral aggregate may also provide benefits in terms of soil function and uniformity in designed landscapes. To assess the environmental impacts of the substitution of natural sand with glass fines in the Soil-less Soil mix, a comparative cradle-to-gate life cycle analysis (LCA) was performed on the two materials. This is the first ever LCA study on recycled aggregates from waste glass in the landscape architecture industry, which was based on both the database and the first hand data. The results reveal that compared with the conventional sand, recycled aggregates produced from waste glass reduce 67% greenhouse gases (GHGs) emission with a saving of 48% water usage. The positive outcomes of the study will provide guidance on maximizing waste glass recycling and encourage the use of waste glass in the green infrastructure application.

Disciplines

Environmental Sciences | Physical Sciences and Mathematics

Abstract:

The management of waste glass is of great concern worldwide due to its non-combustible and non-putrescible nature. Additionally, there is an urgent need for more sustainable alternatives and sources for aggregate, as the world is running out of quarried sand for use in construction. The Soil-less Soils Project, which is currently being run by the Philadelphia-based landscape architecture firm, OLIN, in partnership with the University of Pennsylvania and Temple University, is located at the nexus of two pressing environmental issues associated with urban development: a scarcity of sand and an overabundance of post-consumer glass. To solve these problems, the research initiative aims to develop and test a low-carbon footprint, rapidly renewable manufactured soil mix for use in green infrastructure and urban planting applications. The principle components of the mix are Class A biosolids and fine-ground recycled glass cullet. While the primary goals of the Soil-less Soils Project are environmental, the use of glass, an inert material, in place of mineral aggregate may also provide benefits in terms of soil function and uniformity in designed landscapes. To assess the environmental impacts of the substitution of natural sand with glass fines in the Soil-less Soil mix, a comparative cradle-to-gate life cycle analysis (LCA) was performed on the two materials. This is the first ever LCA study on recycled aggregates from waste glass in the landscape architecture industry, which was based on both the database and the first hand data. The results reveal that compared with the conventional sand, recycled aggregates produced from waste glass reduce 67% greenhouse gases (GHGs) emission with a saving of 48% water usage. The positive outcomes of the study will provide guidance on maximizing waste glass recycling and encourage the use of waste glass in the green infrastructure application.

ABSTRACT

SOIL-LESS SOIL STUDY-A SUSTAINABLE SOLUTION FOR GREEN INFRASTRUCTURE SOIL MEDIA – PART 1, LIFE CYCLE ASSESSMENT

Anqi Zhang

Nancy English, PhD

The management of waste glass is of great concern worldwide due to its non-combustible and non-putrescible nature. Additionally, there is an urgent need for more sustainable alternatives and sources for aggregate, as the world is running out of quarried sand for use in construction. The Soil-less Soils Project, which is currently being run by the Philadelphia-based landscape architecture firm, OLIN, in partnership with the University of Pennsylvania and Temple University, is located at the nexus of two pressing environmental issues associated with urban development: a scarcity of sand and an overabundance of post-consumer glass. To solve these problems, the research initiative aims to develop and test a low-carbon footprint, rapidly renewable manufactured soil mix for use in green infrastructure and urban planting applications. The principle components of the mix are Class A biosolids and fine-ground recycled glass cullet. While the primary goals of the Soil-less Soils Project are environmental, the use of glass, an inert material, in place of mineral aggregate may also provide benefits in terms of soil function and uniformity in designed landscapes. To assess the environmental impacts of the substitution of natural sand with glass fines in the Soil-less Soil mix, a comparative cradle-to-gate life cycle analysis (LCA) was performed on the two materials. This is the first ever LCA study on recycled aggregates from waste glass in the landscape architecture industry, which was based on both the database and the first hand data. The results reveal that compared with the conventional sand, recycled aggregates produced from waste glass reduce 67% greenhouse gases (GHGs) emission with a saving of 48% water usage. The positive outcomes of the study will provide guidance on maximizing waste glass recycling and encourage the use of waste glass in the green infrastructure application.

1. Introduction:

Like naturally occurring soil, manufactured or designed soil is comprised of a mix of organic and inorganic materials. The inorganic or mineral components of a soil mix are often mined from off-site stone or sand quarries and mixed with organic matter to create a designed planting medium. The world is now facing a global sand crisis: we are running out of sand. As the global demand for natural resources used in construction and transport infrastructure increased 23-fold from 1900 to 2010, sand and gravel, the two largest components of these primary inputs, are the most extracted materials worldwide, exceeding even fossil fuels (Torres, Brandt, Lear, & Liu, 2017)

As demand for sand and gravel increase, and the natural supply dwindles, environmental and social impacts of extraction become more severe. First, the over-exploitation of sand has significant environmental impacts on rivers, deltas and coastal and marine ecosystems resulting in loss of land through river or coastal erosion, lowering of the water table, and decreases in sediment supply. Moreover, sand extraction from rivers, beaches, and seafloors physically alters rivers and coastal ecosystems, disturbing the benthic habitats and causing erosion (Torres, Liu, Brandt, & Lear, 2017). Such environmental impacts could even have cascading effects on human well-being, since shoreline and river erosion lead to natural hazards such as storm surges and tsunami events (Asabonga, Cecilia, Mpundu, & Vincent, 2017).

Open-pit mining, the sand sourcing method for our study, is a method of extracting rock or minerals from the earth by their removal from an open pit or barrow (Mine-engineer, n.d.). Exposing and mining the material generally involves excavating, relocating and abandoning large quantities of waste rock, especially for the deep open-pit mining (Mine-engineer, n.d.). Additionally, the process of disrupting the ground leads to the creation of air pollutants where the main source of air pollutants comes from the transportation of minerals (Huertas, Huertas, Izquierdo, & González, 2012). The environmental and social hazards involved in the processes of drilling, blasting and the loading and unloading of overburden include ecosystem disturbance and the damaging of air quality (Huertas et al., 2012). The inhalation of these pollutants can cause issues to the lungs and even increase mortality, which may lead to significant public health and safety crisis (Huertas et al., 2012).

Furthermore, in underdeveloped and developing countries, sand mining creates illegal businesses which cause local conflict. While creating some employment for residents and local business, sand mining, especially in a developing country such as India or China, has a significant social cost (Mine-engineer, n.d.). Due to the increasing demand for construction in India, mining for sand employs more than 35 million people and sand mining is almost as valuable as mining for gold.

To reduce these problems, states and governments have started to take actions to manage and control the extraction of sand. For example, the California Coastal Commission recently approved an agreement to shut down the last beach sand mine in the mainland US completely by 2020 (U.S. News, 2017).

In addition to problems associated with sand extraction, this study addresses another pressing environmental issue: the over-abundance of low-value post-consumer glass waste in the US. Currently in the US, there is a surplus of post-consumer waste glass collected by municipal recycling programs since some colored glass and small pieces cannot be recycled and go into landfills (Building Product Ecosystems, n.d.). Recent changes in China's recycling policies also affect the recycling markets for materials such as plastics and glass. In July 2017, China's Ministry of Environmental Protection told the World Trade Organization that it would no longer accept imports of 24 common types of once-permitted solid waste due to contamination concerns. These changes have drastically reduced demand for recyclable materials, raising the cost to municipalities nearly tenfold, from $4 to $40 per ton in Philadelphia (Newhouse, 2018) . The reasons why recyclers typically do not want glass are the lack of markets for waste glass and the high costs of recycling the glass due to breakage and cross contamination.

To address both problems, that of over-extraction of sand and overabundance of glass, this study will evaluate and compare the environmental footprints of two fine aggregate types, through life cycle assessment: recycled glass fines aggregate and natural sand.

2. Literature Review:

In order to overcome the increasing concern of today's resource depletion and to address environmental considerations, both developed and developing countries begin to seek a more sustainable way to redesign their construction industry (Ortiz, Castells, & Sonnemann, 2009). Life Cycle Assessment is a tool to assess the environmental impacts and resources used throughout a product's life cycle, including raw material extraction, transport, manufacturing, as well as the use phase and the end of life (Finnveden et al., 2009). A study in Italy combined a Geographical Information System (GIS) and the Life Cycle Assessment (LCA) models to compare the environmental impacts of recycled aggregates and conventional aggregates by collecting site-specific data and paying particular attention to categories of land use, transportation and avoided landfill (Blengini & Garbarino, 2010). According to the positive results of that study, avoided impacts exceeded the induced impacts for 13 out of 14 environmental indicators, and the C&DW recycling chain was proved to be eco-efficient (Blengini & Garbarino, 2010). Construction and demolition (C&D) waste refers to the solid waste generated from construction, renovation, repair, and demolition of houses, large building structures, roads, bridges, piers, and dam(CT.GOV, 2013). Although waste glass is less hazardous than the C&D waste, the treatment process of waste glass is similar to the C&D waste, which can be a good reference to our study.

Hong Kong is another city that is exposed to a severe shortage of sand and a C&D and waste glass management challenge. Due to the lack of glass manufacturing industry in Hong Kong, in recent years about 353 t/day of waste glass was disposed of at landfills, equivalent to 3.7% of the total municipal solid waste landfilled, while the recycling rate of glass in Hong Kong was only 17%(HKEPD (Environmental Protection Department), 2015). According to Hossain, recycling C&D wastes and post-consumer glass cullet to produce manufactured aggregates not only minimizes the landfilling impacts but also saves primary resources such as non-renewable energy (Hossain, Poon, Lo, & Cheng, 2016a). Here, the LCA results show that producing recycled aggregates from C&D waste reduced about 49–51% of the net environmental impacts compared to the production of aggregates from crushed stone (Hossain et al., 2016). In addition, about 185 MJ of non-renewable energy consumption and 14 kg CO2eq. GHG emissions can be saved by producing each ton of recycled fine aggregates from waste glass instead of river sand (Hossain, Poon, Lo, & Cheng, 2016b).

Therefore, although there is no related research comparing recycled glass fines with natural sand through LCA in the US, there are previous studies in the international construction industry proving the environmental benefits of renewable aggregates made from C&D and glass waste by means of life cycle assessment, which indicates the rationale and value of this study.

3. Methodology:

According to ISO 14040 (2006a) and ISO 14044 (2006b), life cycle assessment (LCA) methodology is used to capture the environmental impacts and also the environmental benefits of a product, process or system by considering the whole lifecycle. LCA consists of four main steps: (1) goal and scope definition (see Fig. 1 &2), (2) life-cycle inventory, (3) impacts assessments, and (4) interpretation (Finnveden et al., 2009). LCA modelling will be performed using the GaBi 8 software application. To keep the data consistent, the geographical boundary of data will be restricted to within the United States. The impact will be assessed in accordance with the methodology of ReCiPe 2016 to track the hotspots of the LCA since it is the most recent and harmonized indicator approach available in life cycle impact assessment ("ReCiPe | PRé Sustainability," n.d.). In order to capture site specific and meaningful data relevant to the use of transport systems within the network of quarries and recycling plants, average distances will be retrieved from a GIS model.

4. Goal and scope definition

4.1 Goal of the study

The objective of this study is to evaluate the environmental impacts of fine aggregate production from waste glass compared to the extraction and processing of quarried sand. Based on the results of this LCA, a sustainable solution will be designed to improve the sustainability of green infrastructure soil media.

4.2 Scope of the study

4.2.1 System boundary

The system boundaries were as follows (Fig. 1 and 2):

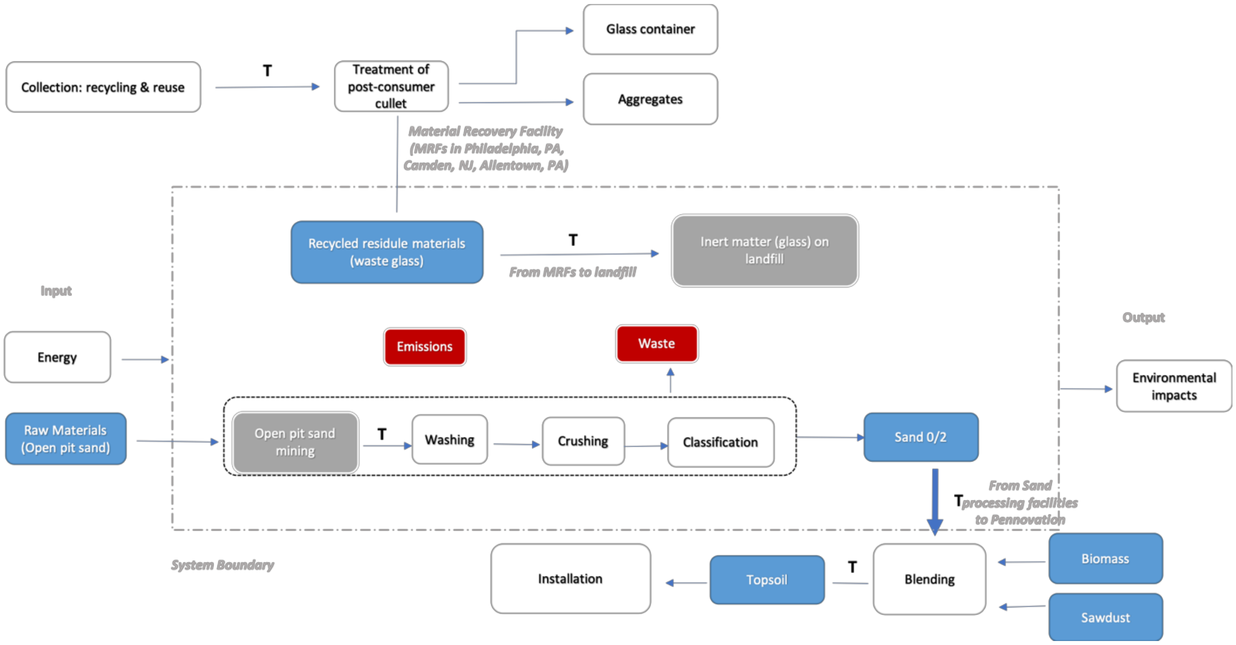

Figure 1 System boundary for producing conventional sand

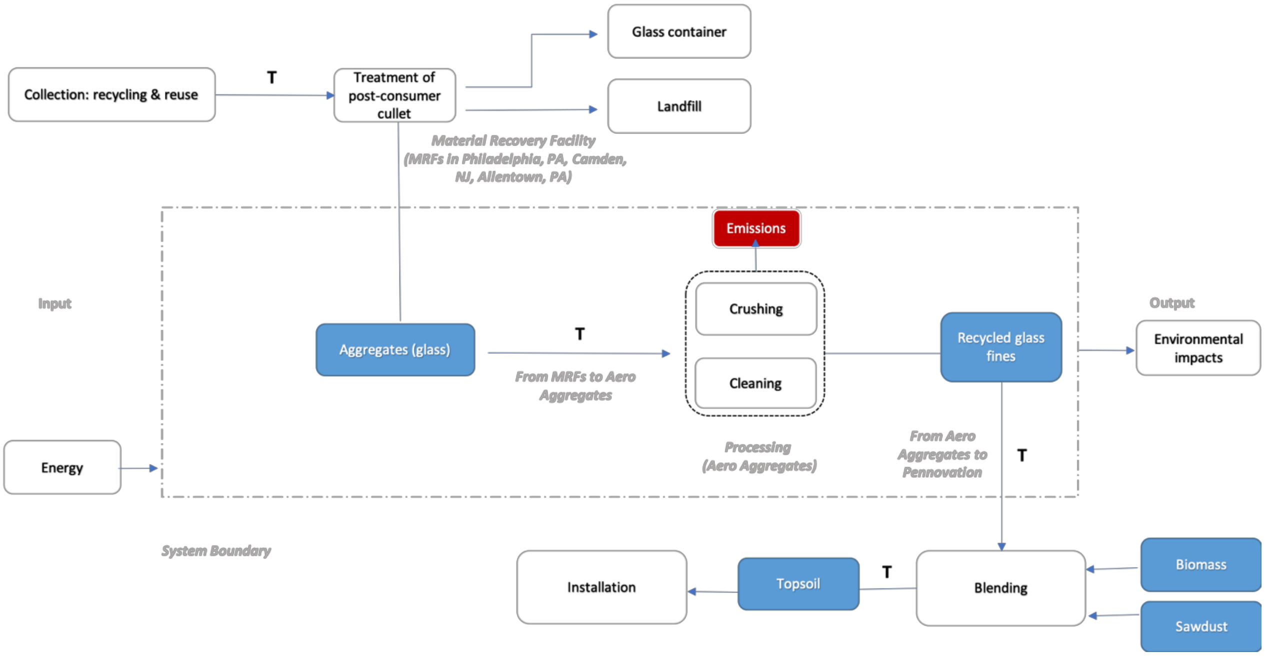

Figure 2 System boundary for producing glass fines

1) Input and output flows of material (mainly chemicals) and energy resources (electricity) were studied in depth for all processes.
2) The system boundaries included the raw material extraction process; manufacturing process; the transport.

3) The system boundaries exclude the blending phases since blending processes for glass fines and natural sand are similar. Thus, I assume these two processes have the same environmental impacts.
4) Transport distance for sand fines: To locate sand mines most likely to supply natural material to green infrastructure installations in Philadelphia, 9 Philadelphia-based OLIN projects are selected as the benchmark projects. The average distances between the sand mining facility and sand processing facility are used in the LCA model.
5) Transport distance for glass fines: the transport distance was calculated based on the local benchmark material recovery facilities (MRFs), waste glass processing facility (Aero Aggregates) and the final project site (Pennovation). The average distance between each facility is used in the LCA model.
6) In this study, the avoided landfill of glass waste is considered as an environmental credit. Therefore, I include the landfill of glass in the system boundary of the conventional sand production to calculate the environment benefits of reusing the waste glass instead of landfilling it. In the final sensitivity analysis, a second scenario without this landfill credit is also considered.
7) The system boundary of extraction and production of the quarry sand (see Fig. 1) includes the avoided inert material (glass) landfilling, open-pit sand mining, transport from quarry to plant, washing, pre-classification, crushing, classification and transport to project site. In terms of the soil made from recycled glass, the system boundary (see Fig. 2) includes waste glass collection, sorting by color, washing, drying, transport from recycling facility to Aero Aggregates, crushing, cleaning, separating and transport to project site. (Pennovation).

4.2.2 **Assumptions**

a) Glass fines processing facility- Aero Aggregates. Due to the similarity of treatment processes of waste glass, this study chooses a local company in Eddystone, PA-Aero Aggregates, which produces Ultra-Lightweight Foamed Glass Aggregates (UL-FGA) from 100% post-consumer recycled glass, as a benchmark. The processes of producing the foamed glass aggregate are almost the same with our study except for the baking and cooling process. Therefore, some primary data is collected from Aero Aggregates, which improves the data quality of the LCA.

b) Sand mining and processing facilities: based on local OLIN projects. Since this LCA will be applied to local green infrastructure installations, nine existing OLIN project case studies were reviewed, and the sand mining and processing facilities used in those projects were referenced to indicate the distance between sand extraction and sand processing.

c) Project location: Pennovation. The Pennovation Center, a 58,000sf business incubator and laboratory, was selected as the assumed project location for this study. This choice reflects the assumption that a future phase of the Soil-less Soil Project will include a horticultural field plot study at this location. Additionally, this is the approximate location of where soil will be mixed if the Soil-less Soil planting medium is adopted by the University of Pennsylvania, a project partner, for use on campus.

d) Cut-off rules for each unit process: According to "GaBi Databases Modelling Principles", the databases model covers at least 95 % of the mass and energy of the input and output flows, and 98 % of their environmental relevance.

4.2.3 Function of the product and function unit

The waste glass and sand in this study both functioned as the inorganic component in manufactured soil, which benefits the drainage function of green infrastructure installations. Sand generally refers to the coarse-textured (less than 2-millimeter) mineral fraction of soil. With high infiltration rates and compaction resistance, sand plays an important role in soil mixes used in green stormwater or "bioswale" infrasturctures (Soil Science Society of America, n.d.). With similar properties of being coarse and gravelly, the post-consumer glass aggregates provide similar functionality in the green infrastructure soil.

The function unit of this study is the production of 1 ton of conventional sand vs. 1 ton of recycled aggregates made from waste glass.

4.2.4 Production of the sand component of manufactured topsoil

As shown in Fig. 3, the preparation of sand consists of a series of basic processes including extraction, washing, pre-classification and crushing. The moisture in the quartz grains is dried in a drying oven with this hot air until it has a water content of less than 0.2 %. The assessment includes the life cycle stages from energy generation and raw material supply to the finished product at the factory gate. The infrastructure and the production of the manufacturing facility itself is not considered.

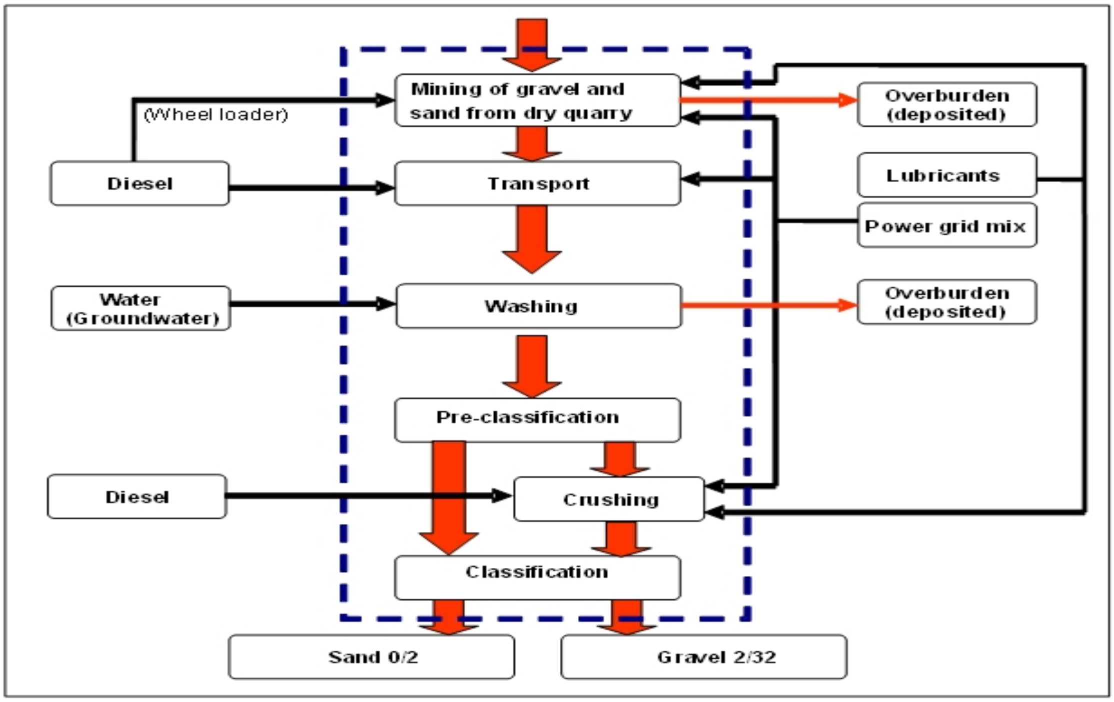

Figure 3 Production of sand from quarry
Source: GaBi dataset document,
retrieved from: http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1e6710e7-d0f3-40f4-ba44-ab5f06a2ea46.xml

To indicate the transport distance for the study, nine Philadelphia-based projects were reviewed, of which sand or soil sources were identified for five projects. Three projects used soil from Green Pro Materials in Jackson, NJ (see Table 1). The others sourced materials from Mays Landing Road, NJ and East Brunswick, NJ. A transport distance of 8.09 miles is used between the quarry and the processing plant, while a distance of 47.33 miles is used between the plant to Pennovation.

In the model, the exploration, mining/production, processing and transport processes of the energy carrier supply chains are modelled according to the specific situation of each electricity producing country. The different production and processing techniques (emissions and efficiencies) in the different energy producing countries are considered, e.g. different crude oil production technologies or different flaring rates at oil platforms.

Table 1 Sand source for OLIN projects

Sand source for 9 OLIN projects							
	Company	Quarry location	Plant location	Distance from mining to blending (miles)	Distance from quarry to plant (miles)	Distance from plant to Pennovation (miles)	Total transport distance
1	GreenPro Material	1143 Tomsriver Rd, Jackson NJ 08527	1143 Tomsriver Rd, Jackson NJ 08527	0*3	0	65.4*3=196.2	196.2
2	Laurel Valley soils	Port deposit Maryland Port Elizabeth, Maurice River, NJ 08332	705 Penn Green Rd, Avondale, PA 19311	30.9 66.2	185.25	39.6	185.25
3	Advanced Soil Technologies	Williams town, NJ	Williams town, NJ	0*2	0	24.1*2=48.2	48.2
	Average distance				48.55/ 6=8.09	284/6=47.33	55.42

To consider the avoided landfill as an environmental credit, the data set for inert matter (glass) on landfill represents deposition of the specified waste material type (e.g., untreated wood, glass/inert waste, plastics) to an average U.S. Municipal Solid Waste (MSW) landfill. This landfill model considers the production and transportation of materials used to cover and line the landfill, as well as the fuels used to operate the landfill. The data set represents the U.S. specific situation for average annual precipitation, landfill construction regulations, rates of landfill gas capture, and landfill gas combustion technologies (GaBi US Dataset, 2019).

According to Archie Filshill, CEO and Co-Founder of AeroAggregates, the main sources of their raw materials (glass cullet) are from MRFs in Philadelphia, Camden and Allentown (see Table 2). Therefore, based on a Google search, 10 active material recovery facilities (MRFs) which accept glass containers were selected as the benchmark MRFs in this study. The average distance from MRFs to the nearest landfills is 9.4 miles.

Table 2 Transport distance calculation from MRFs to landfills

NO.	MRF	Address	Landfill name	Address	Distance (miles)
		MRF in Philadelphia, PA to the nearest landfill facilities			
1	Waste Management - Philadelphia Transfer Station	3605 Grays Ferry Ave, Philadelphia, PA 19146	HARRISON AVENUE LANDFILL	HARRISON AVE & STATE ST, 1507 E State St, Camden, NJ, 08105	11.4
2	PHILLY*WIDE Waste & Recycling Co.	1317, 2415 Morris St, Philadelphia, PA 19145			7.9
3	RoadRunner Recycling	1010 N Hancock St suite 163, Philadelphia, PA 19123			4.2
4	Gold Medal Disposal	3323 S 61st St, Philadelphia, PA 19153			9.2
5	Geppert Recycling	4000 Pulaski Ave, Philadelphia, PA 19140			7.9
		MRF in Camden, NJ to the nearest landfill facilities			
6	National Paper Recycling	1531 Ferry Ave, Camden, NJ 08104	PENNSAUKEN TWP	9600 RIVER RD	8.4
7	ReCommunity	2201 Mt. Ephraim Ave.Bldg 10-10A, Camden, NJ 08104			7.5
8	Waste Management - Camden, NJ	1001 Fairview St, Camden, NJ 08104			7.8
		MRF in Allentown, PA to the nearest landfill facilities			
9	Allentown Recycling	1400 Martin Luther King Jr Dr, Allentown, PA 18102	IESI PA BETHLEHEM LDFL CORP	2335 Applebutter Rd, Bethlehem, PA 18015	15.6
10	Allentown Yard Waste Site	1401 Oxford Dr, Allentown, PA 18103			14.1
		Average distance			9.4

4.2.5 Production of recycled aggregates from waste glass

In terms of glass fines production, for use in Soil-less Soil the processes are transportation from MRFs to Aero Aggregates; crushing; cleaning; drying; sorting; and transportation from Aero Aggregates to Pennovation. Among these processes, primary data for the cleaning, drying and sorting process were collected from Aero Aggregates, while the other processes were based on the GaBi data sets. As shown in Table 2, the average distance from these ten MRFs to Aero Aggregates is 25.5 mile. The transport distance from Aero Aggregates to Pennovation is 12.4 mile based on Google map.

Table 3 Transport distance from MRFs to Aero Aggregates

NO.	MRFs	Distance (miles)
1	Waste Management - Philadelphia Transfer Station	11.8
2	PHILLY*WIDE Waste & Recycling Co.	12.1
3	RoadRunner Recycling	16.6
4	Gold Medal Disposal	10
5	Geppert Recycling	21.6
6	National Paper Recycling	18.2
7	ReCommunity	17.6
8	Waste Management - Camden, NJ	17.1
9	Allentown Recycling	64.7
10	Allentown Yard Waste Site	64.9
	Average distance	**25.5**

5. Life Cycle Impact Assessment

According to the LCA modeling results and ReCiPe midpoints analysis, the contribution analysis by process is shown as Table 4 and Table 5. For the conventional sand production, the primary impacts are the avoided landfill, followed by the process of sand mining and processing as well as the transportation from sand processing facilities to Pennovation. In terms of processes, the contribution analysis of the sand aggregates indicates that the avoided landfill accounts for almost half of climate change potential, 94% of human toxicity potential, and 63% of water depletion potential.

Among the six main processes of the glass fines production, the process of sorting has the most significant impacts on the environment in terms of the 16 impacts categories, followed by the drying process. In terms of climate change, the process of sorting emits 12.1 kg CO_2 (46% of the total) while the drying process emits 1.7 kg more CO_2 than the sorting process. In terms of the human toxicity potential, the sorting process contribute over a half of the total impacts, followed by the process of drying (19%), Transportation to Aero (17%), Transportation to Pennovation (8%), crushing (2%) and cleaning (2%). For the impact of water depletion, the primary impact is the sorting process, accounting for 93% of the total impacts.

Table 4 Contribution analysis by processes (natural sand)

NO.	Impact Categories	Unit	Processes			
			Avoided landfills (environmental credits)	Sand production and processing	Transportation from quarry to blending facilities	Transportation from sand blending facilities to the project site (Pennovation)
1	Climate Change	kg CO2 eq	4.48E+01	4.33E+01	7.51E-01	4.39E+00
2	Terrestrial Acidification	kg SO2 eq	1.80E-01	7.05E-02	1.39E-03	8.16E-03
3	Freshwater Eutrophication	kg P eq	1.06E-04	2.22E-05	3.18E-06	1.86E-05
4	Ozone depletion	kg CFC-11 eq.	8.12E-12	7.29E-12	2.21E-14	1.29E-13
5	Fossil Depletion	kg Oil eq	1.67E+01	1.65E+01	2.68E-01	1.57E+00
6	Freshwater Ecotoxicity	kg 1.4-DB eq	9.41E-03	4.85E-03	1.93E-04	1.13E-03
7	Human Toxicity	kg 1.4-DB eq	8.23E+00	4.05E-01	2.22E-02	1.30E-01
8	Ionising Radiation	kg U^{235} eq	6.88E-01	5.99E-01	1.70E-03	9.95E-03
9	Marine ecotoxicity	kg 1.4-DB eq	2.65E-02	4.94E-03	2.64E-04	1.55E-03
10	Marine Eutrophication	Kg N eq	8.27E-03	4.14E-03	1.34E-04	7.86E-04
11	Metal Depletion	kg Fe eq	1.69E+00	3.77E-01	2.00E-03	1.17E-02
12	Natural Land Transformation	m2	6.91E-04	3.27E-04	2.21E-06	1.29E-05
13	Particulate Matter Formation	kg PM10 eq	6.62E-02	4.72E-02	5.46E-04	3.20E-03
14	Photochemical Oxidation Formation	kg NMVOC	1.91E-01	1.07E-01	2.24E-03	1.31E-02
15	Terrestrial Ecotoxicity	kg 1.4-DB eq	2.40E-03	8.76E-05	1.27E-06	7.43E-06
16	Water Depletion	m3	2.18E+01	1.26E+01	3.54E-02	2.07E-01

Table 5 Contribution analysis by processes (glass fines)

NO.	Impact Categories	Processes						
		Unit	Transportation from MRFs to Aero	Crushing	Cleaning	Drying	Sorting	Transportation from Aero to Pennovation
1	Climate Change	kg CO2 eq	2.37E+00	1.94E-01	5.00E-01	1.38E+01	1.21E+01	1.15E+00
2	Terrestrial Acidification	kg SO2 eq	0.00439	0.000428	1.04E-03	9.08E-03	2.52E-02	2.14E-03

3	Freshwater Eutrophication	kg P eq	1.00E-05	1.57E-07	3.71E-07	1.17E-06	8.98E-06	4.87E-06
4	Ozone Depletion	kg CFC-11 eq.	6.96E-14	1.81E-11	8.48E-13	0.00E+00	2.05E-11	3.39E-14
5	Fossil Depletion	kg Oil eq	0.845	0.0566	1.45E-01	5.51E+00	3.52E+00	0.411
6	Freshwater Ecotoxicity	kg 1.4-DB eq	6.07E-04	8.25E-05	9.82E-05	1.19E-03	2.38E-03	2.95E-04
7	Human Toxicity	kg 1.4-DB eq	7.01E-02	0.00696	9.02E-03	8.05E-02	2.18E-01	0.0341
8	Ionising Radiation	kg U^{235} eq	5.36E-03	0.0233	6.27E-02	5.58E-03	1.52E+00	0.00261
9	Marine Ecotoxicity	kg 1.4-DB eq	8.33E-04	8.11E-04	5.66E-05	1.21E-03	1.37E-03	4.05E-04
10	Marine Eutrophication	Kg N eq	4.24E-04	-2.14E-07	3.40E-05	5.25E-04	8.24E-04	2.06E-04
11	Metal Depletion	kg Fe eq	6.31E-03	0.00233	3.26E-03	1.37E-01	7.88E-02	0.00307
12	Natural Land Transformation	m2	6.96E-06	5.97E-06	1.61E-05	5.68E-05	3.89E-04	3.39E-06
13	Particulate Matter Formation	kg PM10 eq	1.72E-03	1.21E-04	2.90E-04	3.48E-03	7.03E-03	8.38E-04
14	Photochemical Oxidation Formation	(kg NMVOC)	7.06E-03	0.00025	6.02E-04	1.45E-02	1.46E-02	0.00343
15	Terrestrial ecotoxicity	kg 1.4-DB eq	4.01E-06	4.89E-05	5.13E-06	1.15E-05	1.24E-04	1.95E-06
16	Water Depletion	m3	1.12E-01	0.26	6.99E-01	1.11E-01	1.69E+01	0.0542

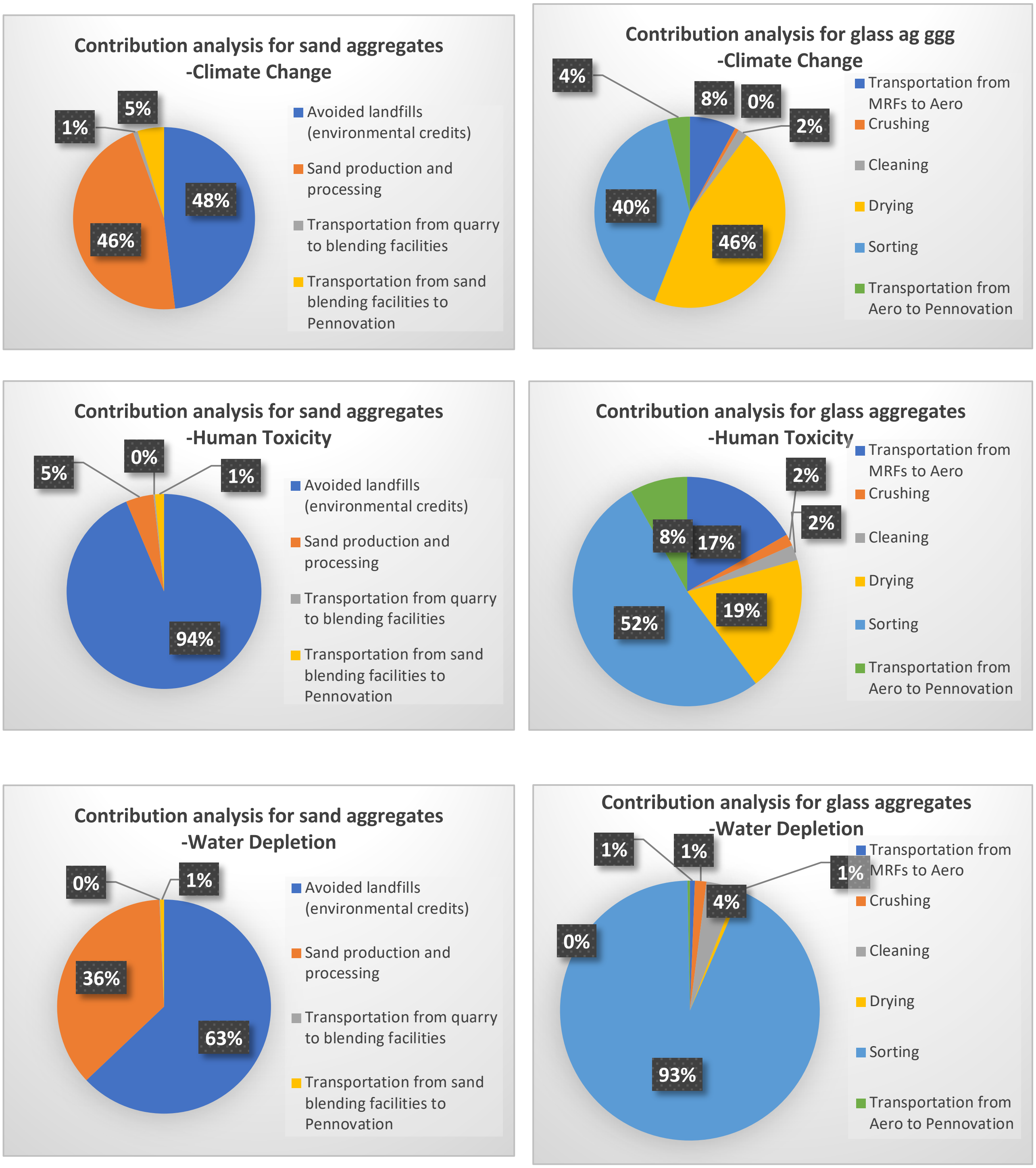

Figure 4 Contribution analysis by process

Table 6 Summary of the total impacts of the production of two aggregates

NO.	Impact Categories	Unit	Conventional sand	Glass fines
1	Climate Change	kg CO_2 eq	9.32E+01	3.01E+01
2	Terrestrial Acidification	kg SO_2 eq	2.60E-01	4.22E-02
3	Freshwater Eutrophication	kg P eq	1.50E-04	2.56E-05
4	Ozone Depletion	kg CFC-11 eq.	1.56E-11	3.95E-11
5	Fossil Depletion	kg Oil eq	3.50E+01	1.05E+01
6	Freshwater Ecotoxicity	kg 1.4-DB eq	1.56E-02	4.65E-03
7	Human Toxicity	kg 1.4-DB eq	8.79E+00	4.19E-01
8	Ionising Radiation	kg U^{235} eq	1.30E+00	1.62E+00
9	Marine Ecotoxicity	kg 1.4-DB eq	3.33E-02	4.69E-03
10	Marine Eutrophication	Kg N eq	1.33E-02	2.01E-03
11	Metal Depletion	kg Fe eq	2.08E+00	2.31E-01
12	Natural Land Transformation	m^2	1.03E-03	4.78E-04
13	Particulate Matter Formation	kg PM10 eq	1.17E-01	1.35E-02
14	Photochemical Oxidation formation	(kg NMVOC)	3.13E-01	4.04E-02
15	Terrestrial Ecotoxicity	kg 1.4-DB eq	2.50E-03	1.96E-04
16	Water Depletion	m3	3.46E+01	1.81E+01

6. Results

6.1 Environmental Advantages of Glass Fines

Within the system boundaries, assumptions and methodology used in the study, the estimated mid-point environmental impacts for producing 1 ton of conventional sand vs 1 ton of glass fines are shown in Table 6. Combining with the information from Table 6 and Figure 4, we can simply state that for 14 out of 16 impact categories, the glass fines perform better than the conventional sand.

6.1.1 Climate Change

It is estimated that about 93.24 kg of CO_2 is produced during the production of 1 ton of aggregates from quarry sand, which is equal to driving a car for a distance of 559.4 km or 349.6 miles (assuming 7.3 litres petrol per 100 km or 39 mpg) (Rohrer, 2016). When producing recycled aggregates, the LCA finding indicates that about 30.1 kg CO_2 eq GHG is emitted for producing 1 ton of recycled fine aggregate from waste glass, which is approximately equal to the emission of driving a car for a distance of 180.6 km or 112.9 miles in terms of CO_2 (Rohrer, 2016).

6.1.2 Terrestrial Acidification

In terms of terrestrial acidification, characterization factors are expressed as SO_2/kg emission. Nearly 82% more terrestrial acidification potential measured as SO_2 equivalents is seen when producing 1 ton of sand aggregates compared to producing 1 ton of glass aggregates. The acidification-increase in acidity leading to decrease in plant performance and biodiversity losses (USDA, n.d.).

6.1.3 Freshwater Eutrophication

Freshwater eutrophication occurs due to the discharge of nutrients into soil or into freshwater bodies and the subsequent rise in nutrient levels (namely, of phosphorus and nitrogen). Equivalency factors for eutrophication have been developed assuming phosphorus (P) is the major limiting nutrient of importance to eutrophication. Therefore, according to Table 6, life cycle of sand aggregates produced 83% more phosphorus than the life cycle of glass fines, leading to a higher freshwater eutrophication potential.

6.1.4 Fossil Depletion

There is no denying the fact that global fossil fuel consumption is on the rise, and experts forecast that based on a consumption rate of more than 4 billion ton of crude oil globally, oil deposits could run out in just over 53 years (Ecotricity, n.d.). In this study, natural sand production consumes 70% more oil equivalent product per ton than the production of glass fines due to its heavily-machine based process of sand extraction and processing. In this case, glass fines have more environmental advantages in terms of resource depletion.

6.1.5 Human Toxicity

The effects of toxic substances on the human environment are the main concerns for this category. This characterization factor includes human toxicity potentials, which are calculated with the Uniform System for the Evaluation of Substances adapted for LCA purposes (USES-LCA), describing fate, exposure, and the effects of toxic substances for an infinite time horizon

(Singh, Dincer, & Rosen, 2018). The measure of 1,4-dichlorobenzene (DB) equivalents/kg emission is used to calculate each toxic substance. As shown in Table 6, nearly 95% more human toxicity measured as 1,4 dichlorobenzene (1,4-DB) equivalents is seen when producing sand aggregates compared to producing glass aggregates.

6.1.6 Freshwater Ecotoxicity

This category indicator refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. Ecotoxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances. The time horizon is infinite. Characterization factors are expressed as 1,4-dichlorobenzene equivalents/kg emission (Ministry for the environment, n.d.). According to Table 6, the production of sand aggregates emits 70% more 1,4-dichlorobenzene than the production of glass fines.

6.2 Challenges

Although the life cycle of glass fines has an overall better performance than the conventional sand, for the impact categories of Ozone depletion and ionising radiation, the performance of glass fines is worse than that of conventional sand.

6.2.1 Ozone Depletion

Ozone depletion occurs when the natural balance between the production and destruction of stratospheric ozone is tipped in favor of destruction, of which 80% is caused by man-made compounds such as CFCs (Enviropedia, n.d.). According to the World Meteorological Organization (WMO), the characterization model defines the ozone depletion potential of different gases relative to the reference substance chlorofluorocarbon-11 (CFC-11), expressed in kg CFC-11 equivalent. Therefore, the production of glass fines causes 61% more Ozone Depletion Potential than the production of conventional sand. Throughout the life cycle of glass fines, 52% of the ozone depletion potential is caused by the process of sorting (see Table 5). Therefore, special waste air treatment is needed for the production especially for the sorting process.

6.2.2 Ionising Radiation

According to the OpenLCA's definition, ionising radiation is an impact category that is linked to the emissions of radionuclides throughout a product and will cause damage to human health and ecosystems. In the building sector, they can be linked to the use of nuclear power in an electricity mix. The unit the impact is given is kg of uranium-235 (U^{235}). In this category, the production of glass fines produces 1.62 kg U^{235} eq while the life cycle of the conventional sand produces 0.32 kg less U^{235} eq. In other words, compared to the production of conventional sand, the life cycle of glass fines emits 20% more U^{235}, leading to a higher ionising radiation potential.

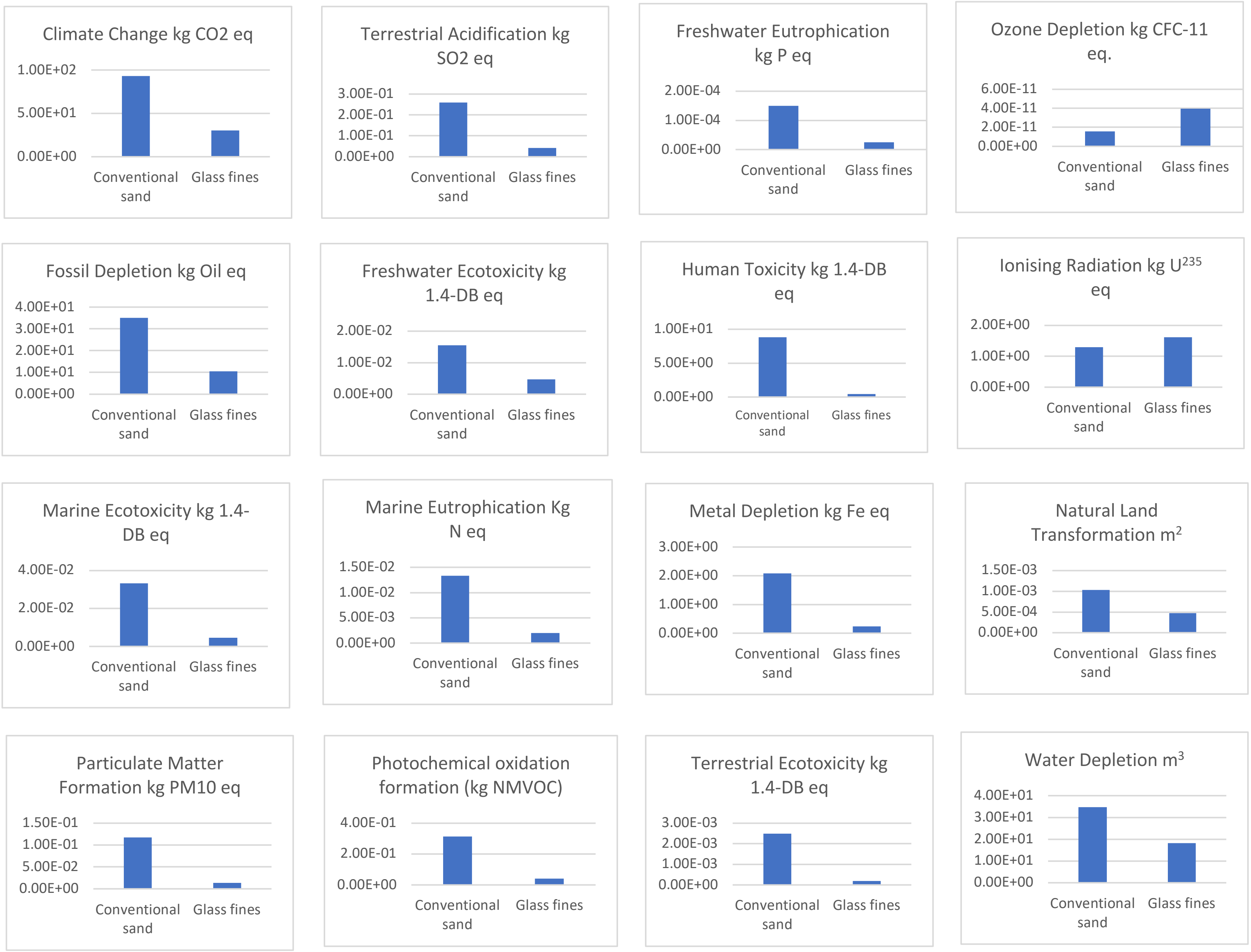

Figure 5 Impact Assessment for two products based on ReCiPe midpoints methodology

7. Discussion

7.1 Sensitivity Analysis

7.1.1 Sensitivity analysis based on varying distance

Based on the above findings (base case analysis), a sensitivity analysis was carried out to assess the effect of varying the transport distance of the aggregate materials on the environmental impacts especially for the aspect of resource depletion and emissions to air and water. The transport distance of the aggregate materials is the major factor affecting the results of the LCA. The findings are presented in Table 7.

Table 7 Sensitivity analysis based on varying distance

	Transport distance	**Climate Change (kg CO2 eq)**	**Human Toxicity (kg 1.4-DB eq)**	**Water Depletion (m3)**
Conventional aggregates	Base case	93.3	8.79	34.6
	-10	92.9	8.78	34.6
	+10	93.8	8.8	34.7
	Variation (%)	**0.43-0.54**	**0.11**	**0-0.29**
	-20	92.4	8.76	34.6
	+20	94.2	8.82	34.7
	Variation (%)	**0.96**	**0.34**	**0-0.29**
Recycled fine from waste glass	Base case	30.1	0.419	18.1
	-10	30	0.415	18.1
	+10	30.2	0.422	18.2
	Variation (%)	**0.33**	**0.72-0.95**	**0-0.55**
	-20	29.9	0.412	18.1
	+20	30.4	0.426	18.2
	Variation (%)	**0.66-1**	**1.67**	**0.55-1**

In this sensitivity analysis, four scenarios of transport distance variation (e.g. -10, +10, -20 and +20%) were considered and then compared with the base case. The results indicate that less than 0.6% of the climate change impact are influenced by a 10% variance of transport distance for the conventional aggregate production. 0.1% of the variation of human toxicity impact is found when changing the transport distance by 10% while the water depletion impact is impacted by 0.29%. A variation of 20% transport distance would lead to <1% change of the climate change impact, 0.34% change in human toxicity impact and <0.29 change in water depletion impact.

For recycled fine aggregate produced from waste glass, a variation of 10% transport distance would induce a 0.33% change of the climate change burdens, <1% change in human toxicity impact and <0.55% change in water depletion impact. Similarly, 20% increase or decrease in the transport distance of production would cause a less than 1% variance of climate change loads for producing sand aggregates. However, an equal variation would cause about 1.67% change than the base case in terms of human toxicity impact. The water depletion impact is changed by <1% by increasing or decreasing the transport distance by 20%.

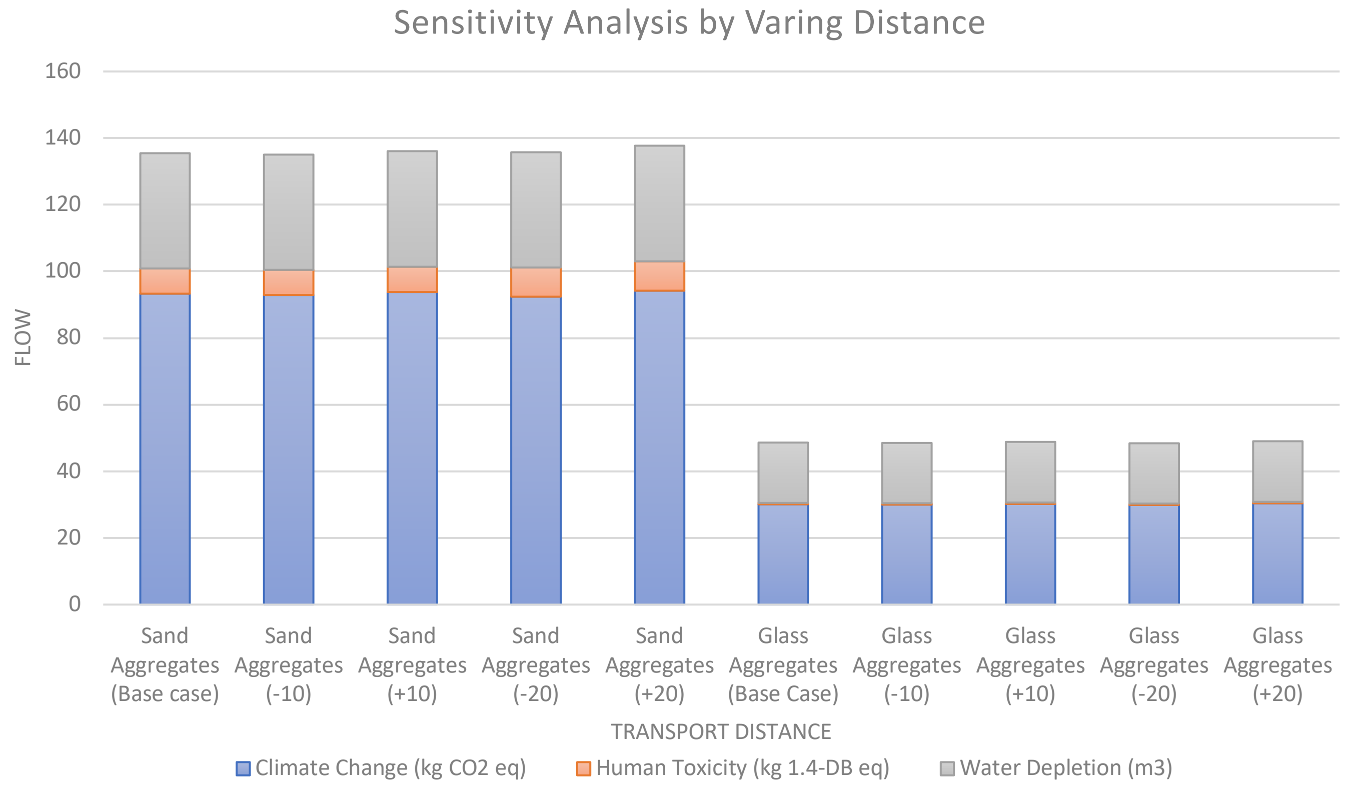

Figure 6 Sensitivity analysis by varying distance

In order to match the GHG emissions of natural sand, it would be necessary to increase the transport distance of glass fines to approximately 700 miles, or the distance between Philadelphia and Savannah, Georgia.

Among the three categories of the environmental impacts, it is indicated that climate change impact is the most influential flow for the life cycle of the conventional sand. However, the transport variation causes more change in the human toxicity impact during the production of glass fines.

7.1.2 Sensitivity analysis based on the landfill process of waste glass

In this study, the landfill of waste glass is considered as an environmental credit and is added in the system boundary of the LCA of sand fines production. To be more critical, a sensitivity analysis removing the environmental credit of avoided landfill is conducted in this study. From both Table 8 and Figure 7, it is clear that removing the landfill credit significantly alters the result by reducing the total life cycle impacts of conventional sand by 48% to 94% for all 16 impact categories. After removing the avoided landfill impact, the environmental burden of glass fines exceeds the conventional sand in 5 categories (Ozone Depletion, Ionising Radiation, Natural Land Transformation, Terrestrial Ecotoxicity, Water Depletion).

Table 8 Sensitivity analysis by removing the environmental credit of landfills

NO.	Impact Categories	Unit	Conventional sand	Conventional sand (no landfills)	Glass fines
1	Climate Change	kg CO2 eq	9.32E+01	4.85E+01	3.01E+01
2	Terrestrial Acidification	kg SO2 eq	2.60E-01	8.00E-02	4.22E-02
3	Freshwater Eutrophication	kg P eq	1.50E-04	4.40E-05	2.56E-05
4	Ozone Depletion	kg CFC-11 eq.	1.56E-11	7.44E-12	3.95E-11
5	Fossil Depletion	kg Oil eq	3.50E+01	1.83E+01	1.05E+01
6	Freshwater Ecotoxicity	kg 1.4-DB eq	1.56E-02	6.17E-03	4.65E-03
7	Human Toxicity	kg 1.4-DB eq	8.79E+00	5.58E-01	4.19E-01

8	Ionising Radiation	kg U^{235} eq	1.30E+00	6.11E-01	1.62E+00
9	Marine Ecotoxicity	kg 1.4-DB eq	3.33E-02	6.75E-03	4.69E-03
10	Marine Eutrophication	Kg N eq	1.33E-02	5.06E-03	2.01E-03
11	Metal Depletion	kg Fe eq	2.08E+00	3.91E-01	2.31E-01
12	Natural Land Transformation	m2	1.03E-03	3.42E-04	4.78E-04
13	Particulate Matter Formation	kg PM10 eq	1.17E-01	5.10E-02	1.35E-02
14	Photochemical oxidation formation	(kg NMVOC)	3.13E-01	1.22E-01	4.04E-02
15	Terrestrial Ecotoxicity	kg 1.4-DB eq	2.50E-03	9.63E-05	1.96E-04
16	Water Depletion	m3	3.46E+01	1.29E+01	1.81E+01

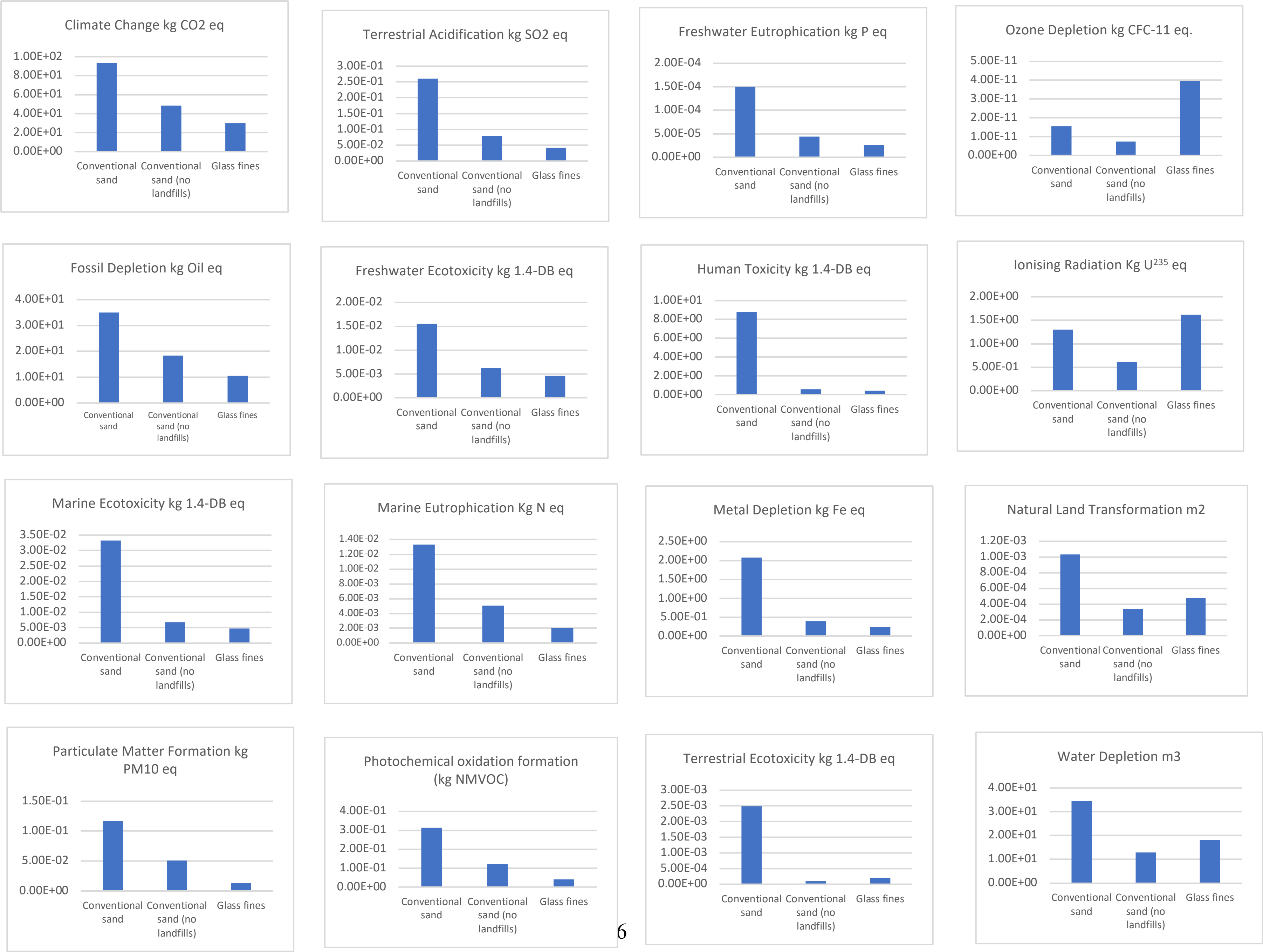

Figure 7 Sensitivity analysis by removing the environmental credit of landfills- Impact Assessment based on ReCiPe midpoints methodology

Table 9 Sensitivity analysis by removing the environmental credit of landfills (three factors)

Flow	Base case	No Landfill
Climate Change (kg CO_2 eq)	9.32E+01	4.84E+01
Human Toxicity (kg 1.4-DB eq)	8.79E+00	5.57E-01
Water Depletion(m^3)	3.46E+01	1.28E+01

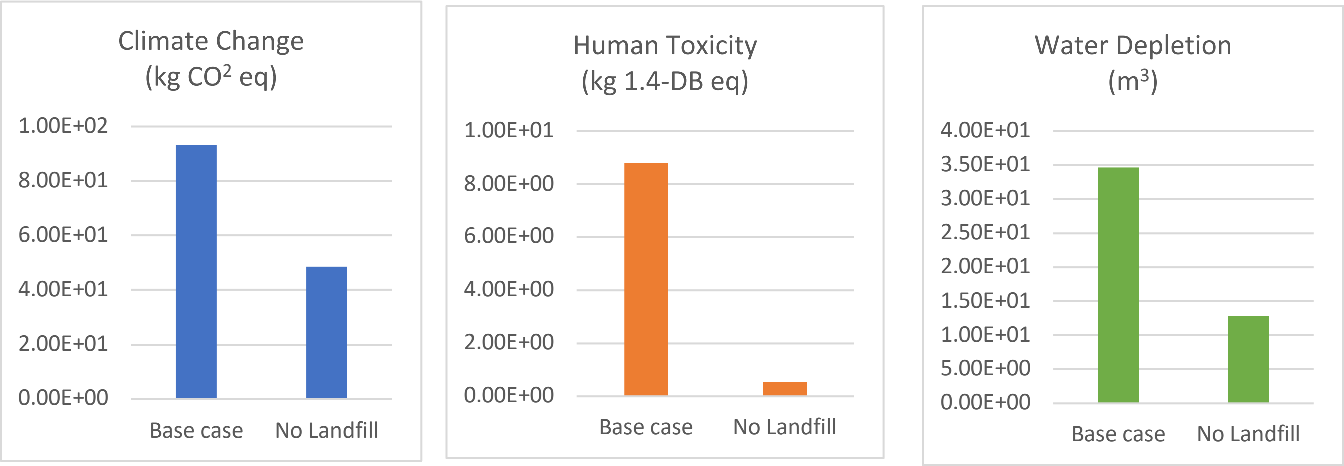

Figure 7 Sensitivity analysis by removing the environmental credit of landfills

7.2 Comparison with other studies

A comparison of the findings from this study with others is given in Table 10. However, it should be noted that a direct apple to apple comparison is not possible between different LCA studies due to the differences in geographical location, waste management system, data quality, energy mix, consideration of end-of-life scenarios, fuel consideration, processes, as well as system boundaries.

It is noted that about 232MJ energy consumption and 14kg CO2 eq GHG emissions are associated with the production of 1 ton natural aggregates from limestone (Estanqueiro, 2011), whereas 496–518 MJ energy consumption with 32–33 kg CO2 eq GHGs are associated with the production of the same amount of natural crushed stone(Hossain et al., 2016b). All these studies demonstrate the potential benefits of the production of recycled aggregates compared to the natural aggregates.

Table 10 Comparison with other studies

Study	Energy consumption, MJ/t	Climate change, kg CO2 eq/t	System boundary
Natural aggregates			
Simion et al. (2013) (Natural inert)	1664	103	Cradle-to-gate
Estanqueiro (2011) (Limestone)	232	14	Cradle-to-site
Blengini et al. (2007) (Sand)	152	10	Cradle-to-gate
Hossain et al. (2016) (Crushed stone)	496-518	32-33	Cradle-to-site
Hossain et al. (2016) (River sand)	341	23	Cradle-to-site
This study (Quarry sand)	1570	93	Cradle-to-gate
Recycled aggregates			
Lamb et al. (2011) (Misc. aggregates)	-	6	Cradle-to-gate
Simion et al. (2013) (Recycled aggregates from C& D waste)	246	16	Cradle-to-gate
Blengini and Garbarine (2010) (Recycled aggregates from C&D waste)	-250	-14	Cradle-to-site
Butera et al. (2015) (Recycled aggregates from C&D waste)	145	9	Cradle-to-site
Hossain et al. (2016) (Recycled aggregates from C&D waste)	211-235	11-12	Cradle-to-site
Hossain et al. (2016) (Recycled aggregates from waste glass)	156	9	Cradle-to-site
This study (Recycled aggregates from waste glass)	527	30	Cradle-to-gate

7.3 Critical review

Life cycle assessment is a complicated method which includes many technical and methodological assumptions, along with analysis of large, complex data sets. Therefore, completing a third-party critical review or a peer review is required by the ISO 14040 standard to support a comparative assertion disclosed to the public. Thanks to Christoph Koffler (Technical Director at Thinkstep, America)'s QA comments on the LCA model, two of the processes changed from the EU's dataset to the US dataset, which improves the accuracy of LCA data. Additionally, all sub-plans are fixed to a specific scaling factor instead of set to 1 by GaBi by default.

8. Conclusion

Based on the above discussion, this study demonstrates the environmental benefits of replacing conventional sand with waste glass fines, including producing less greenhouse gas, having less human toxicity and ecotoxicity. However, due to the heavily-energy concentrated sorting process of the glass fines, the glass fines performed worse than the conventional sand in terms of ozone depletion and ionising radiation.

The sensitivity analysis result shows that the variation of transport distances up to 20% does not affect the climate change impact of the aggregate production from waste glass significantly, whereas aggregate production from conventional sand is more sensitive to transport distances. According to the ReCiPe Method, significant health, resource, climate change and ecosystem damages can be saved in producing recycled aggregates from waste glass compared to producing and importing aggregates from virgin sources (quarry sand). However, removing the environmental credit of avoided landfill induced a significant change for the life cycle of conventional sand. In this case, it is important for the local government to encourage waste glass recycling in order to reduce the environmental impacts of landfilling glass.

Based on OLIN soil specification for green infrastructure tree pit, there are 1-2 cubic yard of soil for one tree pit. GSI soils are composed of 70-80% sand mixed with 20-30% organic matter, silt and clay. Dry sand weights about 1.2 tons per cubic yard, so each tree pit contains up to 2 tons of sand. Therefore, for one tree pit, replacing the conventional sand by the recycled waste glass can save up to 126.1 kg of greenhouse gas, which is equivalent to an average car could be driven for 4.90 hours non-stop (YouSustain, n.d.).

Therefore, considering the positive aspects identified for recycling of waste glass, it is necessary to strengthen the policy aspects, particularly on the procurement policy and the financial incentives of recycled materials to ensure sustainable resource management.

Reference:

Asabonga, M., Cecilia, B., Mpundu, M. C., & Vincent, N. M. D. (2017). The physical and environmental impacts of sand mining. *Transactions of the Royal Society of South Africa*, *72*(1), 1–5. https://doi.org/10.1080/0035919X.2016.1209701

Blengini, G. A., & Garbarino, E. (2010). Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. *Journal of Cleaner Production*, *18*(10), 1021–1030. https://doi.org/10.1016/j.jclepro.2010.01.027

Building Product Ecosystems. (n.d.). Glass in Concrete – Collaborative. Retrieved April 26, 2018, from Building Product Ecosystems LLC website: https://www.buildingproductecosystems.org/glass-in-concrete/

CT.GOV. (2013). DEEP: What is C&D ? Retrieved April 17, 2019, from https://www.ct.gov/deep/cwp/view.asp?a=2718&q=325398&deepNav_GID=1645

Ecotricity. (n.d.). When will fossil fuels run out? - Ecotricity. Retrieved March 28, 2019, from https://www.ecotricity.co.uk/our-green-energy/energy-independence/the-end-of-fossil-fuels

Enviropedia. (n.d.). Causes of Ozone Depletion. Retrieved March 27, 2019, from http://www.enviropedia.org.uk/Ozone_Depletion/Causes.php

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., … Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, *91*(1), 1–21. https://doi.org/10.1016/j.jenvman.2009.06.018

GaBi US Dataset. (2019). Process data set: Glass/inert on landfill; treatment of leachate, no landfill gas for energy use; production mix (region specific sites), at landfill site; (en). Retrieved April 20, 2019, from http://gabi-documentation-2019.gabi-software.com/xml-data/processes/78796b81-3df2-443f-a3a0-7028f736e957.xml

Hawley, S. (2017, March 28). The “sand mafia” fuelling India’s $120 billion building boom [Text]. Retrieved March 27, 2019, from ABC News website: https://www.abc.net.au/news/2017-03-28/the-great-sand-heist-fuelling-india-120-billion-building/8390984

HKEPD (Environmental Protection Department). (2015). *MONITORING OF SOLID WASTE IN HONG KONG Waste Statistics for 2015*. 34.

Hossain, Md. U., Poon, C. S., Lo, I. M. C., & Cheng, J. C. P. (2016a). Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA. *Resources, Conservation and Recycling*, *109*, 67–77. https://doi.org/10.1016/j.resconrec.2016.02.009

Hossain, Md. U., Poon, C. S., Lo, I. M. C., & Cheng, J. C. P. (2016b). Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA. *Resources, Conservation and Recycling*, *109*, 67–77. https://doi.org/10.1016/j.resconrec.2016.02.009

Huertas, J. I., Huertas, M. E., Izquierdo, S., & González, E. D. (2012). Air quality impact assessment of multiple open pit coal mines in northern Colombia. *Journal of Environmental Management*, *93*(1), 121–129. https://doi.org/10.1016/j.jenvman.2011.08.007

Mine-engineer. (n.d.). Basics of an open pit mine. Retrieved April 11, 2019, from http://www.mine-engineer.com/mining/open_pit.htm

Ministry for the environment. (n.d.). Appendix A: Impact Category Descriptions | Ministry for the Environment. Retrieved March 28, 2019, from http://www.mfe.govt.nz/publications/waste/life-cycle-assessment-product-stewardship-options-mercury-containing-lamps-new-1

Newhouse, S. (2018, November 28). Rising costs push Philly recycling to back burner – literally. Retrieved March 27, 2019, from Metro US website: https://www.metro.us/news/local-news/philadelphia/rising-costs-push-recycling-to-back-burner-literally

Ortiz, O., Castells, F., & Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, *23*(1), 28–39. https://doi.org/10.1016/j.conbuildmat.2007.11.012

ReCiPe | PRé Sustainability. (n.d.). Retrieved March 28, 2019, from https://www.pre-sustainability.com/recipe

Rohrer, J. (2016). *ABC of Awareness: Personal development as the meaning of life*. Retrieved from http://timeforchange.org/book-awareness-personal-growth-meaning-of-life

Singh, V., Dincer, I., & Rosen, M. A. (2018). Chapter 4.2 - Life Cycle Assessment of Ammonia Production Methods. In I. Dincer, C. O. Colpan, & O. Kizilkan (Eds.), *Exergetic, Energetic and Environmental Dimensions* (pp. 935–959). https://doi.org/10.1016/B978-0-12-813734-5.00053-6

Soil Science Society of America. (n.d.). Sand | Soil Science Society of America. Retrieved April 11, 2019, from https://www.soils.org/discover-soils/soils-in-the-city/green-infrastructure/building-green-infrastructure/sand

Torres, A., Brandt, J., Lear, K., & Liu, J. (2017). A looming tragedy of the sand commons. *Science*, *357*, 970–971. https://doi.org/10.1126/science.aao0503

USDA. (n.d.). Acidification Impacts. Retrieved March 27, 2019, from https://webcam.srs.fs.fed.us/pollutants/acidification/index.shtml

YouSustain. (n.d.). How Much CO2 Is That? Retrieved April 18, 2019, from http://www.yousustain.com/footprint/howmuchco2?co2=126.1+kg