ENVIRONMENTAL SUSTAINABILITY EVALUATION OF SOLID WASTE MANAGEMENT OF DHAKA CITY THROUGH LIFE CYCLE ASSESSMENT

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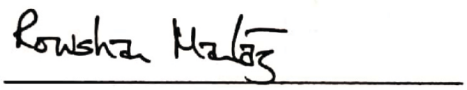

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It is hereby declared that the studies embodied in this thesis are the results of analysis carried out by the author under the supervision of Dr. Rowshan Mamtaz, Professor, Department of Civil Engineering, BUET except where specified by reference to other works. Neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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Dedicated to my wife

Sumaya Islam Ridy

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ABSTRACT

The management of municipal solid waste in an environmentally safe and sustainable way is becoming a major challenge for today's urban areas. Dhaka, the capital of Bangladesh generates an average of 7,476 tons of solid waste daily of which most of its wastes is disposed of in landfills in an unsanitary way. The current Municipal Solid Waste Management (MSWM) practice is posing a serious threat to the environment and public health. Moreover, absence of source separation, recycling, composting, and recovery makes the system unsustainable and heavily dependent on land disposal in a land scarce city like Dhaka.

The present study has been undertaken with an objective to evaluate the MSWM system of Dhaka using Life Cycle Analysis (LCA) and to find out suitable strategies to make the system sustainable. In this analysis, four alternative LCA scenarios (A1, A2, A3 and A4) are formed by combining composting, recycling, and incineration along with the existing baseline scenario B0 (only landfilling). A1 and A2 scenarios are organic waste composting-based alternatives. In alternative A2, other combustibles are considered for incineration. In alternatives A3 and A4, half and full quantity of organic wastes are considered for composting and incineration respectively.

The analysis result shows that the combination of organic wastes composting and incineration of remaining combustible wastes in scenario A2 is the most environmental friendly option in major midpoint and endpoint impact categories. As a second choice, alternative scenario A1 which is formed by composting of organic waste and landfilling of the remaining wastes is found suitable. Incineration of organic waste is found to be less environmentally sound and less energy efficient due to low calorific value and high moisture content of wastes.

In marine eutrophication midpoint impact category, the scenario A2 has the highest environmental savings with negative value of 8.77E+06 kg N equivalent. In this category, baseline B0 has the highest emission with an adverse environmental impact of 9.78E+06 kg N equivalent. Remaining scenarios named A1, A3 and A4 scenarios, values for eutrophication are -5.56E+06, -4.12E+06 and 5.30E+05 kg N equivalent respectively. Similarly, in endpoint marine eutrophication, the values of lost in species per year for B0, A1, A2, A3 and A4 scenarios are 1.85E-3, -1.52E-2, -1.55E-2, -7.71E-3 and 1.12E-4 species per year respectively.

In tropospheric ozone formation and stratospheric ozone depletion categories, baseline practice (scenario B0) is found to be the most suitable. Global warming is least occurred by alternative

scenario A4 where most of the waste is considered for incineration. But incineration is also found to be the most polluting option in ozone formation, carcinogenic toxicity and terrestrial ecotoxicity categories. It has been found that in the incineration process, the land requirement for one year is 7918 m^2 and for a ten-year period it would be 32238 m^2 unless the incineration ash will not be recycled. On the other hand, land requirement for composting of organic wastes would be the same (7918 m^2) for one year. And this requirement will remain unchanged after ten years as this land will be reusable.

The endpoint burdens (impact over human life and change in species on ecosystems) in all the scenarios follow the patterns of midpoint categories. A comparison is also conducted between two city corporations of Dhaka (North and South) and the analysis result indicates that South City Corporation's waste management is more environment friendly although various factors like waste quantity, number of vehicles and secondary transfer stations (STSs), landfill type etc. influence the performance.

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LIST OF ABBREVIATIONS

AD	-	Anaerobic Digestion
AOT40	-	Accumulated Ozone Exposure Over a Threshold Of 40 Ppb
AOX	-	Adsorbable Organic Halides
AP	-	Acidification Potential
APC	-	Air Pollution Control
APOS	-	Allocation At the Point of Substitution
ASTM	-	American Society for Testing and Materials
BOD	-	Biological Oxygen Demand
BOD5	-	5 Days Biological Oxygen Demand
BUET	-	Bangladesh University of Engineering and Technology
CC	-	Container Carrier
CFC	-	Chlorofluorocarbon
CFC11	-	Trichlorofluoromethane
CH	-	Country Short Code for "Switzerland" in Ecoinvent Database
CML	-	Centrum Voor Milieukunde Leiden
CNG	-	Compressed Natural Gas
COD	-	Chemical Oxygen Demand
COPD	-	Chronic Obstructive Pulmonary Disease
DALY	-	Disability-Adjusted Life Year
DCB	-	Dichlorobenzene
DCC	-	Dhaka City Corporation
DDREF	-	Dose And Dose Rate Effectiveness Factor
DL	-	City Short Code for "Delhi" In Ecoinvent Database
DNA	-	Deoxyribonucleic Acid
DNCC	-	Dhaka North City Corporation
DOC	-	Dissolved Organic Carbon
DPDC	-	Dhaka Power Distribution Company Limited
DSCC	-	Dhaka South City Corporation
EEA	-	European Environmental Agency
EF	-	Emission Factor
ELCD	-	European Reference Life Cycle Data System
EMEP	-	European Monitoring and Evaluation Program
EOFP	-	Photochemical Oxidant Formation: Ecosystem Quality
EOL	-	End of Life
EPF	-	Product Environmental Footprint
ESP	-	Electrostatic Precipitator for Fly Ash
FEP	-	Freshwater Eutrophication
FETP	-	Freshwater Ecotoxicity
FFP	-	Fossil Resource Scarcity
FLUWA	-	Filter Ash Treatment
FY	-	Fiscal Year

GHG	-	Green House Gas
GLO	-	Short Code For "Global" in Ecoinvent Database
GWP	-	Global Warming Potential
GWP100	-	Global Warming Potential for 100 Years
HDPE	-	High Density Polyethylene
HDV	-	Heavy Duty Vehicles
HHV	-	Higher Heating Value
HOFP	-	Photo-Chemical Oxidant Formation Potential: Humans
HTP	-	Human Toxicity Potential
IARC	-	International Agency for Research on Cancer
IBA	-	Incinerator Bottom Ash
ILCD	-	The International Reference Life Cycle Data System
IN	-	Country Short Code For "India" in Ecoinvent Database
IPCC	-	Intergovernmental Panel on Climate Change
IRP	-	Ionizing Radiation Potential
ISO	-	International Organization for Standardization
JICA	-	Japan International Cooperation Agency
JRC	-	The Joint Research Centre
LCA	-	Life Cycle Analysis
LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Impact Assessment
LDPE	-	Low Density Polyethylene
LHV	-	Lower Heating Value
LOP	-	Agricultural Land Occupation Potential
LT	-	Low Voltage
LWC	-	Lightweight Coated
MBT	-	Mechanical Biological Treatment
METP	-	Marine Ecotoxicity Potential
MJ	-	Megajoule
MSW	-	Municipal Solid Waste
MSWI	-	Municipal Solid Waste Incineration
MSWM	-	Municipal Solid Waste Management
NMVOC	-	Non-Methane Volatile Organic Compound
NPK	-	Nitrogen, Phosphorus, and Potassium Fertilizer
ODP	-	Ozone Depletion Potential
OECD	-	Organization for Economic Co-Operation and Development
PAH	-	Polycyclic Aromatic Hydrocarbons
PCB	-	Polychlorinated Biphenyl
PCSP	-	Primary Collection Service Providers
PET	-	Polyethylene Terephthalate
PGCB	-	Power Grid Company Bangladesh
PM	-	Particulate Matter
PMFP	-	Particulate Matter Formation Potential
POCP	-	Photochemical Ozone Creation Potential

PP	-	Polypropylene
PS	-	Polystyrene
PSTP	-	Pagla Sewage Treatment Plant
PVC	-	Polyvinyl Chloride
RAJUK	-	Rajdhani Unnayan Kartripakkha
RDF	-	Refuse-Derived Fuel
RF	-	Radiative Forcing
RIVM	-	The Dutch National Institute for Public Health and The Environment
SCR	-	Selective Catalytic Reduction
SDG	-	Sustainable Development Goal
SETAC	-	Society For Environmental Toxicology and Chemistry
SNCR	-	Selective Noncatalytic Reduction
SOP	-	Surplus Ore Potential
SPD	-	Study Design Parameter
STS	-	Secondary Transfer Station
SWM	-	Solid Waste Management
TAP	-	Terrestrial Acidification Potential
TETP	-	Terrestrial Ecotoxicity Potential
TOC	-	Total Organic Carbon
TP	-	Toxicity Potential
U235	-	Uranium-235
UNEP	-	United Nations Environment Program
USEPA	-	United States Environmental Protection Agency
USLCI	-	U.S. Life Cycle Inventory Database
UV	-	Ultraviolet
VOC	-	Volatile Organic Compound
WBA	-	Ward Based Approach
WCP	-	Water Consumption Potential
WHO	-	World Health Organization
WMO	-	World Meteorological Organization

Chapter 1
INTRODUCTION

1.1 General

The Sustainable Development Goals (SDGs) or Global Goals – a collection of 17 interlinked goals – was adopted as a resolution of the United Nations General Assembly in 2015. The SDGs comprise of a set of measurable targets, and the resolution aims to achieve those by attaining agreed levels of sustainable development by 2030. SDG Target 11.6 is stipulated as: "By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality, municipal and other waste management." One of the indicators by which to measure its achievement is the percentage of urban solid waste regularly collected and managed. Establishment of effective municipal solid waste management (MSWM) has a significant role in achieving this goal especially in large cities.

Sustainable development is integration of ecological footprint with quality of life (Shohan 2015). Quality of life depends on the services and opportunities that a city offers to its inhabitants. Waste management is one of these areas that offers both service and opportunities to the people and leads towards sustainable growth. Ecological footprint can be significantly reduced by proper MSWM.

Worldwide, urban areas are expanding rapidly with economic growth. Unfortunately, this growth has a positive correlation with per capita waste generation. This waste includes everyday items that are thrown away such as food leftover, packaging materials, furniture items, clothing, glass bottles, plastic items, and papers (Kreith and Tchobanoglous 2002). Such rapid growth of waste is continuously increasing the demand on a city's waste collection, disposal, and treatment systems. The world produces 2.01 billion tonnes of municipal solid waste (MSW) annually which is expected to grow to 3.40 billion tonnes around the year 2050 with approximately 40% increase in per capita waste generation in low- and middle-income countries (Kaza, et al. 2018). This will further worsen the current situation where 33% of the generated waste is not managed in an environmentally safe manner. Recent statistics suggest that the world's highest amount of waste is generated from the East Asia and Pacific regions and low-cost landfill practice in these regions is creating significant environmental burden (Hondo, Arthur and Gamaralalage 2020, Kaza, et al. 2018). Such a crude waste management arrangement causes transmission of diseases, increase in respiratory problem, global warming

and increased toxicity in the environment (Chen, et al. 2020). Dhaka, the capital of Bangladesh and a highly populated city in South Asia, is a typical example of a landfill dependent MSWM scenario.

Dhaka comprises an area of 306.38 square kilometers at 23°42'N 90°22'E, surrounded by the Buriganga, the Sitalakhya, the Turag and the Balu rivers. Its population was around 10,596,475 in 2020. At a daily rate of 0.61 kilograms per capita, the city produces a total of 6,464 tons of waste each day (Yoshijima, et al. 2021). This quantity, which is already much higher than the management capacity, is rising with the increase in population as well as economic growth, increasingly challenging the city's MSWM system. Aminbazar and Matuail are two landfill sites used by Dhaka North and South City Corporations, respectively, for waste disposal. From 6,464 tonnes, 4,700 tonnes are disposed to the landfill sites although their capacities are already exhausted (Chandan 2021) and continued uncontrolled and crude dumping is making their conditions worse. The requirement of land for landfill increases with the quantity of waste. But Dhaka carries a huge population within a small area and allocating more land for landfill is not a viable option. In developed countries such as Germany, use of landfill for waste management is already prohibited since the 1990's and alternative MSWM techniques are practiced depending on the waste types (Burnley 2001, Kreith and Tchobanoglous 2002). Although landfilling is the simplest and most economical way of disposing waste, it is not necessarily the most environmentally friendly (Barrett and Lawlor 1995).

In Dhaka, the daily life of city dwellers has a close relation with municipal solid waste management. Dustbins and STSs are found quite frequently while roaming around the city. Every day the waste management system faces the challenges of unwanted and decomposing waste resulting in odor, water logging, clogging of drains, and overall environmental degradation. Although in the previous decades, the contamination of air and water resources in vicinity of uncontrolled waste dumping zone was severe, the internal waste management system has significant improvement in some areas (Hai and Ali 2005). The cleaners and workers who are in direct contact with waste lack safety measures and suitable tools which make them vulnerable to pathogen attack. Long term continuous exposure to such pollutions can cause cancer and chronic obstructive pulmonary diseases (COPD) (Anenberg, et al. 2016).

Waste recycling practices are carried out by informal sectors in Dhaka. Consequently, such efforts cannot contribute to a safe and hygienic recycling practice that could improve the safety of the workers or the environment of the city.

Figure 1.1: Waste container near footpath (Dhar 2017)

As all types of waste are commingled, sorting out the recyclable waste and managing it in any systematic manner is quite difficult. No source separation education of waste is provided to the city dwellers which could have made recycling process more efficient. Other issues that contribute to inefficient waste management are lack of waste related data and institutional framework, and non-implementation of environmental policies. All these lead to lack of any scientific analysis and evaluation of the available waste management technologies that might be appropriate for Dhaka city. This in turn makes forecasting the future of the waste management scenario difficult which could have helped understand the emerging challenges.

Life Cycle Assessment (LCA) is an analytical tool to assess the environmental burdens associated with any product, process, and waste management from the origin to the final disposal in significant pollution categories (Zaman 2010). The LCA result is used to identify the options that prevent or minimize their negative environmental impacts and analyze strategies for material and energy recovery from wastes. It helps in decision making and adopting the best approaches in a holistic manner. Furthermore, LCA tool is used worldwide and significant amount of research works have been conducted on waste management LCA (Paes, et al. 2014, Pandyaswargo, Onoda and Nagata 2012, Xin, et al. 2020, Rieradevall, Domènech and Fullana 1997, De Feo, et al. 2016, Malmir, Ranjbar and Eicker 2020, Jain, et al. 2015). In some developing countries, which has similar MSWM scenario to that of Dhaka, LCA studies are adopted to develop alternative waste management strategies (Cheela, et al. 2021, Mali and Patil 2016). The recently conducted research works and reports related to Dhaka city MSWM are focused either on a specific part of the whole waste management system

or some specific waste treatment techniques relevant to waste composition types. Therefore, to address the overall problem, it is necessary to assess the whole waste management system combining other waste treatment techniques, rather than focusing only on specific waste types or specific waste treatment methods. LCA combines all these treatment methods and compares the alternatives. Keeping this in mind, an attempt has been made to evaluate the MSWM system of Dhaka using LCA and analyze suitable strategies to make the system environmentally sustainable that can be useful to the two city corporations of Dhaka City.

1.2 Justification of The Study

Waste management is important for accomplishing resource efficient society. Currently, Dhaka city waste treatment method is still not mature enough to achieve that efficiency. Therefore, to make the management more efficient, new waste treatment methods should be introduced as well as weaknesses in current practice should be identified. Life cycle provides the best means to evaluate any waste treatment method and identify the areas. The evaluation will provide understanding of the greener approach with least environmental burden outcome. The idea of how much resource is consumed and how much is recovered can indicate how much efficient the system is (Gala, Raugei and Fullana-i-Palmer 2015). Therefore, LCA study associated in a holistic approach can guide towards sustainable decision making which is the main rationale of this study. Recently two City Corporations of Dhaka --- North and South, are planning to adopt new strategies like incineration instead of landfilling. The present study attempts to evaluate such strategy along with other options such as composting, recycling etc. considering the waste composition and hereby provides an insight into the environmental burden due to the whole waste management scenarios. Therefore, this study aims to use LCA for sustainability evaluation of Dhaka city's MSWM existing practice and the possible future practices with a view to identifying the environmentally most suitable strategies using a holistic approach.

1.3 Objectives of The Study

The main objective of this study is to evaluate the impacts of Dhaka City's existing Solid Waste Management practice using LCA and propose suitable strategies to make the system sustainable.

The specific objectives of this study are:

i. Evaluation of the current practice and alternatives based on the LCA approach and compare the LCIA outputs

ii. To compare the effectiveness of the SWM system between Dhaka North and South city corporations.

The possible outputs will be:

i. A Life Cycle Inventory (LCI) database of input and output of all components (collection to disposal) of SWM system
ii. Quantified value of the environmental impacts of the baseline and the alternative waste management scenarios by Life Cycle Impact Assessment (LCIA) on categories like acidification, eutrophication, ozone layer depletion, photochemical ozone formation, respiratory effects, ecosystem toxicity, human health (carcinogenicity and non-carcinogenicity), global warming and resource depletion (fossil fuels) etc.

The analyses will be used to assess the significant aspects of the waste management process, the combination and techniques that will be most suitable for Dhaka city, areas of improvement and suggestion on future sustainable waste disposal. As there is no such study on Dhaka City waste management available, this study can work as a good basis for future research and development on SWM.

1.4 Scope of The Research

To assess the sustainability of waste management practices, firstly the total environmental burden should be assessed for existing practice and then the alternatives. To form the alternatives, the primary goal is to identify the suitable approach that can be adopted as per waste composition and city corporations plan in future to treat waste as per waste reports (DNCC 2019-2020, DSCC 2019-2020). Therefore, the next goal is to make combination of these waste management technologies and varying waste quantities in different treatment methods to form distinguished alternatives. Lastly, the baseline current practice and alternative scenarios are compared to find the most suitable approach to reduce the environmental burden. A separate analysis is conducted to compare the current practice of city corporations following the above-mentioned scopes.

1.5 Organization of The Thesis

The thesis is composed of five chapters. Following are the key aspects of each chapter in brief:

1st Chapter

Introduction reflects an overview of global and local MSWM problems, association of LCA in waste management, the rationale of conducting the study, objective, scopes, and organization of the thesis.

2nd Chapter

Literature review on Dhaka city waste management problem, characteristics of Dhaka city MSW, common SWM practices, use of LCA approach in MSWM, basics of LCA, Life Cycle Impact Assessment (LCIA) categories and contribution of pollutants in pollution categories with their damage pathways, LCIA methodologies, discussion on various LCA software.

3rd Chapter

Research methodology contains the following step by step analysis:

1. Derivation of different types of waste percentage in baseline MSWM scenario
2. Formation of alternative scenarios
3. Selection of database for LCA
4. Scopes of analysis of different MSWM components
5. Life Cycle Inventory (LCI) preparation for whole Dhaka city SWM in all scenarios and modification of predefined datasets as per scopes and suitability
6. Software analysis: defining global parameters, creation of flow, process, defining local parameters, formation of product systems, formation of project in openLCA
7. Impact assessment operation in selected methods and different categories
8. LCA analysis between two Dhaka city corporations baseline scenario

4th Chapter

This chapter focuses on the analysis of the obtained results, graphical presentation analysis, discussion, and comparison of the scenarios, finding the key components of MSWM regarding environmental burden, the driving factors behind pollution in different categories. Also, the limitations of the study, scopes for future improvements are discussed in this chapter.

5th Chapter

This chapter summarizes the findings from the whole study. The best and the worst strategies for MSW management, key components, focus areas are discussed in brief in this concluding chapter.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

This literature review is carried out on the environmental pollution caused by existing MSWM practice of Dhaka city, characteristics and composition of waste, waste utilization and reduction techniques and their appropriateness, application of LCA for evaluation of MSWM worldwide, basic concept of LCA, LCA software, LCIA methods and impact categories, and damage pathways of pollutants.

2.2 Dhaka MSWM: The Environmental Burden

Almost all the studies regarding MSWM of Dhaka city suggest that population increase, rapid and unplanned urbanization and industrial development are the prime causes of the amount of waste increase in Dhaka city. This amount is increasing exponentially at an alarming rate which cannot be managed without a detail and long-term planning (Waste Concern 2014).

Dhaka city contributes majorly to the economic development of Bangladesh. In the 90's, according to Enayetullah (1995) inadequate management and indiscriminate waste dumping were responsible for degradation of environment from uncollected waste on streets, public areas, and contamination of water resources in developing countries. That condition has seen some improvement in the last two decades. However, the city expanded rapidly with economic growth which is continuously challenging the waste management system.

Kabir, 2015, stated that change in the waste composition pattern with people's lifestyle and diversification of the major waste categories responsible for major adverse effects. Water pollution from low land dumping, air pollution during waste brunt also adds significant environmental burden. There are chance of explosions from the escaping landfill gas (Hai and Ali 2005). Methane emissions from large organic components from landfill contribute to global warming. Aminbazar and Matuail are controlled landfills, but there are scopes of reducing the environmental burden. Kabir (2015) also suggested on converting solid waste to safe land filling materials. From the waste composition and treatment point of view the study suggested pre-C/N ratio balancing of organic waste before introducing the waste for composting which may increase cost. Also, high moisture content and low heating value make the waste inappropriate for combustion. On the other hand, there is shortage of manpower in waste

management department of city corporations, insufficient infrastructure, lack of resident awareness, weak law enforcement. Some other major aspects of pollution include waste decomposition, air and nearby water body emission, pathogen, and toxic and carcinogenic substance emission and GHG emission (Kabir 2016, JICA 2005).

There are also some administrative weaknesses with inadequate collection system and outdated landfills (Alam, Hossain and Elahi 2020). Mahmuda and Saify, (2016) showed in their study that problem lies in constrained assets, collection of waste from old Dhaka area, tight and narrow roads, unplanned markets, old and compact building structures, and mixed land use pattern. Community level engagement in SWM is another area to be prioritized (Gozun and Palomata 2000). Clean Dhaka Master Plan project formulated by JICA (2005), urges for strengthening capacities. The report finds weakness in planning, equipment, and low sanitation awareness.

Urme et al. (2021) described that landfill pollution is the pollution of surface and groundwater from leachate, pungent odors, bio-aerosol, and hazardous organic compounds. Leachate percolated to groundwater causes contamination of aquifer as well as surface water. Figure 2.1 shows a leachate collection junction in Matuail landfill. The exhausted landfill facility is identified as another problem (Urme, et al. 2021). Adjacent residents suffer from malnutrition, low birth weight, congenital anomalies, respiratory problems, nervous defects, and other chronic symptoms. The placement of landfill also situated within 300 meter of nearby water bodies which is within the buffer zone of 500 meter of landfill (Şener, et al. 2010). Sumaiya (2020) performed detail analysis on STS and found issues with maintenance, coverage zone and collection inadequacy mentioning there are scopes of development.

The waste management education at mass level is another major concern. People who generate the waste through daily activities do not know how waste should be managed efficiently at their level in Dhaka. Developed countries provide waste education to the citizens specially to the school children on waste reduction, separation, and segregation to raise awareness of their responsibility in waste management (Kreith and Tchobanoglous 2002). This helps manage waste at very primary level of MSWM. Although being largely populated the percentage of people having mere knowledge of managing waste in household is quite significant. Also, traditional education system offers very little knowledge about source separation and segregation of waste. As a result, people have less education on effective waste management options and low-income areas are not waste educated at all. People are also unaware of the consequences of random open waste dumping and understand the importance of reduction and

separation from ecological footprint perspective. Therefore, the implication of source reduction and separation may not work efficiently unless people become educated about waste management.

Figure 2.1: Leachate collection system at Matuail landfill (Urme, et al. 2021)

There have been some efforts by the city corporations and government to manage waste efficiently. But most of the plans did not come out as expected. In 2016, City Corporations installed 6700 curbside bins expending Tk4.49 crore with a goal to reduce the waste from roadside and footpath as well as make people habituated with dumping waste on the designated place rather than in the open (Antara 2019). The project totally failed due to lack of assessment before implementation and no public awareness raised to use those bins properly as analyzed by the urban planners. Figure 2.2 shows an uprooted waste bin. Drug abusers stole nearly half of the bins and people rarely used the remaining halves.

Figure 2.2: Waste bin uprooted from designated place (Bablu 2016)

A 3R project was formulated by Department of Environment (DoE) back in 2010 with a view to eliminating disposal of garbage in open dumps and surface waters. But the project was unable to raise concern or change the waste dumping culture of the city people. This project also failed due to lack of action plan and coordination between the government and the city corporations (R. Hasan 2021). Some statistics of recent waste management initiatives are shown in Figure 2.3.

Figure 2.3: Some statistics and problem regarding MSWM (Mahmud 2018)

The construction of STS in important road intersections and nearby significant structures like school, museums, markets, and public parks are hampering environment in nearby vicinity as per the report "Unplanned waste transfer sites causing trouble in city" published in Daily Sun by Rashidul Hasan (2021). The report mentioned that the city corporations blamed capital development authority for not providing any provision for STS where RAJUK (Rajdhani Unnayan Kartripakkha) or capital development board blamed city corporations for not preparing local area action plan as providing land for STS is not within the responsibility of RAJUK. Therefore, city corporations are bound to build STS in any possible open space stating that the MSWM situation would have been worse without these STS even if it hampers nearby citizens directly. Clearly, the lack of long-term planning on land use, long term waste management provision and lack of coordination between the governing authorities are responsible for this current mismanagement of STS implementation.

In continuation of JICA "Clean Dhaka Master Plan, 2005" another "New Clean Dhaka Master Plan, 2018-2032" from JICA was approved which was built on the principle of recycle, biogas extraction, compost production and power generation maintaining the hierarchy of waste. But

city corporations retracted from that master plan and now focusing mostly to produce energy from the waste which is yet to be implemented (Rahman 2021).

2.2.1 MSWM Workflow of Dhaka City

Integrated waste management is the idea of selection and application of suitable technologies according to its nature. For example, before introducing waste to different treatment processes, the prime target will be to follow the 3R policy (Reduce, Reuse, Recovery). Firstly, reduce waste from the source, secondly reusing the waste if reduction is not possible and then collecting waste separately if reduce and reuse do not work. But, under the current waste education level of Dhaka's citizen, it can be easily assumed that people will not be able to reduce or separate the source of waste due to lack of knowledge and unawareness. So, the next option that can be implemented is to make the waste collection and transportation system efficient.

Dhaka city waste collection system starts from the door-to-door collection by Primary Service Collection Provider, PCSP. Then the waste is transferred to a specific waste collection container or a secondary collection point. The waste collection system was way inefficient at the beginning of 2000. In 2005, JICA with the Clean Dhaka Master Plan Project started Ward based Approach (WBA) for collecting waste. The program included institutionalization of wards for SWM, establishment of Primary Collection Service Providers (PCSPs)etc. The generated wastes are collected by PCSPs by steel hand carts and steel vans as shown in Figure 2.4. A certain amount of charge (maximum 100 BDT) is paid to the service providers by the waste producers for managing the waste (TBS 2021). Moreover, the project improved waste transportation by adding more environmentally friendly vehicles for carrying waste. Currently, the collection system is 75% to 80% efficient according to the waste reports from city corporations and World Bank (2021). Remaining uncollected waste goes to drain and unserved areas causes pollution, pathogen reproduction and enhance the path for disease vector (Shohan 2015, Yoshijima, et al. 2021).

The next phase of MSWM is to gather waste collected from a ward to a distinctive area. These areas are called Secondary Transfer Stations (STS). Sumaiya, (2020) performed detail analysis of STSs performance in DNCC. These transfer stations may or may not have a formed structure. Figure 2.5 shows STS in Malibagh area under Moghbazar flyover. MSW gathered at STS are managed in various ways depending on the facilities available. In some STS waste from vans directly unload at the floor of the STS whereas in some STS, 3,5 and 7ton capacity

waste containers are available and waste from PCSP van unload the waste to fill these containers (Tabassum 2020). Sometimes, people dump into these containers directly from the households and shops where they do not get or do not take part with PCSP waste collection services. The waste is sorted in STSs for landfilling and recycling. The separated wastes are then recycled by informal sectors. The STS waste fraction is loaded manually by the workers or using mini dozers and pay-loaders and then transported to landfills using container carriers, compactor trucks and open/dump trucks of various capacity (Tabassum 2020). Typical vehicle types are shown in Figure 2.6.

Figure 2.4: Primary Collection Service Provider (PCSP) van (Rajiv 2012)

Figure 2.5: Malibagh STS (Islam, 2022)

The manual unloading and loading of waste, sorting recyclables with bare hand is unhygienic for the workers, especially for the children. The STSs facilities are still on the improvement and should be a major priority in integrated solid waste management (R. Hasan 2021)

Figure 2.6: Waste collection vehicle types (Waste Report 2019-2020)

Figure 2.7: Waste handler working in bare hand causing skin infection (Hossain 2018)

On the landfills, wastes are unloaded by dump truck following a certain disposal plan and daily compaction is applied. Although, there is necessity of application of daily soil cover, the cover is applied only once over a certain section when that part is claimed to be unusable for dumping

waste (Chandan 2021). In addition to landfilling, the leachate produced from the waste is treated in leachate treatment facilities. However, waste handling remains a major problem at this stage of waste treatment. Moreover, the advanced technique of treating waste as per the waste hierarchy is presently lacking. Figure 2.7 demonstrates an infectious hand of waste handlers in landfill area which indicates the possible damage that waste handling can occur in bare hands.

Recycling exists informally by waste pickers and scavengers from curbsides, PCSPs, STSs and landfills. Recyclable waste can be reduced more efficiently by improving separation efficiencies and improving markets. There is absence of institutional framework for recycling. Other significant waste treatment methods are composting and waste combustion (waste to energy) techniques. Figure 2.8 shows a boy collecting recyclable waste from Matuail landfill. Landfilling is the least expected option but cannot be avoided as all other treatment process produce some ash or inert materials that has no market value and should be dumped in landfill (Kreith and Tchobanoglous 2002).

Figure 2.8: A boy collecting recyclable items in Matuail landfill (Mudditt 2011)

Currently, there is no published study available that represents a unit value of the environment impact from the whole waste management system. Therefore, it is rational to conduct this study to understand the current practices environmental burden with quantified value.

2.3 Characteristics of MSW of Dhaka City

The study on Solid Waste management (SWM) of Dhaka city started around 90s. In that early period, there was rarely any data available on waste composition. Iftekhar, 1995 demonstrated residential municipal waste contains as: plastics 1.74%, paper 5.68%, metal, glass, and construction waste 6.38%, textile 1.83% and food wastes 84.37%.

JICA in 2005, published Clean Dhaka Master Plan report with solid waste data on volume 04 of the report. From the analysis of the data the waste generated and landfilled is calculated. The waste composition at generation and disposal varied as there were some informal recycling practices that changed the incoming waste composition at landfill site. The generated and disposal waste composition is provided in table 2.1. Waste Concern (2005), published a report on urban solid waste management provided their own waste composition study for urban areas on Bangladesh. This study shows the major percentage of waste is organic (67.65%) followed by paper (9.73%), rock, dirt, and miscellaneous items (8.79%) and plastic (5.10%). Bari et al., 2007 analyzed waste composition and moisture content of Dhaka city. This composition shows the majority is organic waste fraction (74%). In 2014, Waste Concern, conducted detail research on waste management and published "Bangladesh Waste Database, 2014". The data is also provided in Table 2.1. Kabir (2015) provided some comparative statistics from different studies conducted between 1993 to 2013. The organic portion varied from around 55% to as high as 88%. Rasul (2016) provided a details analysis on moisture content % of wide variety of organic food residue with their volatile matter, ash content and fixed carbon collected from Matuail landfill. The high heating value (HHV) for these biomasses is also derived experimentally and theoretically in that study. The inorganic composition of the MSW fraction is produced by ash analysis of the samples. The details are provided in Table 2.2.

Dima et. al. (2022), published a very recent solid waste composition data collected from Aminbazar landfill following ASTM D5231 standard. The composition is supplied as the supplementary material (S1) of the paper "Fate of nutrients during hydrothermal carbonization of biogenic municipal waste" and the supplementary data is collected from Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET) through communication while conducting this LCA study. This data is a very rational resource of recent waste combination pattern as these are found experimentally based on ASTM standard procedure, major waste categories are enlisted that is qualitative for life cycle analysis data and the level of confidence is 90% for the major organic fraction (Dima, et al. 2022). The small 1.37% of other inorganics can be analyzed as "inert". For more details analysis of solid

waste, this inert inorganic portion can be divided into the % of inorganics materials provided in Rasul (2016). This combination of Dima et al. (2022) and Rasul (2016) can be used as a reference data for future circumstantial analysis of landfill solid waste of Dhaka city.

Although these data are promising and more complete than the previous data, for the sustainability evaluation of Dhaka city MSWM through LCA, another latest dataset from World Bank (2021) report "Towards a Multisectoral Action Plan for Sustainable Plastic Management in Bangladesh" will be used. In December 2021, the report is published with the latest waste composition data of Dhaka North and South City Corporation from households and landfills. The composition was prepared by conducting a field survey. The landfill compositions are provided in Table 2.1. According to the report, the quantity of food and vegetables is highest in both DNCC and DSCC (86.29% and 84.94%). Coconut is shown as separate material, but in this analysis, coconut is added with organic waste percentage.

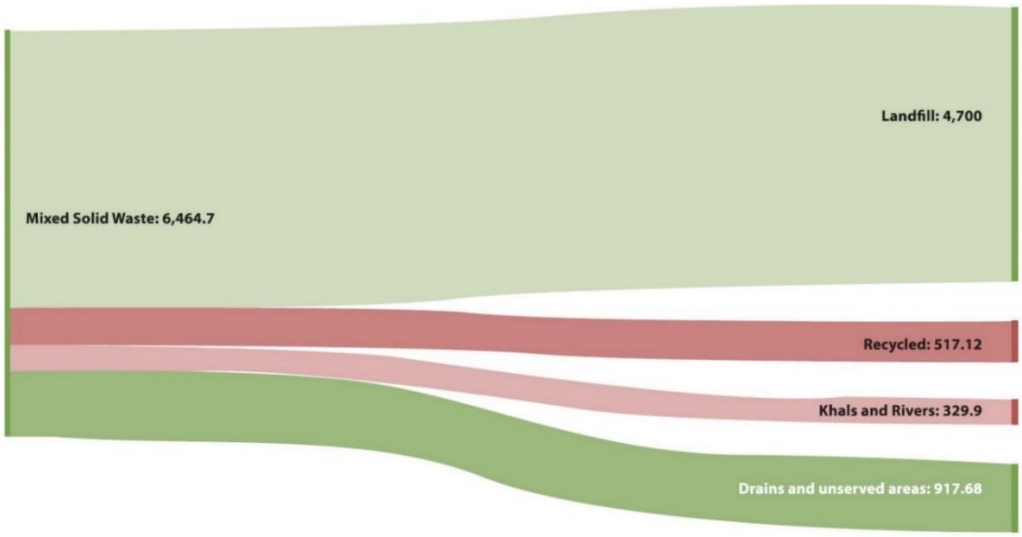
Table 2.1: MSW composition of Dhaka

<table>
<tr><th>Literature</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th></tr>
<tr><td>Location</td><td>DCC</td><td>DCC</td><td>DCC</td><td>Urban</td><td>DCC</td><td>Urban</td><td>Aminbazar</td><td>Aminbazar</td><td>Matuail</td></tr>
<tr><td>Waste Types</td><td>%</td><td>%</td><td>%</td><td>%</td><td>%</td><td>%</td><td>%</td><td>%</td><td>%</td></tr>
<tr><td>Organic/biowaste</td><td>84.37</td><td>59.60</td><td>65.96</td><td>67.65</td><td>74.00</td><td>77.70</td><td>74.19</td><td>86.29</td><td>84.94</td></tr>
<tr><td>Wood, grass etc.</td><td>-</td><td>0.41</td><td>0.94</td><td>4.20</td><td>4.00</td><td>2.72</td><td>0.95</td><td>-</td><td>-</td></tr>
<tr><td>Paper</td><td>5.68</td><td>5.12</td><td>4.63</td><td>9.73</td><td>5.00</td><td>4.84</td><td>4.56</td><td>2.55</td><td>0.74</td></tr>
<tr><td>Textile</td><td>1.83</td><td>1.64</td><td>6.25</td><td>2.50</td><td>2.00</td><td>2.56</td><td>7.01</td><td>1.34</td><td>1.20</td></tr>
<tr><td>Plastic</td><td>1.74</td><td>3.21</td><td>5.21</td><td rowspan="2">5.10</td><td>8.00</td><td>7.35</td><td>11.83</td><td>5.24</td><td>7.92</td></tr>
<tr><td>Rubber and Leather</td><td>-</td><td>1.01</td><td>2.03</td><td>1.00</td><td>-</td><td>0.08</td><td>Concluded in Others</td><td>Concluded in Others</td></tr>
<tr><td>Metal</td><td rowspan="4">6.38</td><td>0.73</td><td>0.81</td><td>0.26</td><td rowspan="2">3.00</td><td>0.44</td><td rowspan="4">1.38</td><td>Concluded in Others</td><td>Concluded in Others</td></tr>
<tr><td>Glass</td><td>1.38</td><td>0.94</td><td>1.13</td><td rowspan="2">4.38</td><td>1.24</td><td>0.40</td></tr>
<tr><td>Construction Waste</td><td rowspan="2">26.90</td><td rowspan="2">13.23</td><td rowspan="2">9.43</td><td rowspan="2">3.00</td><td>Concluded in Others</td><td>Concluded in Others</td></tr>
<tr><td>Others/Inert</td><td>3.34</td><td>4.80</td></tr>
</table>

1 is the generated waste of DCC residential area by Ahmed, (1993)
2 is the generated waste composition by JICA, (CDMP 2005)
3 is the landfill waste composition by JICA, (CDMP 2005)
4 is the generated waste composition by Waste Concern (2005)
5 is the generated waste composition by Bari et al. (2007)
6 is the generated waste composition by Waste Concern (2014)
7 is the Aminbazar landfill waste composition by Dima et al. (2022)
8 is the Aminbazar landfill waste composition by World Bank (2021)
9 is the Matuail landfill waste composition by World Bank (2021)

Table 2.2: Inorganic ash % of Matuail MSW (Rasul 2016)

*Inorganics %	Ca	K	Si	P	S	Mg	Fe	Al	Na	Ti	Zn	Sr	Rb
*Inorganics are expressed as oxides in the actual study of the element presented here.													
MSW-01	24.08	23.70	21.43	12.55	4.41	3.90	3.27	3.14	2.59	0.53	0.13	0.05	0.03
MSW-02	32.46	4.50	38.36	6.93	1.85	2.40	4.73	4.28	3.15	0.68	0.09	0.05	0.02
MSW-03	36.42	24.69	12.57	9.50	5.25	4.52	1.90	1.44	2.82	0.28	0.43	0.04	0.04
MSW-04	23.07	24.03	19.68	8.82	5.32	5.31	3.54	2.96	6.19	0.50	0.23	0.05	0.06
MSW-05	43.59	19.36	13.06	7.71	3.47	4.58	2.13	1.62	3.95	0.32	0.13	0.05	0.02
Adjusted Average	31.92	19.26	21.02	9.10	4.06	4.14	3.11	2.90	3.74	0.46	0.21	0.05	0.03



Note: All values in the figure are in tons per day.
Source: Field survey, Waste Concern Consultants 2020.

Figure 2.9: Total MSW flow of Dhaka in year 2020 (Yoshijima, et al. 2021)

Now with this landfill composition, the daily quantity of each waste type can be derived. For individual analysis of city corporations, the total waste quantity disposed per day to each landfill and recycling quantity of respective city corporations need to be known. In the world bank report, total MSW flow analysis is provided. But the report did not mention DNCC and DSCC landfill and recycling quantity particularly. The process of dividing the total quantity is discussed on research methodology. The waste going to khals, rivers, drains and unserved areas are kept outside of the system boundary. The combined daily waste generated in year 2020 in both city corporations was 6465 tons per day from which 4700 ton is landfilled as per the report. The material flow is shown in Figure 2.9.

Recyclable items mostly paper, plastic, glass, and metal are sorted and recycled at different stages from waste collection to landfill disposal by informal sector. Plastics that are easily

recyclable and has good market value is recycled most. According to the report recyclable plastic can be categorized as shown in following Table 2.3 with their individual percentages:

Table 2.3: Different waste plastic percentage in MSW (Yoshijima, et al. 2021)

Plastic	PET	HDPE	PVC	LDPE	PP	PS
%	26.19	11.17	13.09	21.89	14.88	12.68
PET= Polyethylene Terephthalate; HDPE= High Density Polyethylene; PVC= Polyvinyl Chloride; LDPE= Low Density Polyethylene; PP= Polypropylene; PS= Polystyrene						

As the report is on the sustainable use of plastic, there is no mention of recyclable paper categories. There is no other specific data available for different types of paper recycled or any reference data to distribute the total paper quantity into different types of paper. In this situation, the percentage of different types of paper produced per year in Bangladesh can be a good reference. It is assumed that this percentage of different types of paper produced will remain the same in paper waste both landfilled and recycled. Percentage of different types of paper produced in Bangladesh according to Bangladesh Bureau of Statistics, Banglapedia is provided in the following Table 2.4:

Table 2.4: Percentage of different types of paper produced (Rabbi 2021)

Production % of Different Types of Paper	
Writing	15%
Printing	35%
Newsprint	40%
Packaging and Others	10%

Now, with all these divisions, subdivisions and waste composition obtained from different studies, the waste fraction and quantity of specific type of waste will be estimated for use in LCI and detailed analysis are discussed on research methodology.

2.4 Common Solid Waste Management Practices

Following are some common MSW management elements worldwide:

2.4.1 Landfill

Landfill is defined as the facility for disposing waste in earth surface (Kreith and Tchobanoglous 2002). Although, there has been significant improvement in landfill design and application in developed countries, the scenario is not the same in developing countries since

there are variability of resource, national regulatory standards, and rapid urbanization (Kreith and Tchobanoglous 2002). In modern landfills, the most common landfill components are the cell, daily cover, final cover, lift, bench, liners, leachate treatment facility. Open dumping should not be mixed with landfill as there is no compaction or cover applied while dumping in open. It is also called uncontrolled waste disposal. When, the waste is controlled by collection system, thus treated by other method, or disposed directly to landfill with compaction, daily cover, and landfill gas recovery facility available, the landfill may be called sanitary landfill (Doka 2018). The controlled landfill without landfill gas recovery, liner and leachate collection system is called unsanitary landfill. Aminbazar falls on the controlled but unsanitary landfill category since daily cover and landfill gas recovery system is absent. In Aminbazar leachate treatment facility is also functioning poorly. On the other hand, Matuail landfill has a better leachate treatment system and final cover has been applied once a certain block in filled. Landfill mostly emits methane and carbon dioxide in air due to decomposition of MSW (Menikpura and Sang-Arun 2013). Leachate is the liquid that percolates through the waste. Source of this moisture may be internal or external, but it carries contaminants as it moves through the waste piles. Therefore, leachate is treated to protect the nearby water bodies and environment from contamination. The design criteria are discussed in Kreith & Tchobanoglous (2002) such as, type of waste to be handled, surface water managements, environmental monitoring, capacity, local geology etc.

2.4.2 Composting

Composting is the conversion of organic materials to produce compost with the help of microorganisms. It is an integral part of waste management specifically on the developing countries as the waste is mostly organic in nature (Yoshijima, et al. 2021). Composting reduces the volume of organic waste up to 50% by releasing water and carbon dioxide (Kreith and Tchobanoglous 2002). In developing Asia, local government prefer composting to other methods for treating organic waste as it is simple, easy to implement and low cost (Menikpura and Sang-Arun 2013). Environmentally, compost improves soil fertility, nutrient, plant growth and reduces erosion of soil and desertification as well as applied as bioremediation (Gigliotti, et al. 2005, Sayara, et al. 2020, Ayilara, et al. 2020). The carbon dioxide emission from composting is biogenic i.e., the amount of carbon dioxide plant absorbs to grow is released after death by decomposition from microorganisms, therefore balancing the carbon dioxide in nature (IPCC 2019). Composting process involves receiving of waste, sorting and primary screening, size reduction, waste piling for decomposition, adjusting C/N ratio, moisture content

and final packing (Kreith and Tchobanoglous 2002). There are various types of composting methods such as windrow composing, vermicomposting, pit composting, Indian Bangalore composting, Indian Indore composting, Berkley Rapid composting, static windrows etc. (Kreith and Tchobanoglous 2002, Mengistu, et al. 2018, Ayilara, et al. 2020).

For composting the main factors are temperature, oxygen, pH, moisture content and C/N ratio. There are three phases of composting (Kreith and Tchobanoglous 2002) which are 1) lag phase, 2) active phase, 3) maturation phase. Initial lag phase is a mesophilic stage where microbes break raw waste at 20°C-40°C temperature. On active stage, microbes exponentially increase in numbers and temperature rises due to intense microbial activities. This process continues until readily available nutrient decreases. Thermophilic bacteria dominate this stage as temperature can rise to 70°C. When the decomposable waste reduces maturation phase starts. Oxygen plays significant part in composting as in aerobic condition, carbon is oxidized for energy formation but in anaerobic condition, methane, ammonia, and other odorous gas is produced (Ayilara, et al. 2020). Optimum pH for compost is 5.5 to 8.5 (neutral to slightly acidic). Initially pH drops due to organic acid formation during decomposition (Shilev, et al. 2007, Kreith and Tchobanoglous 2002). Eventually pH increases to 8.0 to 9.0 due to rise in microbial populations and remains on the final compost. Moisture is important for microorganisms for nutrient exchange. C/N ratio in the raw waste depends on the types of organic waste. The ideal ratio is 20-25:1. Higher than 20/1 slows down the composting whereas less than 15/1 cause loss of nitrogen (Kreith and Tchobanoglous 2002). Depending on the final product requirement the raw waste can be co-composted with either nitrogen or carbon enriched materials.

There are some constraints for using compost. Presence of harmful substance, toxic compound and pathogen can enter food chain and damage animal and human health (Kreith and Tchobanoglous 2002). Sole use of fertilizer produced from compost can increase salinity of soil, leaching of nutrients can contaminate soil and water (Sayara, et al. 2020). Some study recommends use of chemical and organic fertilizers together for optimal output (Chandini, Kumar and Om 2019). Although, the fertilizer produced from compost take longer period for plants to absorb, its environment benefit is massive (Menikpura and Sang-Arun 2013). Organic fertilizers do not have the side effects of chemical fertilizer which make it more environmentally friendly. Bari et al. (2007) studied composting on Dhaka city organic waste and produced compost with good NPK value that can be replaced chemical fertilizer.

2.4.3 Incineration

Waste to Energy or WtE is the process of generating energy as heat and electricity from exothermic reaction during the combustion of waste at 850°C-1100°C with the presence of air/oxygen (Liu, et al. 2020, Ungureanu, et al. 2017, DEFRA 2013). Waste combustion reduce the volume of waste by 90% and mass by 75% (Menikpura and Sang-Arun 2013). The basic components of an incineration plant are the waste receptor, grate or fluidized bed, hopper, combustion chamber, boiler, generator, slag system, flue gas cleaning, incinerator bottom ash (IBA) collection and disposal system, air pollution control (APC) system, stack (Liu, et al. 2020, Rand, Haukohl and Marxen 2000). Typical incineration technologies examples are grate or stoker type technology, fluidized bed, rotary kiln (DEFRA 2013). According to the World Bank (2000) report the average lower calorific value of the waste must be at least 6 MJ/kg throughout all seasons and annual average should not be less than 7 MJ/kg. It is mostly suitable for combustible waste like plastics (LHV 20.14 MJ/kg), leather and rubber (LHV 14.26 MJ/kg), textiles (HHV 11.79 MJ/kg). Incineration technology removes methane emissions from waste and can replace energy produced from fossil fuels (Menikpura and Sang-Arun 2013). But due to high moisture content, low calorific valued organic nature of waste and difficulties in plant operation, high initial cost it is mostly failed in developing Asia (Menikpura and Sang-Arun 2013). The main pollutant from incineration is fly ash (APC residue) that includes heavy metals like antimony (Sb), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), gaseous pollutants like hydrochloric acid, sulfur dioxide, hydrogen fluoride, nitrogen oxides, carbon monoxide (partial combustion of waste), volatile organic compounds, dioxins and furans, ash residues like calcium, sodium, aluminum, silicon etc. (Rand, Haukohl and Marxen 2000, DEFRA 2013, Kreith and Tchobanoglous 2002, Liu, et al. 2020). These compounds can cause chronic diseases, cancer, birth defects, respiratory diseases if exposed to the environment. Soil acidification, deposition of acid gases, dioxins, NOx, SO_2 damage vegetation. Therefore, incineration plant needs careful handling and supervision with mandatory air and wastewater pollution control measures like electrostatic precipitator, fabric filter, wet scrubber, catalytic or non-catalytic reduction or various combination of these technologies so that the output lies within the environmental standards (Rand, Haukohl and Marxen 2000, Ungureanu, et al. 2017).

2.4.4 Recycling

According to the World Bank, recycling is the process of transformation of waste materials into new products so that the original products lose their actual identity (Hoornweg and Bhada-

Tata 2012). William Russell and Rex Burch introduced the concept of the 3R (reduce, reuse, recycle) during the 1950s. It is a vital tool to achieve circular economy (Yoshijima, et al. 2021). Most common recyclable wastes are paper, glass, metals, and plastics (Kreith and Tchobanoglous 2002). Recycling can be done in multiple steps in waste management such as reducing at source, from commingled recyclable, from mixed MSW at transfer stations and landfills. The presence of recycling in developing countries is mostly informal where high income countries have regulated higher end technologies for sorting and processing and higher rates of recycling (Hoornweg and Bhada-Tata 2012). These efforts are made effective by placing recycling markets near to source. Recyclable recovered from mixed waste has lower value thus making source separation operations cost effective and creating more market opportunities (Hoornweg and Bhada-Tata 2012). Plastic and paper recycling require much less resources and energy and emits little GHG compared to products produced from virgin materials. In developing countries informal waste pickers are the major contributors to material recycling. According to Matter and Dietschi (2013), the attitude of "we dump-they collect" is one of the major facts as the resident's belief that only municipalities will be responsible for the waste management which is a key impediment towards national 3R policy. The study also finds that recyclable buyers (feriwallas), cycle-van drivers (gariwallas), waster pickers (tokai) contribute largely to recycling in Dhaka. In Bangladesh, plastic recycling can greatly reduce environmental burden and create more opportunities to foster economic development (Yoshijima, et al. 2021).

2.4.5 Anaerobic Digestion

The main difference of anaerobic digestion (AD) to composting is that the waste is composted anaerobically and produce biogas with digestate (Potts and Martin n.d.). The digestate can be used for land improvement which can minimize the use of chemical fertilizer (DEFRA 2004). The main advantages of anaerobic digestion are low carbon dioxide emission, suitable for wet organic waste, odor elimination, no toxic compound production like dioxins while, on the other hand, the process takes long time and digesters are expensive, wastewater treatment facilities needed additionally, presence of other non-decomposable waste will need separate treatment and poor quality of digestate will produce low quality compost (Potts and Martin n.d.).

2.4.6 Refuse Derived Fuel

The combustible part of MSW is defined as fuel that is derived from refuse (Rezaei, et al. 2020). The raw waste is grounded, sorted, crushed, and optimized to desired moisture content,

mixed with desirable proportion if the waste type is heterogenous and then pelletized by compaction. Paper, plastics, wood, and organic waste are generally combustibles, but the pellet mix should be formed in such a way that the desired calorific value can be obtained (EPA, South Australia 2010). Moreover, the fuel must be risk free and environment friendly to humans and surrounding environment. Also, the particle size distribution should be appropriate for efficient combustion. RDF is used in pulp, paper, and wood industry in India generation up to 7.5 MW of electricity (Shukla and Srivastava 2017).

2.4.7 Mechanical Biological Treatment

Mechanical biological treatment is assembled by combining the mechanical processes such as shredding, sorting, compacting waste, and biological processes like aerobic and anaerobic digestion (Di Lonardo, Lombardi and Gavasci 2012). The main advantage of these sorts of treatment facilities is to make the best energy recovery as per the waste composition. The approach is very site specific. Environmentally, MBT plant is greatly beneficial due to recovery of recyclable materials, production of RDF, production of biologically stabilize matter which combinedly make the reduction minimal as well as respecting the waste hierarchy defined in EU Waste Framework Directive (Ferrara, Chechile and De Feo 2017). The overall challenges are like the challenges of the different types of treatment method adopted.

2.4.8 Pyrolysis and Gasification

Pyrolysis is the thermal degradation of carbonaceous materials in absence of oxygen. It is an advanced method of thermal treatment. Temperature requirement is 300°C to 850°C for MSW (DEFRA 2013). Before introducing raw waste, separation of glass, metals and other inert is conducted. The product of pyrolysis are syngas, oil or char and slug (Zaman 2013). Gasification is the process of introducing oxygen partially between the pyrolysis and combustion at above temperature 650°C (DEFRA 2013). In gasification stage, water gas is formed by reaction of carbon with air. Water gas is a mixture of hydrogen gas with carbon monoxide produced from synthetic gas. Combined pyrolysis gasification has four steps namely drying, pyrolysis, oxidation and reduction and gasification is introduced in oxidation and reduction stage. Gasification can be done by air, oxygen, steam, hydrogen and water vapor-oxygen mix, water-vapor air mix etc. (Zeng, et al. 2018). The technology is complex and not used widely around the world. Energy and heat produced from the combustion of gases (DEFRA 2004).

2.5 Worldwide MSWM Evaluation by LCA

Evaluation of SWM system by LCA is commonly accepted worldwide. There is plenty of research on LCA of different waste management strategies. Some of these studies focused on whole SWM system while some focused on specific technologies.

Ozeler et al. (2006) studied SWM of Ankara, Turkey. Five scenarios are compared combining source reduction, transportation, landfill, material recovery facilities, incineration and anaerobic digestion. The study found out that source reduction combined with recycling and landfilling was the most sustainable method. The use of energy is minimal, and emissions are lowest than other methods.

Bhander et al. (2010) studied the functional abilities of a LCA software EASEWASTE to meet the goal of assessing environmental performance of different waste management approaches. They concluded that it is versatile software that is specially developed for SWM and offer a comprehensive way of waste modelling. A typical waste treatment flow chart is shown in Figure 2.10.

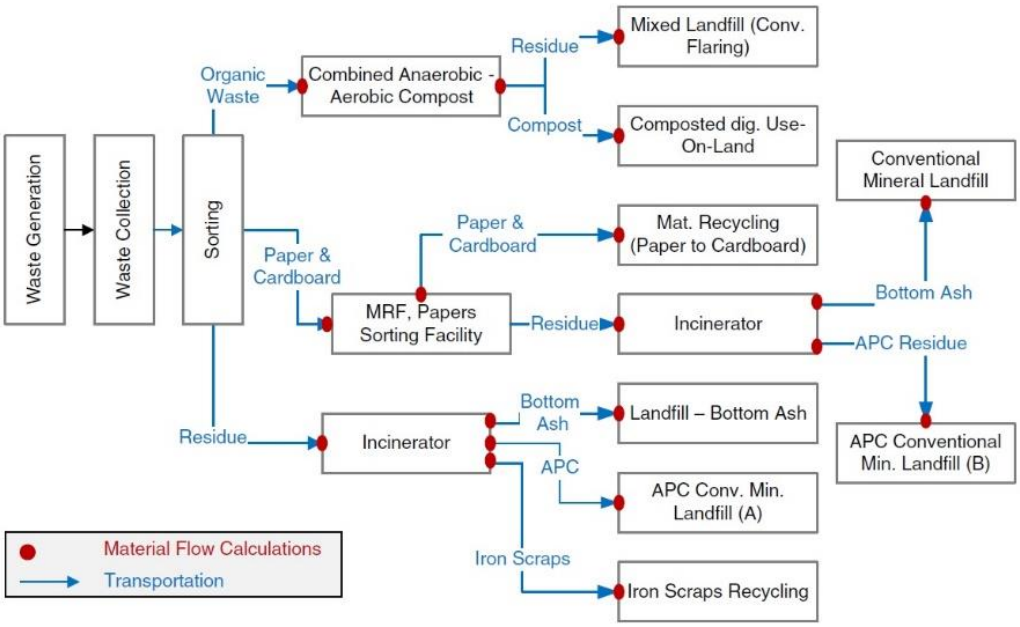


Figure 2.10: EASEWASTE MSWM flow chart (Bhander, Christensen and Hauschild 2010)

A case study LCA was conducted with EASEWASTE from real data of a city in Denmark. The impact assessment result was rationale, and the model offers a holistic approach for assessment. Some recommendations were also made for further development of EASEWASTE.

Mali et al. (2016) conducted LCA on MSW of Kolhapur city, India. Figure 2.11 illustrates the waste flow diagram used in the Kolhapur waste LCA study. SimaPro software was used for the LCA study. The results were evaluated in major impact assessment categories. The nature of the waste being mostly organic, composting, anaerobic digestion and pyrolysis gasification method is adopted for alternative waste treatment strategies. The result revealed that composting and pyrolysis gasification are the two most environmentally suitable methods.

Paes et al. (2014), analyzed environmental sustainability of SWM of Piedade, São Paulo, Brazil by LCA. The EcoIndicator 99 impact assessment method was used. The study found that increase in recycling improves environmental performance. The system also helped forecasting the impact reduction from the targeted rate of composting.

De Feo et al. (2016) performed LCA on MSW in Baronissi, Italy. The impacts were assessed with IPCC 2007, Ecological Footprint and ReCiPe 2008 LCIA methods. The analysis identified that transportation was the key factor behind environmental loading. The results from Ecological Footprint and ReCiPe were similar but IPCC 2007 differed significantly. The authors suggested that multiple evaluation methods should be adopted as some LCIA methods considerations are different.

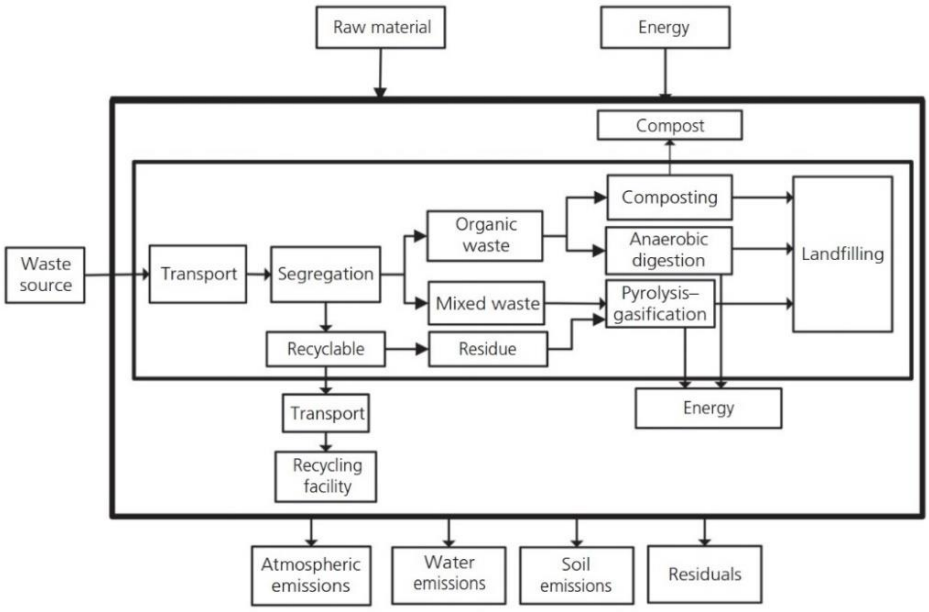


Figure 2.11: System boundary of MSWM LCA, Kolhapur city (Mali and Patil 2016)

Ortiz et al. (2020), assessed the SWM of Quito, Ecuador by LCA. SimaPro 8.4 was used for the study. The study found the biogas utilization from landfill save GHG emissions greatly. Due to high organic fraction, composting and anaerobic digestion were another two suitable

methods if considered environmentally. The waste flow diagram and system boundary in this study is shown in Figure 2.12.

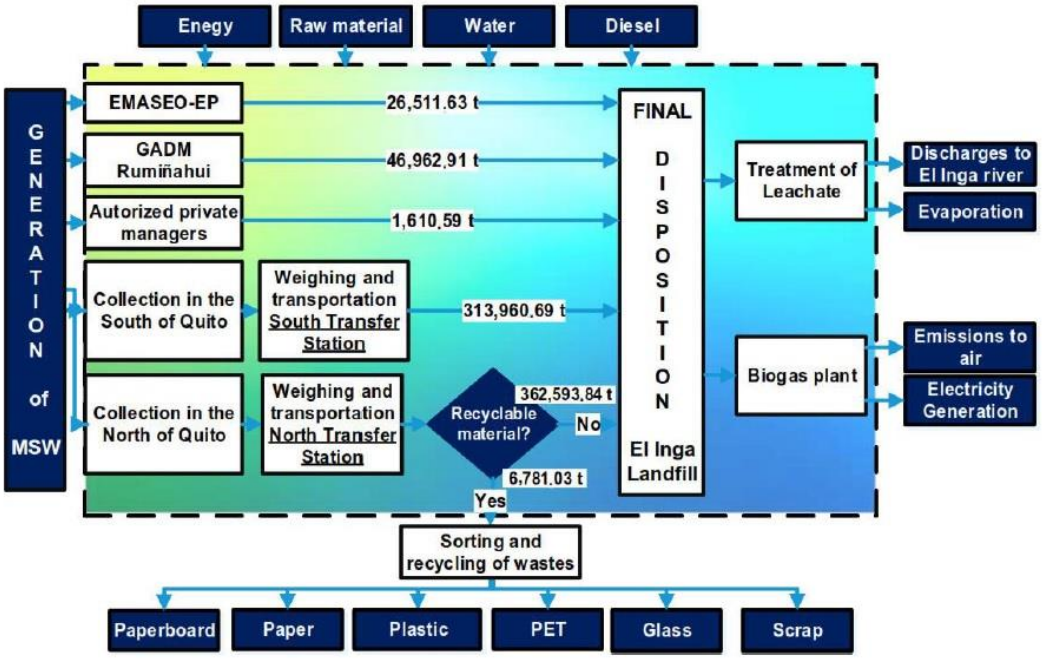


Figure 2.12: LCA System Boundary of MSWM in Quito (Ortiz, et al. 2020)

Vahidi et al. (2018) evaluated SWM using LCA of Iranian city Sirjan. openLCA used for the analysis. Impact assessment method was TRACI2014. The study shows that impact assessment results vary according to the varying composition of different types of waste. Akhavan Limoodehi et al. (2017), performed LCA on Tehran, Iran. The study found that recycling with composting has the most positive benefit for human health.

Similar LCA research were conducted on SWM of Central Macedonia, Greece and Montreal, Canada by Banias et al. (2020) and Malmir et al. (2020) respectively. Abeliotis (2011) reviewed some peer reviewed publications on LCA over different area and treatment methods and concluded that most of the finding from LCIA were largely rationale.

Technology specific LCA analysis and their impacts are analyzed by many researchers. Waste management techniques like landfilling, recycling, composting, incineration, pyrolysis and refuse-derived fuel are discussed comprehensively by these studies (Rieradevall, Domènech and Fullana 1997, Hansen, et al. 2006, Al-Rumaihi, et al. 2020, White 2012, ROU 2007, Komilis and Ham 2004, Andersen, et al. 2010, Zaman 2010, Pandyaswargo, Onoda and Nagata 2012, Assamoi and Lawryshyn 2012); (Beylot, et al. 2017, Evangelisti, et al. 2013).

2.6 Life Cycle Assessment (LCA)

LCA is a worldwide used and accepted method to assess the environmental impact/ burden of a product, system, or services from cradle to grave. According to ISO 14040 LCA is the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle." LCA covers all major aspects of the environmental impacts like extraction of different raw materials, hazardous pollutants emissions (Guinée, et al. 2002). By using LCA methodology economic analysis of product system is also possible. In this study, the focus will be on the environmental impact only. So, no economic analysis is conducted.

Early development of LCA began in 1980s which is currently governed by the ISO 14040 and ISO 14044 standards (Gala, Raugei and Fullana-i-Palmer 2015). The LCA approach is used widely in waste management sector which started at the of 90s (Hauschild and Barlaz 2011). Moreover, LCA methodology helps compare alternative strategies mixed with different waste management strategies from a holistic point of view. The LCA approach makes it possible to identify important contexts from different processes in a system.

LCA application involves the green/ eco labeling of product which enables consumers to identify eco-friendly products. Whether it is product manufacturing or construction or agricultural sectors or transportation, LCA helps strategically to compare different path and identify the major factors in decision making (Guinée, et al. 2002).

Besides the broader aspects, LCA methodology has some limitations. LCA is steady -state approach. It's not dynamic. Also, LCA is based on linear approaches (Guinée, et al. 2002). There is research ongoing to develop the social impact assessment through LCA and make it more sensitive to functioning of specific locality. The availability of data is another challenge for conducting a LCA study when local data is not available.

2.6.1 Steps of LCA

Based on ISO standards, LCA study is divided into four steps:

1. Goal and Scope Definition

Any LCA study is conducted according to the needs of specific impact analysis like product manufacturing analysis or waste management efficiency evaluation etc. So, the first step of LCA is to set a goal for the study. ISO refers to goal and scope as study design parameters (SPDs). The goal and scope should be defined so that it clearly states the intended application, the rationale of the study, for whom the report is prepared and if the results are used

comparative assertion released publicly. Within the scope the processes and their collective terms called the product system must be defined. Functional units should be defined considering the item, quantity, repetitive nature of the process, location and qualitative prospective. The reference flow is the defined for qualitatively and quantitively expressing the functional unit. The projecting system boundary falls within this step of LCA.

Allocation is another aspect of scope that is considered when multiple products are produced from a single product system. According to ISO 14044, for the choice of allocation method four hierarchical steps can be followed. These are:

i. Avoid allocation by subdivision: The production of main product and co-product is separated into sub process
ii. Avoid allocation through system expansion: Producing the co-products independently and alternatively by expanding to secondary function rather than merging with the main product unit process
iii. Allocation based on physical relationship: Allocate product according to their inputs and outputs and bonding their physical relationships
iv. Allocation based on other relationship: allocate products based on non-physical relationships

As for this study, the goal is to evaluate the current SWM practices of Dhaka city and recommend a better SWM alternative that would be friendly with respect to environmental burden. The study scope is limited to two Dhaka City Corporations. Overall LCA process covers the whole waste management scenario from the generation of SWM at households to secondary transfer stations (STS) and then disposal to landfills. Recycling of waste is also considered with specific assumptions. In the alternative approaches different waste management technologies adopted considering future-plan mentioned in waste reports of Dhaka City Corporations and feasible waste treatment as per local waste composition. This study can be a potentially strong guideline for future waste management strategies which in turn make the goal of this analysis rational. Further details on the scope of specific process analysis, functional units, system boundary, assumptions and limitations are discussed in respective process discussion section.

2. Inventory Analysis

In this step all the necessary data, inputs, and outputs of each process of a LCA study is gathered as a Life Cycle Inventory (LCI). For example, the burning of Diesel emits mostly Carbon dioxide (CO_2), Carbon monoxide (CO), Nitrogen Oxides (NOx), Particulate matter (PM) from

diesel engine. Now, suppose a dozer is compacting 1 ton waste in landfill and burning "x" kg

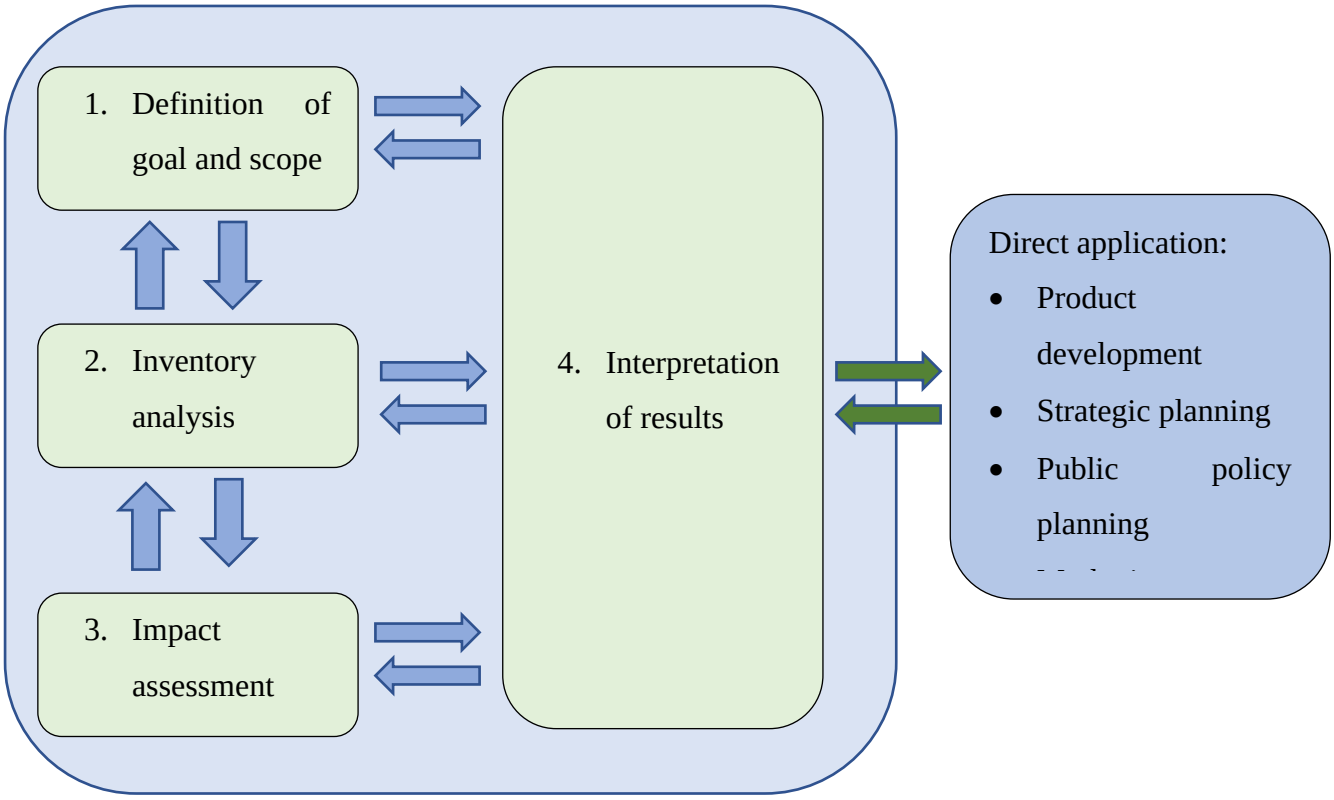


Figure 2.13: Life Cycle Assessment Phases (ISO 14040)

of diesel during the process. So, under the process landfill compaction, the quantity of diesel burning, and waste compacted is inventoried as input whereas the output is the emissions of the pollutants. The inventory analysis generally consists of inputs on energy, materials and outputs consists of products, byproducts, emissions to air, water, and land (Jain, et al. 2015). Inputs can be raw materials derived from another process, recycled or virgin materials, natural elements like water, element from technosphere like electricity, trucks etc. The details inventory is discussed on methodology of this study. Figure 2.13 demonstrates the phases of LCA.

3. Life Cycle Impact Assessment (LCIA)

This third step of LCA analysis is LCIA. The LCI quantity is multiplied with the corresponding characterization factors to assess the environmental burden. In a life cycle impact assessment method, there is a certain factor for the corresponding pollutant is assigned for each different impact assessment category which is called the characterization factor. These impact categories are broadly divided into two major divisions. One is impact category which is also called as midpoint category, and another is damage category alternatively known as endpoint category (Menoufi 2011). Midpoint categories are natural substance emissions which are modelled to

estimate the change in environment. The formulation and choice of LCIA is a complex procedure. As there are thousands of types of pollutants with different impact in different categories, it is very difficult to formulate a single impact assessment method to address all the emissions. Normalization is used to express the comparison of impact indicators among each other (Menoufi 2011). It is convenient to divide the substances into some major groups and then put an appropriate characterization factor over that group. It is also possible that the characterization factor differs from one LCIA methodology to other. All the complex inventory inputs are processed and expressed in comprehensive format based on characterization, normalization, and impact categories.

4. Interpretation of Results

This step is connected to three other steps of LCA process and conclusions are drawn at this of the analysis. This step is used for making decisions, identifying critical environmental burdens, evaluation of results in terms of consistency and completeness. ISO 14043 identified three activities as interpretation:

i. Evaluation of results
ii. Analysis of results
iii. Conclusion and recommendations

Depending on the analysis, the obtained LCIA result can be verified by following three checking:

i. **Completeness check:** To ensure that all the data needed for interpretation are complete.
ii. **Consistency check:** To ensure assumptions, model choices and methodology are within the scope of the study.
iii. **Sensitivity check:** To determine the uncertainties that can affect the result and conclusions. It is a sort of what if analysis which can be done by different simulations such as Monte Carlo simulation.

2.7 LCIA Categories

The elements of LCI are analyzed and connected to the environmental burden in some relevant impact categories. According to ISO 14044, “the category indicator can be chosen anywhere along the environmental mechanism between the LCI results and the category endpoint(s)”. Also, there are number of recommendations provided in ISO which helped LCA developers to make the default list of impact categories and differentiate ways of dividing impact categories i.e., midpoint and endpoint approaches. Stressors according to their fate spread in the

environment creating direct impact to environment at midpoint followed by damage at Areas of Protection (AoPs) like human life and ecosystems at endpoint. The midpoint and endpoint categories are discussed on the following sections:

2.7.1 Midpoint Categories

Midpoint methods are problem-oriented approach. They are based on cause-effect chain relationship (Menoufi 2011). Mainly these impacts are the primary effects in the atmosphere and these factors has relatively low uncertainty (Guinee 2015). For example, Dinitrogen monoxide (NO) has primary effect on stratospheric ozone depletion. 1kg of NO is equivalent to 0.011 kg of CFC11 equivalent which means 1kg NO will be responsible for ozone depletion that is equal to the damage that will be occurred by 0.011kg of CFC11 (openLCA database). Figure 2.14 provides a flow diagram that demonstrates the midpoint and endpoint categories covered in ReCiPe midpoint and endpoint methods. The other methods also follow these categories most commonly. In Guinee (2015), 91 default midpoint categories are tabulated with methodologies that determine these features from different literatures.

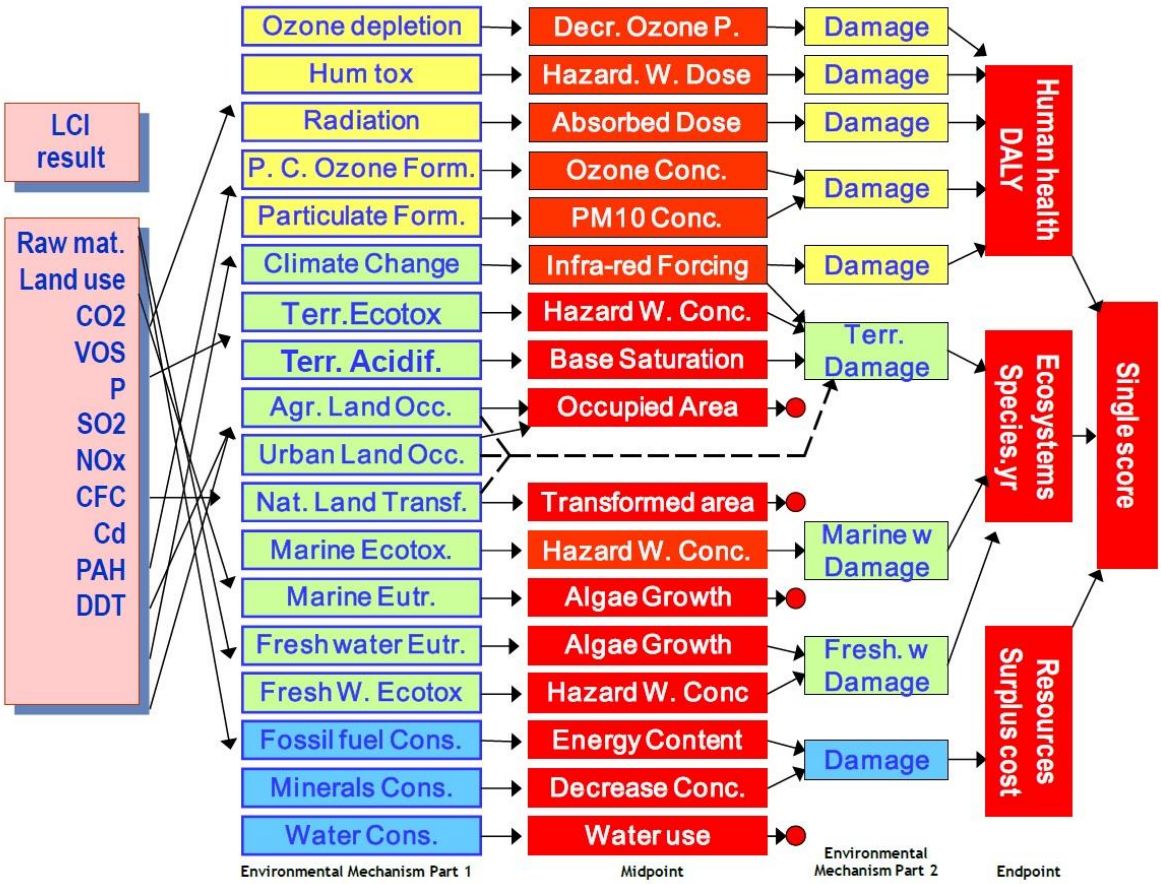


Figure 2.14: Impact categories, covered in ReCiPe 2008 (Goedkoop, et al. 2013)

2.7.2 Endpoint Categories

Endpoint methods are damage-oriented approach (Menoufi 2011). For example, the Dinitrogen monoxide that depletes ozone at midpoint will cause the penetration of Ultra Violets (UVs) into the atmosphere and increase probability of skin cancer at endpoint. Generally, damage to human health, damage to natural environment and scarcity of resources are considered mostly as endpoint categories. Damage to human health is expressed in Disability Adjusted Life Years (DALY), which means the number of years of heathy life lost (S. Anenberg 2017). Natural environment damage is expressed in species*year that is, the time integrated species loss from biodiversity (Huijbregts, et al. 2017). Endpoint results provide environmental burden that is related to the midpoint, but these are subjected to more uncertainties.

2.8 Some Specific Pathway Based Common Impact Categories

2.8.1 Acidification

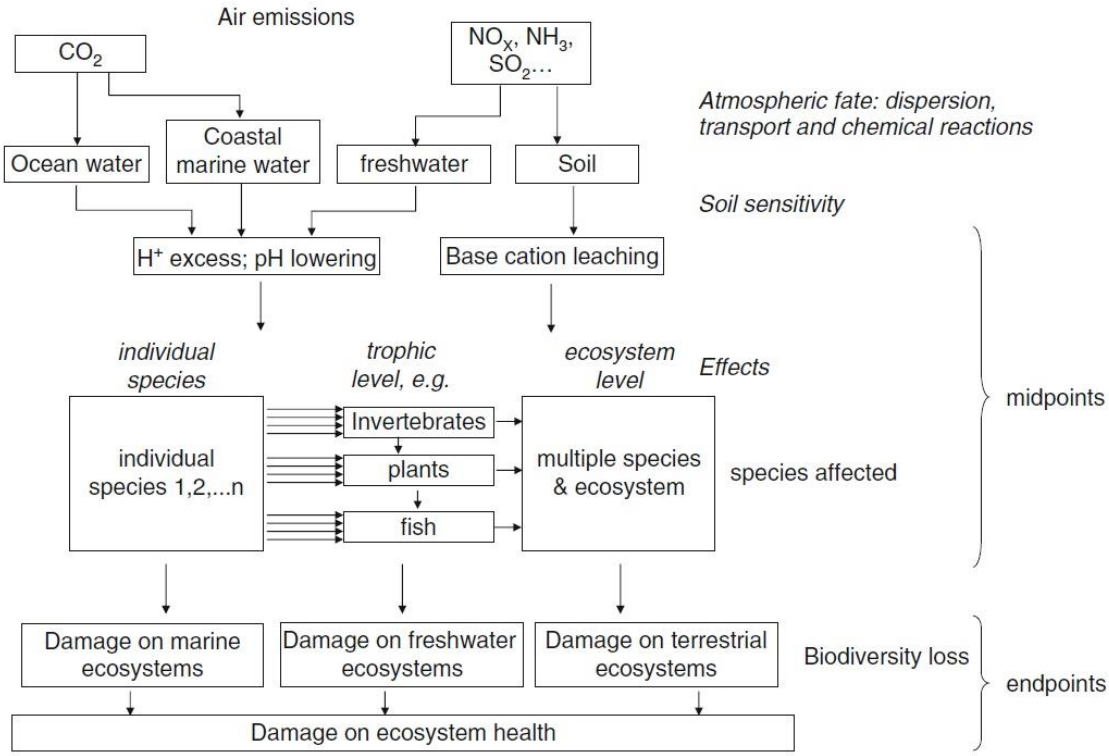


Figure 2.15: Acidification cause-effect pathway (Hauschild, et al. 2011)

Acid forms when oxides of Sulfur and Nitrogen and ammonia (NH_3) react with atmospheric water. This acid is deposited on the earth's surface and resulting acidity in soil and water. Terrestrial and freshwater ecosystems are affected by this acidification. The level of acidity is relatively optimum for any biodiversity in ecosystem. With the increase in acidity the pH of

soil and water changes which alter alkalinity and inorganic carbon storage in oceans (Zelm, Roy and Hauschild 2015). With change in soil alkalinity, the crop production hampered and causes shift and disappearance of species (Huijbregts, et al. 2017). Figure 2.15 shows the acidification pathway with the causes and the effects.

Following are the reactions occur during acidification by SOx and ammonia (Zelm, Roy and Hauschild 2015):

$SO_2 + H_2O \rightarrow H_2SO_3 \leftrightarrow 2H^+ + SO_3^{2-}$… … … … (2.1)

$NH_3 + 2O_2 \rightarrow H^+ + NO_3^- + H_2O$ … … … … (2.2)

In equation (2.1), SO_2 produces sulfurous acid and in equation (2.2) ammonia releases hydrogen ion and oxidized by bacteria to form NO_3^-. Acidification Potential (AP) is expressed as "kg SO_2 equivalent/ kg emission" at midpoint and "species*year/ kg SO_2 equivalent" at endpoint.

2.8.2 Climate change

According to IPCC, (2012), the definition of climate change is stated as follows:

"A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."

In IPCC 2013, anthropogenic radiative forcing (RF) is identified unanimously as the biggest contributor in climate change as it increases the temperature by trapping the heat in earth atmosphere by greenhouse mechanisms. The main factor behind it is the emission of greenhouse gases (GHGs) from human activities.

The four principal GHGs are CO_2, N_2O, CH_4 and halocarbons. CO_2 is generally emitted from fossil fuel combustion. Methane is emitted from agricultural activities and industries. Halocarbons are emitted mainly from industrial process (Levasseur 2015). The effects of increased temperature are causing rise in sea levels, drying up certain areas, extreme meteorological events, flooding, and agricultural losses etc. Following image is the pathway of GHGs to human health and ecosystems:

All the LCIA methods follow Global Warming Potential (GWP) characterization factor by IPCC. There are three-time horizons (20, 100 and 500 years) that are adopted in three

archetypes (I, H, E) in several LCIA methods. GWP100 is (hierarchist) the baseline for analysis. In ReCiPe, the endpoint impact of GWP is human health (DALY/ kg CO_2), terrestrial ecosystems (species*year/kg CO_2 eq.), aquatic ecosystems (species*year/kg CO_2 eq.) (Levasseur 2015).

2.8.3 Depletion of abiotic resources

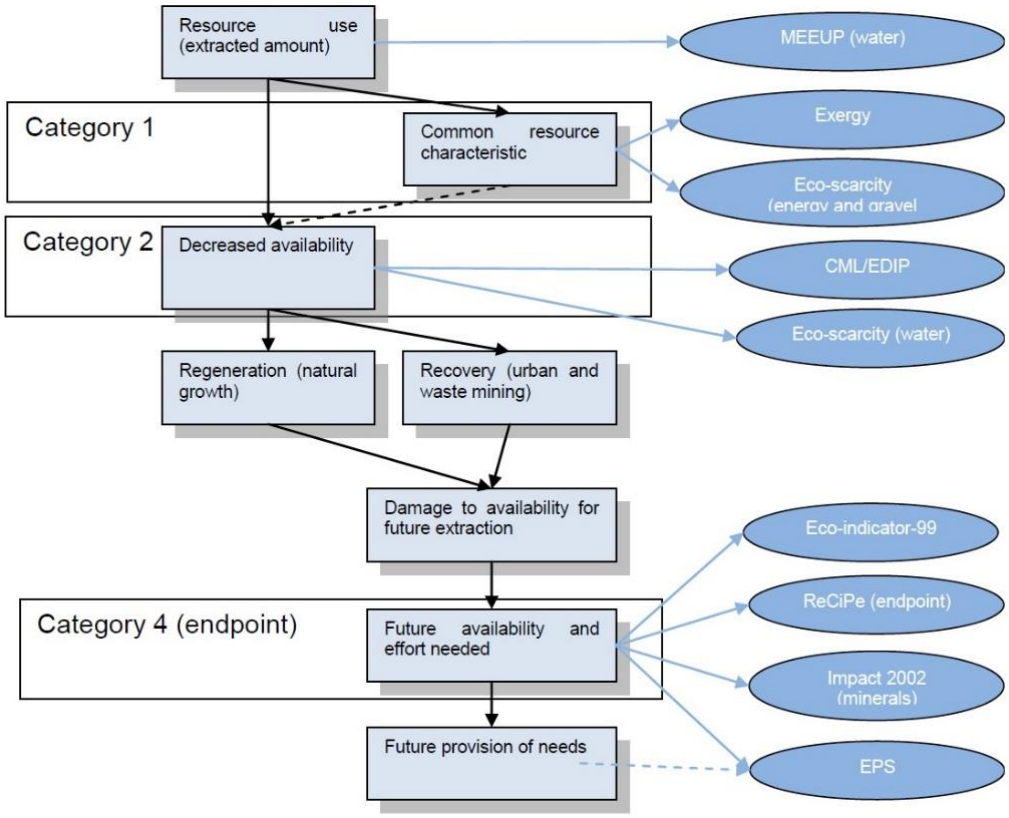


Figure 2.16: Cause-effect pathway for abiotic resource depletion (Hauschild, et al. 2011)

Figure 2.16 shows the cause-effect pathway for non-biological resource depletion. The general abiotic resources are fossil fuels, minerals, metals, water etc. They are divided into four broad categories by ILCD Handbook, (2011):

i. Category 1: Using inherent property of material for characterization

ii. Category 2: Using scarcity of the resource leading to higher uncertainty

iii. Category 3: Focusing water depletion

iv. Category 4: Covering entire LCA by focusing on endpoint

2.8.4 Ecotoxicity

The environment is affected by enormous amounts of chemicals. It is very complex to conclude about a linear development of characterization factors for this wide variation (Fantke,

Aurisano, et al. 2018). Ecotoxicological cause-effect is divided into four steps (R. K. Rosenbaum 2015) shown in Figure 2.17:

i. Chemical fate (distribution of chemical in the environment)

ii. Exposure (exposure to biodiversity)

iii. Effects (effect on biodiversity)

iv. Severity (Disappearance of species)

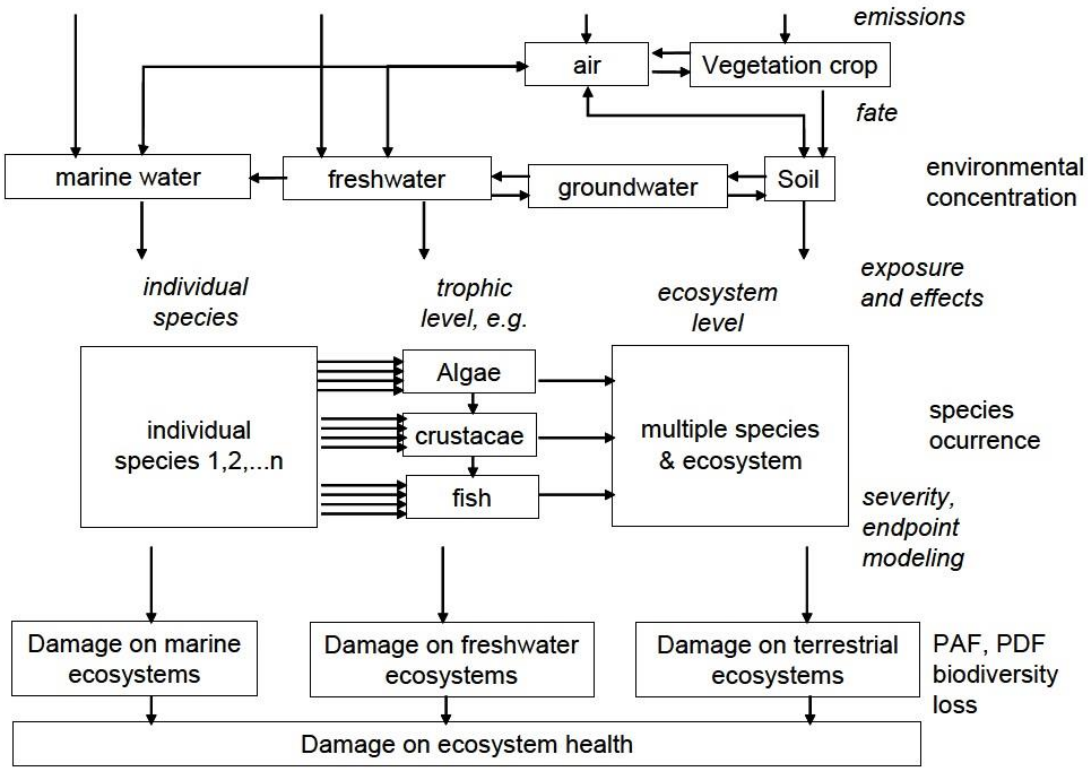


Figure 2.17: Impact pathway for ecotoxicity (Hauschild, et al. 2011)

Toxicity potential (TP) is expresses as 1,4-dichlorobenzene- equivalents (1,4DCB-eq) in midpoint categories (Huijbregts, et al. 2017). Endpoint is calculated as species*year/ kg 1,4-DCB equivalent. Chemicals from industries discharge wastewater that contaminate aquatic systems. Chemicals that are exposed in air deposit on surface may wash off and enter the animal food chain. Some chemicals metabolize to produce toxic substances. Ecotoxicity is determined for three types of environments: i) Freshwater aquatic ecotoxicity, ii) Marine aquatic ecotoxicity, iii) terrestrial ecotoxicity.

2.8.5 Eutrophication

Eutrophication is the rise of phosphorus and nitrogen (main nutrients) at a certain level so that the algae and cyanobacteria will bloom causing oxygen depletion and creating dead zones that

kill fishes and heterotrophs (Henderson 2015, Huijbregts, et al. 2017, Acero, Rodríguez and Ciroth 2015).

This movement of nutrient hampers both aquatic and terrestrial ecosystems. After death Algal decomposition consumes O_2 that create an increase in biological oxygen demand (BOD), where lesser light is penetrated. This category is characterized by an assumption that, freshwaters are limited in phosphorous and terrestrial and marine ecosystems are nitrogen limited which means not enough nitrogen to cover N:P ratio (Henderson 2015). This basic principle is used to characterize eutrophication potential (EP) as kg P equivalent/ kg emission for freshwater eutrophication and kg N equivalent for marine and terrestrial eutrophication.

2.8.6 Human toxicity

The toxicity pathway is almost the same as ecotoxicity, the only difference is that ecotoxicity damages the environment and human toxicity damages human health. The tropospheric environment and water bodies near humans are the prime sources of absorbing toxic substances into human bodies. Direct contact with chemical from industries can cause skin diseases, inhaling toxic air can cause diseases, drinking water with toxic substances will cause damage to internal organs. The injection of chemicals to human food chain is another pathway to intake toxicity.

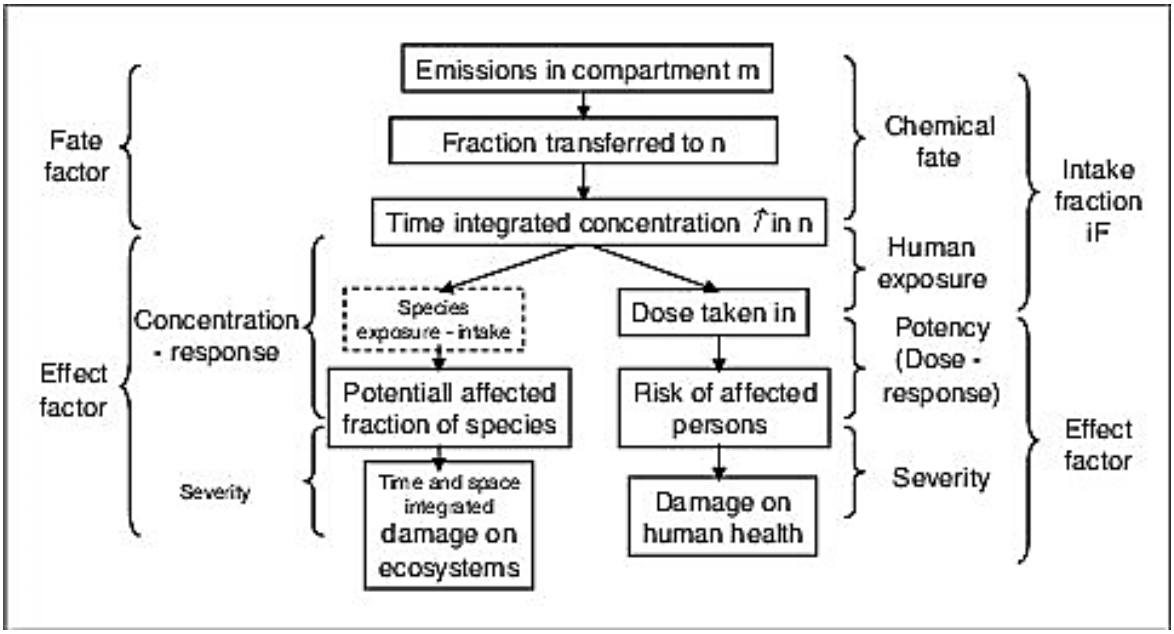


Figure 2.18: Impact pathway for human ecotoxicity (Jolliet, et al. 2003)

There is a large variation in classifying chemicals but based on damage impact the toxic substances are divided into two categories: 1) carcinogenic (responsible for causing cancer) and 2) non-carcinogenic (not known for causing cancer). The main factors behind the cause-

effect chain for determining human toxicity include fate factor (quantity of chemicals released into environment), exposure factor (exposure of human to chemical), dose-response factor (effect on human body due to chemical intake), severity factor (the disabilities caused). Dose-response factor is the limiting factor for characterization of toxic substances (Jolliet and Fantke 2015). Figure 2.18 demonstrates the impact pathway for human toxicity.

2.8.7 Ionizing radiation

Emissions from radionuclide originating from human activities are considered the main drivers to this category. Addressing the damage to human health is the prime target of this category. α, β, γ rays and neutrons impacts are mainly characterized in this method. Midpoint is expressed in various ways such as kg U235 equivalency, becquerel (Bq) per kg emission etc. and endpoint is expressed as DALY (Acero, Rodríguez and Ciroth 2015, Guinée, et al. 2002). Radionuclide's exposure damages DNA-molecules (Huijbregts, et al. 2017).

2.8.8 Ozone layer depletion

Ozone depletion potentials (ODPs) by WMO is the standard report the benchmark for characterizations that is followed in all LCIA analysis. Stratospheric ozone is called the good ozone which is responsible for preventing UVs from entering the earth's atmosphere and saving humans from health hazards. UVs have a direct impact on agriculture and crop production also. The emissions involved in ozone layer depletion are N_2O, CH_4, CO_2 and CFCs. Stratospheric ozone chemistry combined ozone breakdown by chemicals and photons, and it is hampered by the anthropogenic emission of the key compounds (Lane 2015). UVs like UV-B increase the risk of skin cancer, eyesight problems, viral and bacterial infections. It is expressed as kg CFC-11 equivalent damage at midpoint and DALY at endpoint.

2.8.9 Particulate matter formation

Particulate matters are mainly categorized as $PM_{2.5}$ (micrometer, fine particles) and $PM_{2.5}$-PM_{10} (coarser particles). $PM_{2.5}$ involves chronic morbidity according to WHO, 2003. WHO, 2021 report provided air quality guideline for $PM_{2.5}$ and PM_{10} based on cause specific mortality. Generally, PM are mixture or variety organics and inorganics that is inhaled will cause respiratory diseases. PM_{10} is likely to cause less the damage than $PM_{2.5}$. PM contains primary and secondary aerosols that can cause severe negative impacts like reduced life expectancy, lung cancer, cardiovascular diseases, diabetes etc. on human health (Huijbregts, et al. 2017, Humbert, Fantke and Jolliet 2015). Secondary $PM_{2.5}$ aerosols are formed by chemical

transformation of NOx, SOx, NH_3 and Volatile Organic Compounds (VOCs). The functional unit to measure PM pollution is kg $PM_{2.5}$ equivalent at midpoint and DALY at endpoint.

Following are the five steps of PM cause-effect chain:

i. Transformation of NOx, SOx, NH_3 and VOCs to secondary PM, primary PM is already at stack height
ii. Atmospheric chemistry
iii. Exposure to Human
iv. Dose and causalities
v. Final damage

2.8.10 Photochemical oxidation

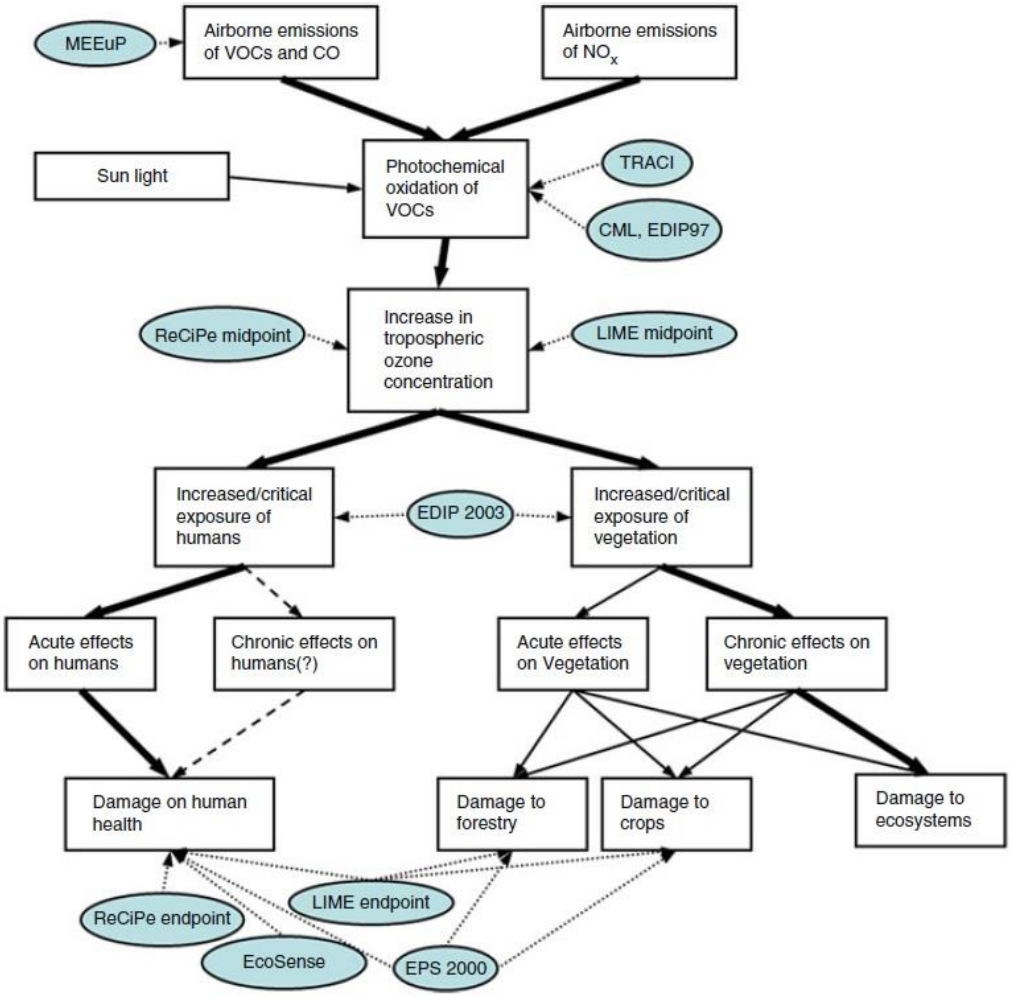


Figure 2.19: Photochemical oxidation pathway (Hauschild, et al. 2011)

As shown in Figure 2.19 the sunlight causes oxidation of VOCs that causes an increase in tropospheric ozone concentration. Although the good ozone in the stratosphere prevents UVs

from entering the atmosphere, the ozone present at troposphere is toxic to human. The primary and secondary aerosols are formed by reaction of ozone with NOx, SO_2, CO, and Non-Methane Volatile Organic Compounds (NMVOCs) (Hauschild, et al. 2011, Huijbregts, et al. 2017). The resulting impacts of bad ozone concentrations are damage to lungs, Chronic Obstructive Pulmonary Diseases (COPD), agriculture and crop production. Impact factors are expressed as kg NMVOC equivalent of kg formed ozone depending on the model.

2.9 LCIA Methodologies

There are some LCIA methodologies that are used widely. Hischier et al. (2010), on ecoinvent report No.3 report "Implementation of Life Cycle Impact Assessment Methods" discussed several life cycle impact assessments techniques. Another report from the GreenDelta (Acero, Rodríguez and Ciroth 2015) provided a clear insight of how to use these LCIA techniques. Menoufi (2011) discussed the classification of LCIA methods mainly in four types. These are:

- **i.** Midpoint methods (following midpoint categories)
- **ii.** Endpoint methods (following endpoint categories)
- **iii.** Combined midpoint and endpoint (following both categories)
- **iv.** Other methods that deal with energy demand, ecological footprint (specific category demand)

2.9.1 Archetypes

This classification is done according to the value of different culture that is based on "Cultural Theory" (Thompson, Ellis and Wildavsky 1990). Based on the perspective of human behavior, future technological choices to reduce damages and time assumptions, the following archetypes or approaches are adapted in some LCIA methods like ReCiPe. Eco-indicator, ILCD etc. (Huijbregts, et al. 2017):

i. **Individualistic perspective:** Reflection of short-term interest, focused technology considering human adaptivity, noted as I
ii. **Hierarchist perspective:** Default consensus model, most rational impact mechanism, some scientific models criticize this approach, noted as H
iii. **Egalitarian perspective:** More focus on future and long-term impacts, precautionary perspective, taking count of the longest time frame, noted as E

2.9.2 Common LCIA methodologies

Some widely used LCIA methods are discussed in the following.

i. CML

CML is first introduced in 1992 by University of Leiden in the Netherlands (Acero, Rodríguez and Ciroth 2015, Gabathuler 2006). A group of scientists from CML (Center of Environmental Science of Leiden University), published a new version of CML in 2001, which is known as CML 01 (Hischier, et al. 2010). It is a problem-oriented midpoint method. The categories covered by this method are provided in Table 2.5. In openLCA LCIA method CML is divided into two categories, i) baseline, ii) non-baseline. Baseline contains the most common categories where non-baseline is for extensive analysis. CML used standardized normalization factors from EU25, EU25+3,2000, The Netherlands, 1997, World, 2000 (Acero, Rodríguez and Ciroth 2015). The method is valid globally apart from acidification and photochemical oxidant. CML covers a very broad range of pollutants and compounds and is one of the state-of-the-art methods.

Table 2.5: LCIA methods and impact categories

Methods ⟶ Categories ⇩	CML (baseline)	CML (non-baseline)	Eco-indicator 99 (E, H, I)	JRC-IES 2011, midpoint	ReCiPe (E, H, I)	TRACI	USEtox	Impact 2002+
Acidification	C	C	C	C	C	C	NC	C
Climate Change	C	C	C	C	C	C	NC	C
Resource depletion	C	C	C	C	C	C	NC	C
Ecotoxicity	C	C	C	C	C	C	C	C
Eutrophication	C	C	C	C	C	C	NC	C
Human toxicity	C	C	C	C	C	C	C	C
Ionizing radiation	NC	C	C	C	C	NC	NC	C
Ozone layer depletion	C	C	C	C	C	C	NC	C
PM matter/ Respiratory effects	NC	NC	C	C	C	C	NC	C
Photochemical oxidation	C	C	NC	C	C	C	NC	C
c= covered in the methodology, nc= not covered in methodology								

ii. TRACI

TRACI stand for “Tool for the Reduction and Assessment of Chemical and other environmental Impacts” (Bare 2012). It is developed by United States Environmental Protection Agency (USEPA) in subsequent stages from 1996 to 2003 (Hischier, et al. 2010). It is invented not only for LCA but also for determining the sustainability metrics, industrial

ecology, process design and pollution prevention (Bare 2012). It is specially designed for U.S. and input parameters, characterization factors, normalization factors are provided that are aligned with U.S. regulations and standards. The methods mostly considered midpoint indicators like resource depletion, global warming, ozone depletion, human health criteria, smog formation, acidification, and eutrophication. It covers Particulate Matters ($PM_{2.5}$, PM_{10}), respiratory pollutants like NOx, SOx, heavy metal emissions etc. TRACI has 960 elementary flows characterization factors among which only 206 chemicals match with ecoinvent database (Hischier, et al. 2010).

iii. Eco-indicator 99

Eco-indicator is mostly used as an endpoint method. It started developing in 1995 and introduced in 1997 (Hischier, et al. 2010). The endpoint damage categories are divided into midpoint categories such as ecotoxicity, human toxicity, depletion of abiotic resources (Acero, Rodríguez and Ciroth 2015). Although it has expressed the damage to human health as DALY, the damage to ecosystems is expressed as plant species extinction per square meter per year and damage to resources as their energy content in Mega Joules (MJ). Emissions are characterized as per Dutch and European region (Menoufi 2011). Normalization and weighting factors are considered differently in hierarchist, individualist and egalitarian perspectives.

iv. JRC-IES 2011

ILCD was introduced by the Joint Research Center (JRC) of the European Commission. The full form of ILCD is "International Reference Life Cycle Data System" (Acero, Rodríguez and Ciroth 2015). It focuses on both the midpoint and endpoint categories. The characterization factors are divided mainly in three classes according to their quality:

- Level 1: Considered as satisfactory and recommended
- Level 2: Recommended with few improvements
- Level 3: Should be applied with caution

There is another optional class named "interim" which is stated as promising but immature to be recommended. For example, climate change midpoint is recommended as level 1 but climate change, endpoint is interim in ILCD LCIA. Mostly the endpoint of human toxicity, ecotoxicity, ionizing radiation, acidification is recommended as interim. Therefore, this method is problem oriented.

v. USEtox

USEtox is introduced in 2002 by United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) (Fantke, Huijbregts, et al. 2015, Rosenbaum, et al. 2008),. The focus was to identify the impacts on human health and ecosystems because of emissions of toxic substances. The challenge was to provide specific toxicity characterization factors to each toxic substance as it was difficult to address some in other LCIA methodologies and make it usable worldwide. Therefore, this consensus model is developed to forecast the fate, exposure, and effects of chemicals (Rosenbaum, et al. 2008). Impact category groups are divided into two types of toxicity: i) Freshwater ecotoxicity, ii) Human ecotoxicity. It has a vital application in ranking hazardous substances according to their toxicity level to human health.

vi. Impact 2002+

This methodology is developed by Swiss Federal Institute of Technology and federal Polytechnique School of Lausanne (EFPL)-France (Menoufi 2011). The present methodology combines 14 midpoint and four endpoint categories same as compared to CML and Eco-indicator 99 (Hischier, et al. 2010). Characterization factors are adapted from IMPACT 2002 (earlier IMPACT version), CML 2001, Eco-indicator, Cumulative Energy Demand, and IPCC (Intergovernmental Panel on Climate Change). It specializes in human toxicity and ecotoxicity. Human toxicity is sub-categorized as carcinogens and non-carcinogens. In addition to the major three damage category this method includes climate change as another damage category which is directly related to global warming category at midpoint.

vii. ReCiPe

Goedkoop et al. (2013) developed ReCiPe2008 with a view to harmonize characterization of midpoints and endpoints. It is then developed in its second phase in 2013 and currently updated to the ReCiPe2016 version. The name “ReCiPe” is named with the initial letters of the major collaborators RIVM and Radboud University, CML and PRé (Hischier, et al. 2010).

It is a state-of-the-art methodology that represents characterization factors in a global scale (Huijbregts, et al. 2017). This method is developed by considering the three cultural perspectives (I, H, E). Panel approach is adopted for weighing the factors (Menoufi 2011). The value choices in deriving characterization factors, midpoint categories and indicators, midpoint to endpoint factors in three perspectives in ReCiPe2016 are provided in Appendix A. There are certain impact pathways demonstrating the cause-effect chain are followed in this method. One

example is provided in following Figure 2.20. Figure 2.21 shows the all the midpoint and endpoint categories analyzed in this method.

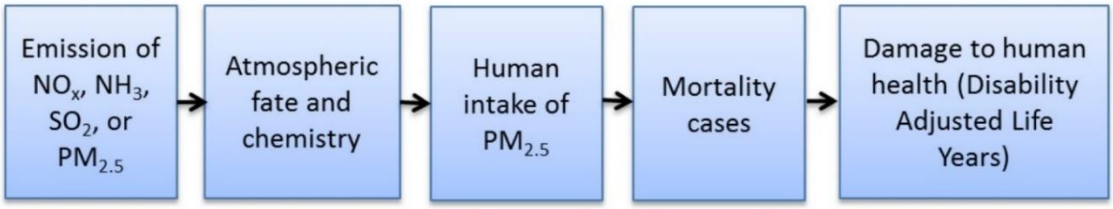


Figure 2.20: NO_x, SO_x, and PM damaging human health (Huijbregts, et al. 2017)

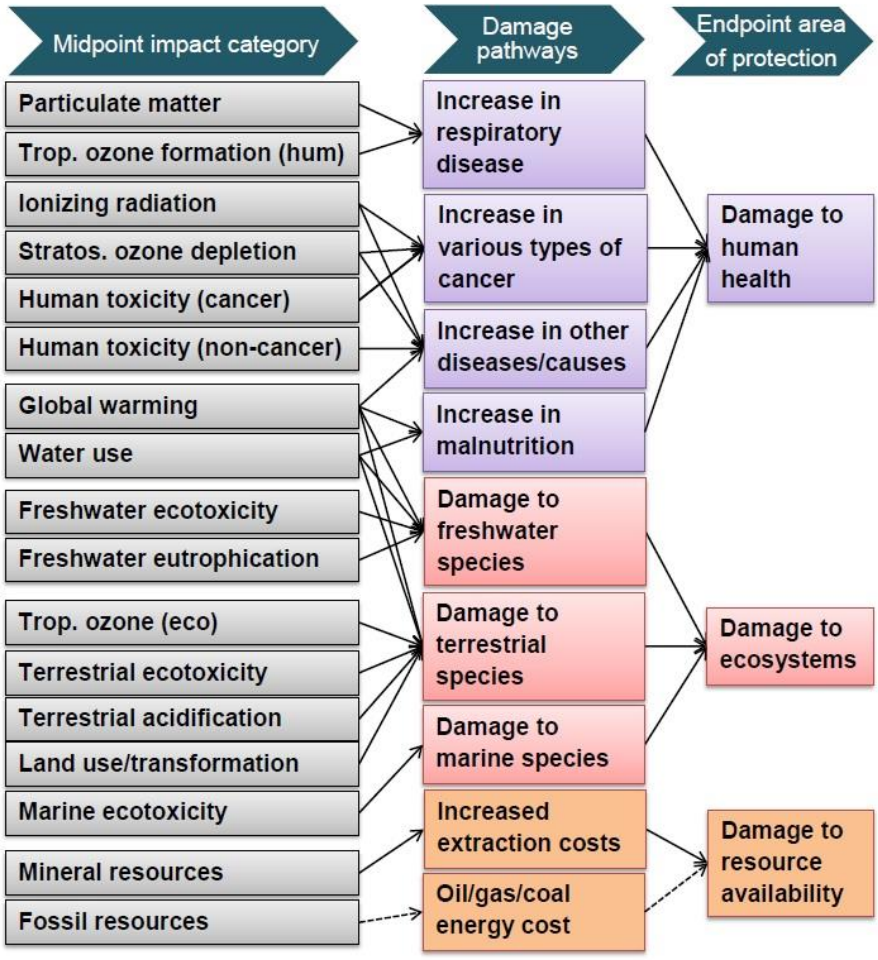


Figure 2.21: ReCiPe2016 midpoint and endpoint categories (Huijbregts, et al. 2017)

For global warming potential (GWP) characterization, 207 GHGs are listed in Huijbregts et al., 2016 following the IPCC 2013 report. For stratospheric ozone depletion potential (ODP), the World Meteorological Organization (WMO) 2011 report data is adopted. Similarly, for other impact categories different relevant reports and literature is followed for characterization. Most

importantly, this method has country specific characterization factors for P, $PM_{2.5}$, NH_3, NOx, SO_2, NMVOC, aquatic ecosystems including Bangladesh (Huijbregts, et al. 2017).

2.10 Life Cycle Assessment Software

On a study by USEPA (Jain, et al. 2015), 29 End of Life (EOL) LCA software is identified. Among these, some tools are generic and can be used for the entire life cycle of products, systems and wastes e.g., openLCA, Simapro, Gabi etc. which are wider scope than necessary for waste LCA. Some LCA software provides problem specific support dedicated to waste management. Some of these are WRATE, MSW-DST, EASETECH, WARM, SWOLF etc. Some of these commonly used software evaluations are discussion as follows:

2.10.1 Waste Management Support and Decision Making LCA Tools

i. WARM

WARM is developed specifically for GHG emissions with the ability to identify around 54 material types (e.g., food scraps, yard trimming etc.) (Jain, et al. 2015). It has its own database for end-of-life treatment. Users can change default values to as per necessity. The last version is updated in June 2014.

ii. MSW-DST

Another tool developed by USEPA for evaluating MSW management options like landfill, waste to energy, materials recovery etc. (Jain, et al. 2015). It estimates energy consumption, GHG emissions, and emission to air and water. It uses the characterization factors from TRACI to calculate the final impacts. The tool cannot produce more than one scenario result at a time. Manual documentation for different scenarios will be necessary for comparison. Documentation and tools (spreadsheet) are available on RTI International website.

iii. EASETECH

Developed by Technical University of Denmark. It is a state-of-the-art tool with availability of different waste management options like bio gasification, composting, material sorting, thermal treatment, recycling, bottom and fly ash management, energy recovery and landfilling (Bhander, Christensen and Hauschild 2010). The parameters are based on Danish 3R policies (Residual Resources Recovery). The software package is available as training and software package, costly as approximately 5500 USD at 2015 exchange rates (Jain, et al. 2015).

iv. WRATE

WRATE was developed by Environmental Agency (UK) and now owned and supported by Golder Associates (UK) Ltd (Jain, et al. 2015). The software is mainly representative of UK EOL. The demo version is free but not with adequate features to run the analysis necessary for this study. The academic version is available for free only as per evaluation of academic identity. Remaining standard and expert version requires purchase of the product. Both expert and standard uses ecoinvent database is used and only in expert version ecoinvent database can be edited (Golder Associates 2014).

2.10.2 Some Generic LCA Tools

i. openLCA

openLCA is an open source, generic tool for LCA. The tool allows users to have full control over the inventory database, impact assessment and full life cycle scenario. The tool is developed by GreenDelta. It is an ISO compliant tool with features like data quality system evaluation, automatic and graphical modelling, impact contribution tree (Hollerud, et al. 2017), parameter definition and Monte Carlo simulation (Ciroth, et al. 2020). It also allows allocation and system expansion in a model. It is compatible with several databases like ecoinvent, IMPACT world+, Environmental Footprints, Agri-footprint, Agribalyse, ELCD, worldsteel etc.

ii. SimaPro

SimaPro is widely used in a variety of sectors. It is another generic tool that allows users to model complex scenarios in a transparent way. The software identifies the sensitivities in supply chain, raw materials, manufacturing, distribution, and use. Simapro is developed by PRé Sustainability. No free version available and it's rather expensive. The library of Simapro is the agglomeration of ecoinvent, USLCI, ELCD, Agri-footprint and many other databases (Hollerud, et al. 2017). Datasets are comprehensive and enable users to pick from numerous inputs and outputs categories. This vast majority of data makes it powerful software to use.

iii. Gabi

Gabi is developed by Thinkstep (currently Sphera). Like Simapro, it is not free. It is another widely used software offering 8000 processes from various industries and sectors (Hollerud, et al. 2017). The full version is said to be more user friendly.

2.11 Choice of software

openLCA software is chosen from the software that discussed above. The rationale is that it is free of cost, user friendly, and provides full control over the whole life cycle analysis. The impact category is editable which means if some pollutants are not present in certain LCIA method they can be added or modified. Also, the database available to use with openLCA provides full access to change and modification as per necessity. The linking method of subsequent processes can be automatic or manual. A full system model can be formed in product systems and comparative analysis is possible in project report analysis. Also, various databases can be imported and combined while performing a custom LCA modelling giving option to variety which is not possible in most MSWM related software. Simapro and Gabi provide access to databases, but these options are expensive. Another very significant feature is that databases can be easily exchanged with Microsoft Excel. The results can also be saved in a spreadsheet. This saves a lot of time and makes the analysis more dynamic.

Chapter 3
RESEARCH METHODOLOGY

3.1 Introduction

The method of conducting the Dhaka city's MSWM LCA is the main context of this chapter. There is a detailed discussion on data collection method, analysis of the waste composition, defining goal and scope of LCA, preparation of LCI and impact assessment process. The scenarios formation, system boundary and method of conducting comparative LCA analysis between DNCC and DSCC is also explained in this chapter.

3.2 Data Collection Method

The study is conducted based on the secondary data collected from different reports and literature. Following Table 3.1 presents the sources of secondary data related to different process in LCA:

Table 3.1: Data related to MSWM LCA and their sources

Data	Source
Basic waste composition	World Bank Report Data (Yoshijima, et al. 2021)
Total waste quantity	World Bank Report Data (Yoshijima, et al. 2021)
Waste quantification, sub-division, and final fraction composition	(Yoshijima, et al. 2021, DSCC 2019-2020, DNCC 2019-2020, Rabbi 2021)
Waste transportation data such as nos. of vehicle, load, trip nos. etc.	(DSCC 2019-2020) (DSCC 2019-2020)
Diesel emission factor for non-road machinery	(Winther, et al. 2017)
Diesel emission factor for waste carrying vehicles	(Ntziachristos, et al. 2021)
Diesel consumption data	(DSCC 2019-2020) (DNCC 2019-2020) (Caterpillar 2016)
Landfill emissions from different waste landfilling	Ecoinvent 3.8
Recycling process emissions, savings, and net environmental burden	Ecoinvent 3.8

3.3 Waste Composition and Quantification

The waste composition and quantification analysis will be finalized by combining several reports as mentioned in the data collection section of this chapter. Following are the steps shown in Figure 3.1 that will forecast the waste quantification process. These steps are elaborately discussed below.

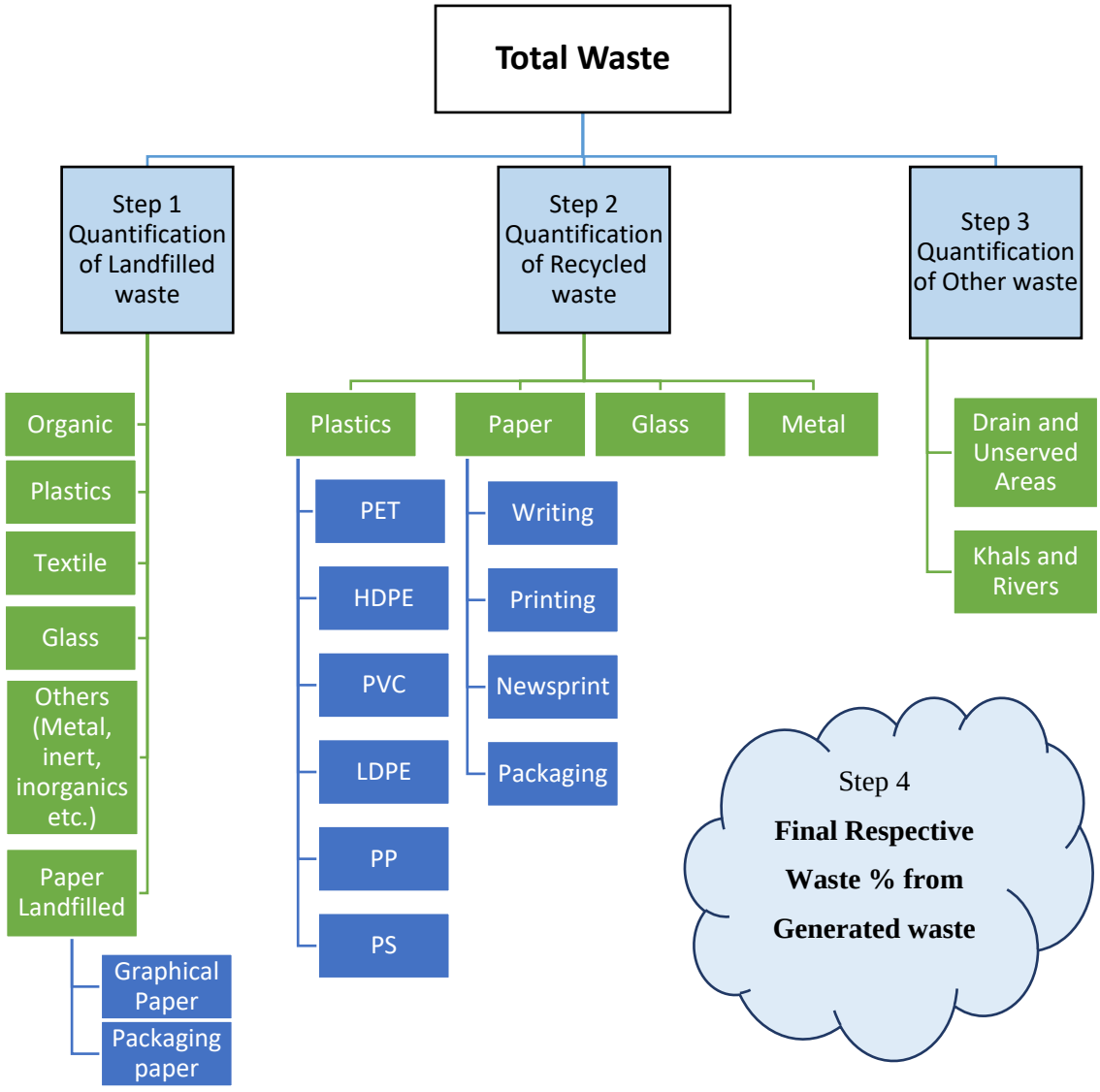


Figure 3.1: Schematic diagram of the waste quantification process

3.3.1 Step 1: Quantity of Waste Landfilled

From the World Bank (2021) report, the waste fraction of different waste types from both landfills are averaged. Therefore, the average fractions are applied on the total waste quantity taken from the World Bank report. There is a variation of total landfill quantity in City Corporation 2019-2020 waste reports and in World Bank reports. In city corporation waste

reports, DNCC and DSCC disposed 2750 tons and 2540 tons per day respectively in 2019-2020 fiscal year. Combining these two produces 5290 tons/day of landfill waste. In the World Bank report it is 4700 ton/day which is 590 ton less from the waste reports and the data collection period is year 2020. For this LCA study World Bank data is used.

Paper is divided into two categories i.e., graphical paper and packaging paper. Graphical paper can be subdivided into three categories i.e., writing, printing, and newsprint but that is not necessary for landfill as ecoinvent database provides the emission data from combined graphical paper landfilling. The landfill waste allocation for different types of waste is provided in the following Table 3.2:

Table 3.2: Various waste percentage in landfills and combined baseline quantity distribution

Item	Waste % Aminbazar	Waste % Matuail	Waste % Average	Combined Waste ton/day
Organic/biowaste	86.29	84.94	85.61	4023.91
Graphical paper (90% of total paper)	2.55	0.74	1.48	69.58
Packaging paper (10% of total paper)			0.16	7.73
Plastic	5.24	7.92	6.58	309.26
Textile	1.34	1.20	1.27	59.69
Glass	1.24	0.40	0.82	38.54
Others (metal, inorganics, inert etc.)	3.34	4.80	4.07	191.29
Total	100.0	100.0	100.0	**4700.00**

3.3.2 Step 2: Quantity of Waste Recycled

As per the World Bank, 2021 report, total recycling waste is 517.12 ton/day. But there is no division of this quantity among different recyclable items except recycled plastics of 240.50 ton/day. Therefore, the total quantity will be divided into remaining recyclable items.

i. Paper in recyclable waste:

To find the fraction of paper in recyclable waste the paper waste percentage in World Bank will be used. The average of the paper percentage at generation point (household) is estimated from the average of all the six data from DNCC and DSCC. Therefore, this percentage is applied to the total generated waste quantity of 6465 tons and the average total paper produced daily is 246 tons. Similarly, the average paper landfilled is estimated to be 77.32 tons. Subtracting this landfill waste from the total waste is the remaining quantity that is recycled and disposed of in drains, khals and other unserved areas. The paper waste percentage in high-, middle- and low-income households and landfills are provided as follows in Table 3.3:

Table 3.3: Recyclable paper quantity estimation

Categories	Percentage DNCC	Percentage DSCC	Average % of paper in generated waste	Combined waste quantity, ton/day	Combined paper quantity, ton/day	Combined remaining paper, ton/day	**Combined recyclable paper, ton/day**
High-income	5.6	3.4	3.8	6465 (Generated)	245.66 (Generated)	168.34	**84.17 (50% of the remaining after landfilling)**
Middle-income	3.9	4.4					
Low-income	2.3	3.2					
Landfill	2.5	0.7	1.6	4700 (Landfilled)	77.32 (Landfilled)		

For this study, it is assumed that 50% of this remaining paper will be recycled as there is no other reference data available. Therefore, the final quantity is found as 84.17 ton/day. Now, this recyclable quantity is divided into different paper categories as shown in Table 3.4:

Table 3.4: Various recyclable papers percentage

Total recyclable paper	Writing	Printing	Newsprint	Packaging
100.00%	15%	35%	40%	10%
84.17 ton/day	**12.63**	**29.46**	**33.67**	**8.42**

ii. Glass quantification:

Glass is similarly quantified as paper, but the only difference is that from the remaining quantity after excluding the landfill portion, 95% is recycled instead of 50% as used in paper. Details are provided in the following Table 3.5:

Table 3.5: Recyclable glass quantity estimation

Categories	Percentage DNCC	Percentage DSCC	Average % of glass waste generated	Combined waste quantity, ton/day	Combined glass quantity, ton/day	**Combined remaining glass, ton/day**
High-income	2.6	1.9	1.25	6465 (Generated)	80.81 (Generated)	**40.16 (95% recycled)**
Middle-income	1.0	0.8				
Low-income	0.6	0.6				
Landfill	1.2	0.4	0.8	4700 (Landfilled)	38.54 (Landfilled)	

iii. Other recyclable waste:

Remaining other recyclable waste quantity is estimated as follows:

Other recyclable = Total recyclable – plastic recyclable – paper recyclable – glass recyclable
Other recyclable = 517.12 – 240.5 – 84.17 – 40.16 = **152.29 ton/day**

This quantity mostly contains metals, alloys and no further division of this quantity is required as it will not be necessary for this study due to its nature of recycling. Details are discussed in "waste management components scope: recycling" section.

iv. Division of recyclable plastics:

Estimated quantities of these plastics using the World Bank report data are provided in the following Table 3.6:

Table 3.6: Percentage of different plastics in total recyclable plastic

Total recyclable plastic	PET	HDPE	PVC	LDPE	PP	PS
100%	26.19	11.17	13.09	21.89	14.88	12.68
240.5 ton/day	**62.99**	**26.87**	**31.49**	**52.64**	**36.02**	**30.49**

3.3.3 Step 3: Quantity of Remaining Waste

The remaining waste going to drains, khals, rivers and other unserved areas are kept out of this Dhaka city MSWM LCA study. Therefore, these quantities will not be used directly in LCA, rather these data will be used for determination of final waste percentage of different types of wastes and recyclables in terms of generated waste. The data is provided in the following Table 3.7.

Table 3.7: Uncollected waste quantity that is not considered for this LCA

Item	Khals and rivers	Drains and unserved areas
Quantity, ton/day	330	918

3.3.4 Step 4: Final Respective Waste % from Generated waste

Now combination of the above 3 steps will provide an overview of the waste going in different flows. Each type can be expressed as a fraction of the total generated waste. This composition will provide a more flexible waste data for the LCA analysis so that if in future, the total waste generation quantity changes, the whole LCI will be changed too according to this quantity. But the waste fractions will remain unchanged. Following Table 3.8 provides the details of the waste percentages and yearly accumulations:

Table 3.8: Baseline waste composition for total generated waste

Treatment Method	Waste Item	Waste Quantity, ton/day	Waste Quantity, ton/year	Waste Fraction, %
Landfill Items	Organic/biowaste	4024.00	1468725	62.24
	Graphical paper	69.58	25398	1.08
	Paperboard	7.73	2822	0.12
	Plastic	309.26	112880	4.78
	Textile	59.69	21787	0.92
	Glass	38.54	14067	0.60
	Metal/Other Inorganics/Inert	191.29	69821	2.96
Recyclable Papers	Writing	12.63	4608	0.20
	Printing	29.46	10753	0.46
	Newsprint	33.67	12289	0.52
	Packaging and others	8.42	3072	0.13
Recyclable Plastics	PET	63.00	22990	0.97
	HDPE	26.87	9806	0.42
	PVC	31.49	11495	0.49
	LDPE	52.64	19215	0.81
	PP	36.02	13148	0.56
	PS	30.49	11128	0.47
Recyclable Glass	Recycled Glass	40.16	14657	0.62
Recyclable Metals	Recycled Others	152.29	55587	2.36
Khal and Rivers	Mixed	329.90	120413	5.10
Drains and unserved areas	Mixed	917.68	334953	14.20
Total		**6465**	**2359615**	**100.00**

Similar data for DNCC and DSCC is provided in Appendix C with the estimation process of individual recyclable waste items.

3.4 Life Cycle Assessment (LCA) Methodology

To carry out the present research, relevant literature on MSWM of Dhaka City has been reviewed thoroughly (Chapter 2). Primary and secondary data of solid wastes of two City Corporation has been collected from secondary sources, by field visits at different transfer stations and from two landfill sites. OpenLCA, a free software, has been used with ecoinvent database to assess the environmental impacts for managing MSW. Figure 3.2 shows the waste flow and system boundary adopted for the present LCA study.

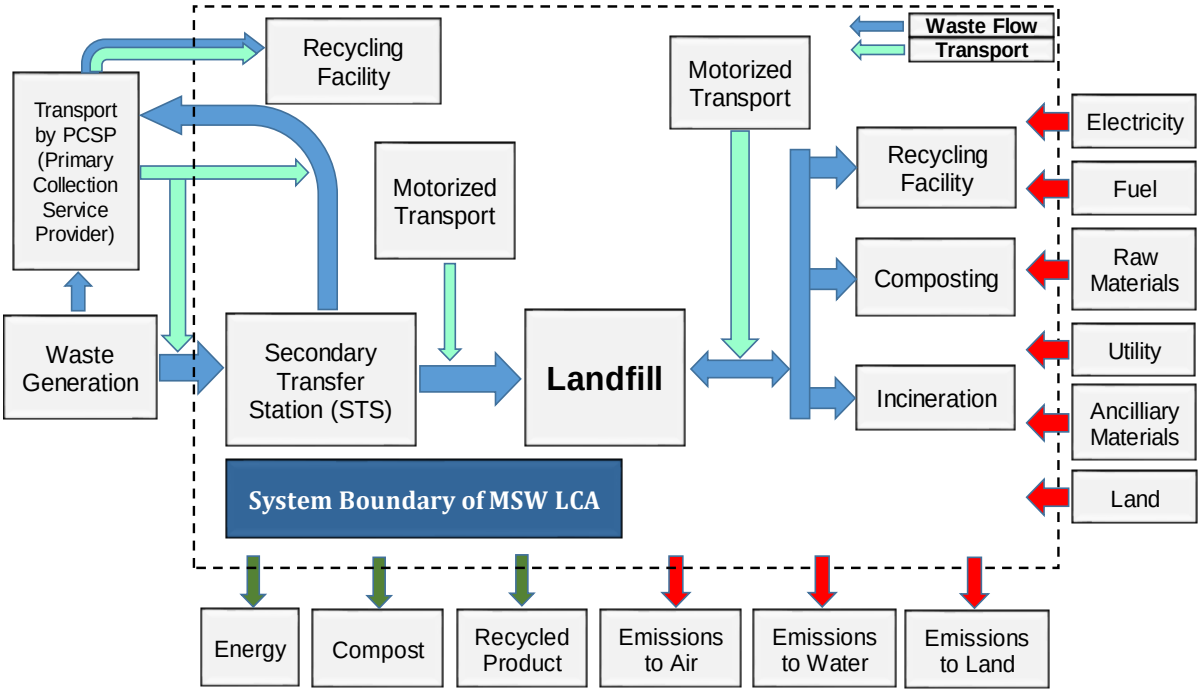


Figure 3.2: Waste Flow Diagram with System Boundary for present LCA analysis

According to Figure 3.2 primary waste flow LCI input is the total waste collected by Primary Collection Service Provider (PCSP) and delivered to secondary transfer station (STS). For STS LCI, input data is mainly the fossil fuel burned by vehicles and cleaning water whereas the output will be the emissions to air and water. The recyclable waste LCI data are the waste portion sorted as recyclable, the utilities necessary for reproduction of the recyclables, emission from this process and recycled product quantity. For transportation, the vehicle fossil fuel consumption and emission to air will be considered. The landfill input inventory is prepared considering consumption of energy, water, land, fossil fuel for maintenance vehicle and output inventory will have discharge and emission to air, water and land. While introducing the alternative strategies like composting, incineration, RDF, the LCI will be prepared with their corresponding input and output combining with landfill. For LCIA analysis, input and output

of the relevant processes will be connected to form a single model. LCIA analysis then will be run for each model to obtain the final environmental impacts.

3.4.1 Objective of LCA

The objective of this LCA is to evaluate the sustainability of the Dhaka city municipal solid waste management system (MSWM) in context of current and other suitable waste management strategies with varying waste percentages in different waste treatment methods and finding the most suitable approach environmentally.

3.4.2 Scope of LCA

Scope definition of this LCA comprised of formation of the scenarios, scopes of different waste treatment methods, defining functional unit and demarcation of the system boundary.

3.4.3 Formation of the scenarios

The scenarios are formed based on the components of current MSWM practice combining with the alternative waste treatment methods which has the possibility to be implemented in future as mentioned in waste reports and according to the types of major waste fractions. Baseline LCA will be done on DNCC, DSCC and combined condition. Alternative scenarios LCA will be conducted combinedly or on whole Dhaka city.

3.4.3.1 Baseline Scenario B0

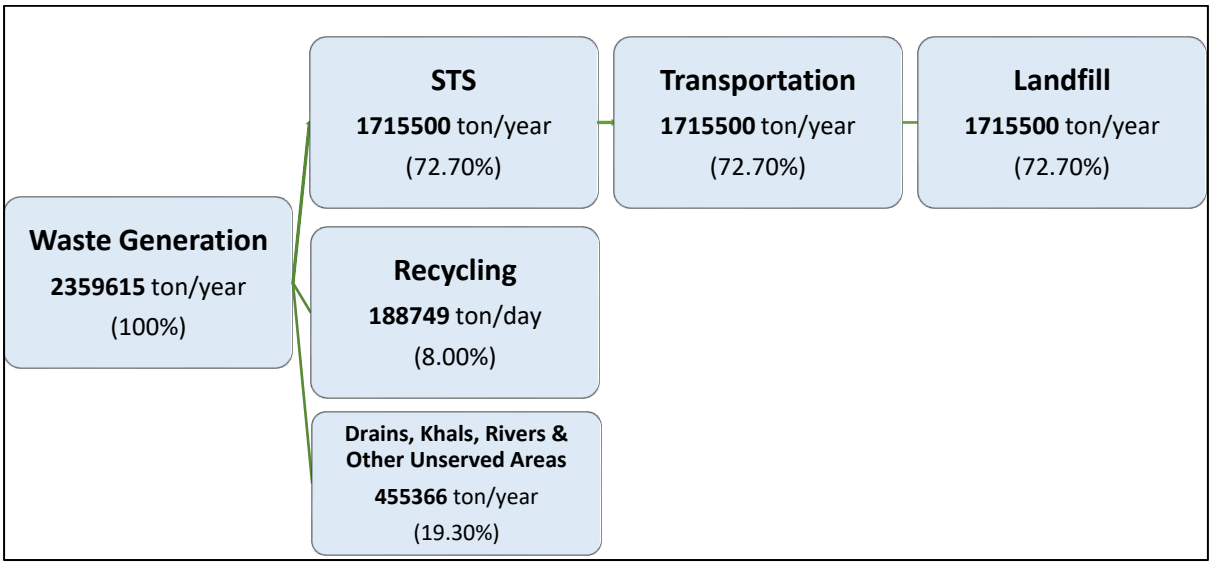


Figure 3.3: Baseline SWM Scenario

Baseline scenario reflects the existing waste management practice. The waste collected from household is mostly disposed to landfills and part of the generated waste is recycled. The waste flow is provided in Figure 3.3.

3.4.3.2 Alternative Scenario A1

Composting is introduced in this scenario. Organic waste has the highest percentage of generated waste. It is assumed in this scenario that 97% of the total organic waste i.e., 60.37% of the total generated waste is subjected to composting and the remaining 3% of the organic waste goes to landfill. Other wastes flow remains same as the baseline scenario B0. The flow chart for this scenario is shown in following Figure 3.4.

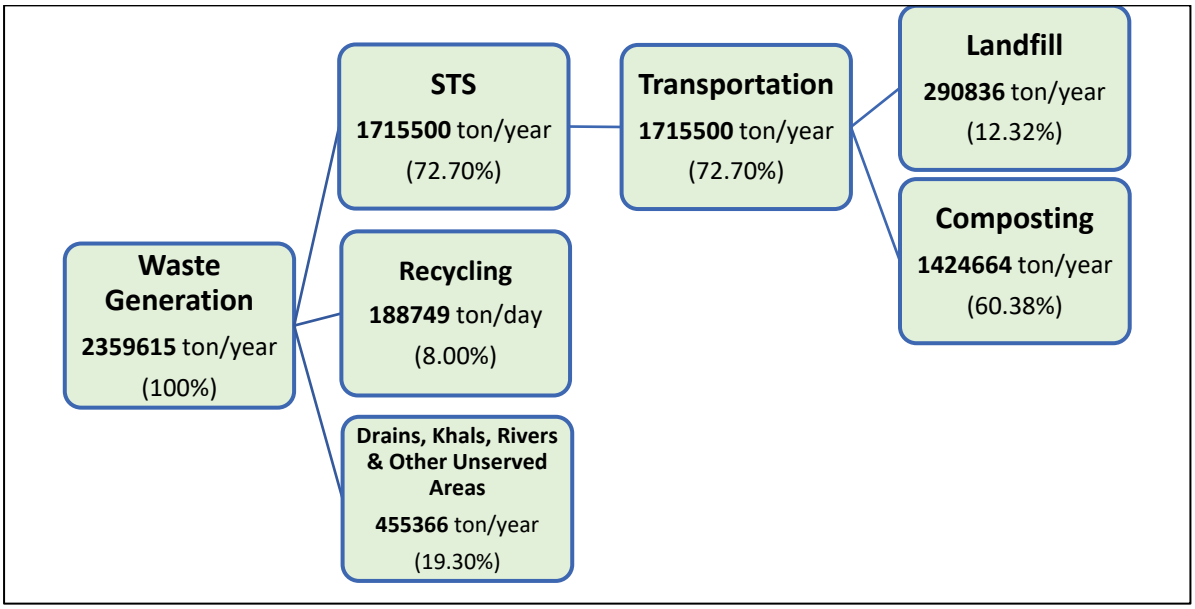


Figure 3.4: Alternative Scenario A1

3.4.3.3 Alternative Scenario A2

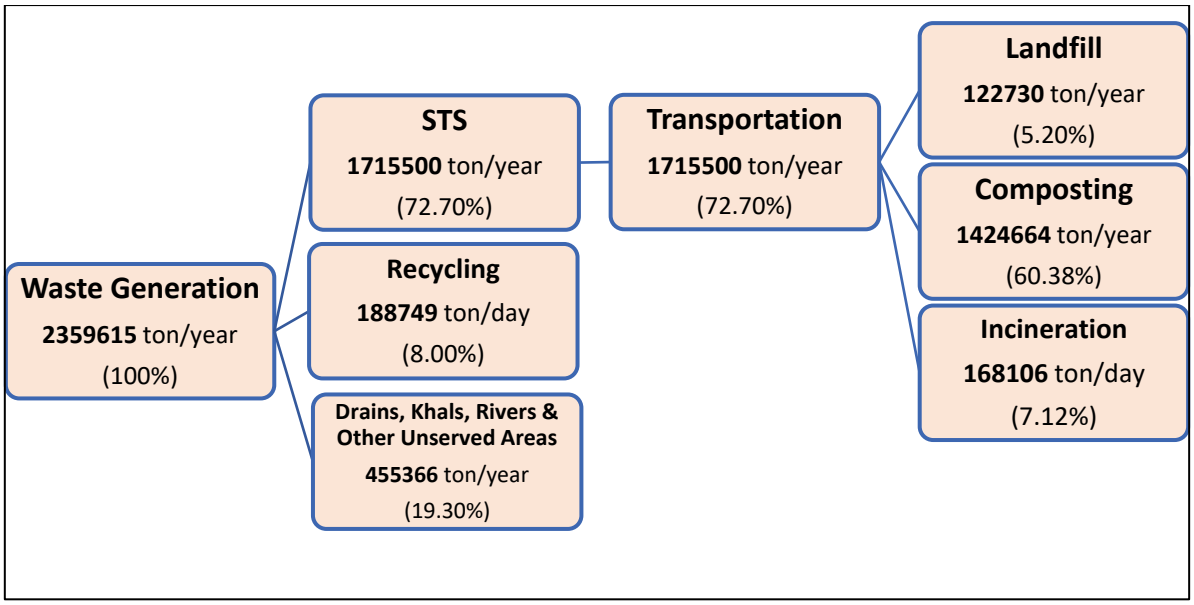


Figure 3.5: Alternative Scenario A2

In city corporations waste reports, incineration of waste is referenced on future landfill development plan. The Waste to Energy (WtE) method is very beneficial for waste volume reduction and effective policy where there is scarcity of land for landfill expansion. Therefore, incineration process analysis is necessary to assess the impacts on the environment. In this A2 scenario, incineration, and composting both are considered. The organic waste flow remains the same as the alternative scenario A1. Other combustible wastes like paper, plastic, textile, and glass that are transported from STS are taken for incineration. 95% of these combustible wastes are assumed to be considered for incineration and the remaining unused portion is landfilled. The combined quantity of these incinerated wastes remains 7.12% of the total generated waste. The waste flow chart with quantity is shown in Figure 3.5.

3.4.3.4 Alternative Scenario A3

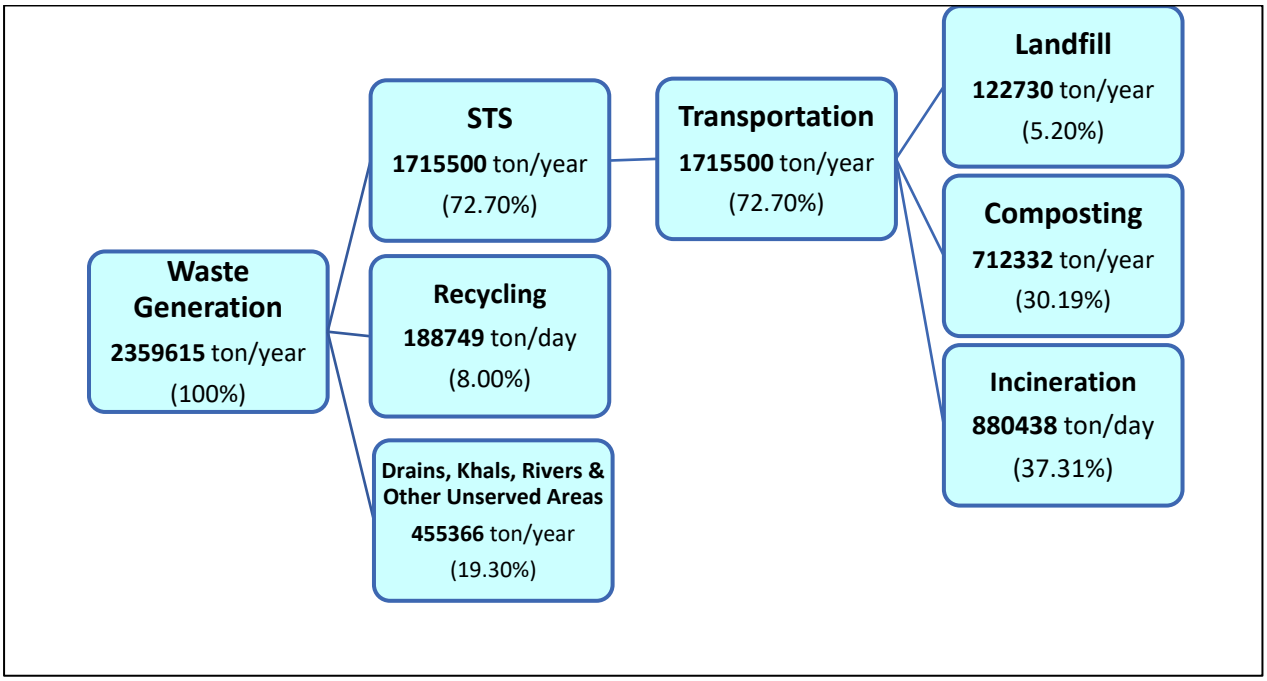


Figure 3.6: Alternative Scenario A3

In this scenario, organic waste that is considered for composting in previous scenarios is cut in half. The remaining half of this organic waste is considered for incineration. Other waste flows remain the same as alternative scenario A2. Also, 30.19% of the organic waste is composted, whereas 37.31% of the waste is incinerated compared to total generated waste. Figure 3.6 demonstrates the waste flow diagram.

3.4.3.5 Alternative Scenario A4

In this scenario, composting is omitted, and 97% of organic waste and 95% of other waste that is transported from STS are considered for incineration. The percentage of total combustible waste quantity becomes 67.50% and the waste quantities in different waste treatment processes are shown in the Figure 3.7.

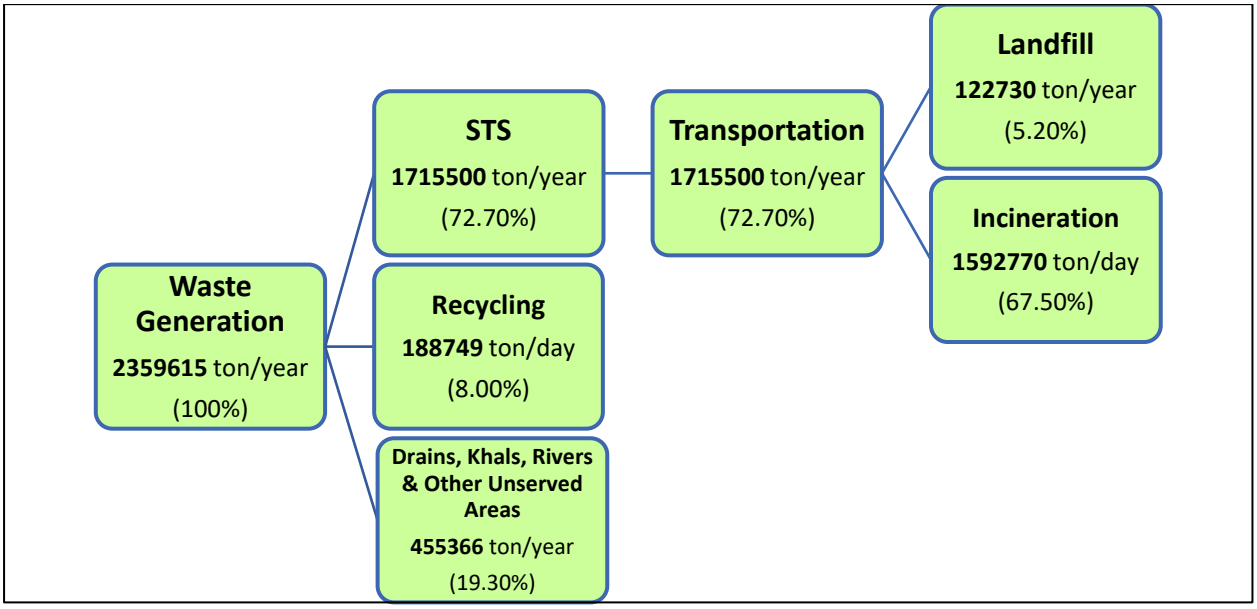


Figure 3.7: Alternative Scenario A4

3.5 Waste Management Components Scope

From the scenarios formation the basic components for LCA can be listed as: STS, transportation, recycling, composting, incineration, and landfill. The scopes and considerations for these components is discussed as follows:

3.5.1 MSW Generation

Waste generated from household carried to STSs by PCSP by manually driven steel vans. In this LCA analysis this step is not considered. Additionally, the estimation of environmental burden from waste collection process, health damage of related people during the collection, odor pollution is a matter of comprehensive study and these sorts of analysis or data necessary to conduct the LCA is unavailable. The total waste quantity collected from household is considered to have no loss during the transportation by PCSP.

3.5.2 STS

The main environmental burden considered in this step is the emissions from the burning of diesel by pay-loaders for waste maintenance in STSs. The burden due to manufacturing pay-

loaders, waste management and sorting manual tools (e.g., shovels, spades, bucket) are kept out of the scope of this study. Emission factors are used as per European Environmental Agency, 2017 guideline for non-road mobile machinery (Winther, et al. 2017). Waste handling in bare hands and unhygienic conditions put the waste handler's health at risk. Since assessing this burden is an issue of long-term complicated research and data collection and there is no data available that can help the life cycle assessment. Therefore, this part is omitted in this analysis. Figure 3.8 shows the LCA inputs and outputs considered in STS LCA.

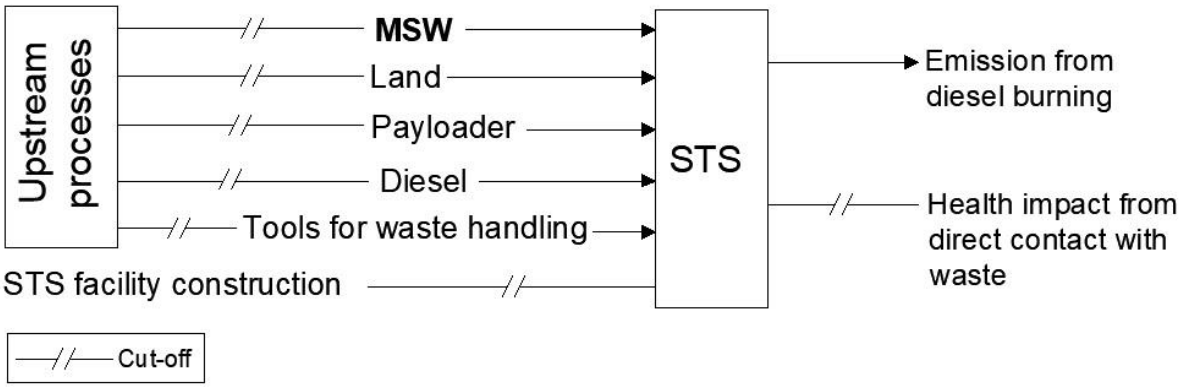


Figure 3.8: LCA scopes of STS

3.5.3 Transportation

Waste is sorted in two parts at STS; one part is for landfill and the other is for recycling. The landfill part is transported by different types of vehicles to the landfill. These vehicles are:

i. Container Carriers
ii. Arm Roll
iii. Compactor
iv. Open Truck and Dump Truck

The transportation process of recycled waste to recycling facilities is complex as the recycling facilities are scattered all over the city and there may or may not be any motorized emission from carrying of this waste. There is no data available for the informal sector transportation. Therefore, due to absence of data this step is not considered for this study. However, the net burden from recycling will be considered and discussed in detail in the recycling section.

Most of these vehicles are diesel fueled with only a few container carriers using CNG. In this study, the upstream processes of vehicle manufacturing, fuel extraction, import of vehicles and fuel etc. that happened before fuel burning are cut-off from the system LCI. Only the emissions

from burning fossil fuels are considered. Figure 3.9 shows the inputs and outputs during transportation of waste.

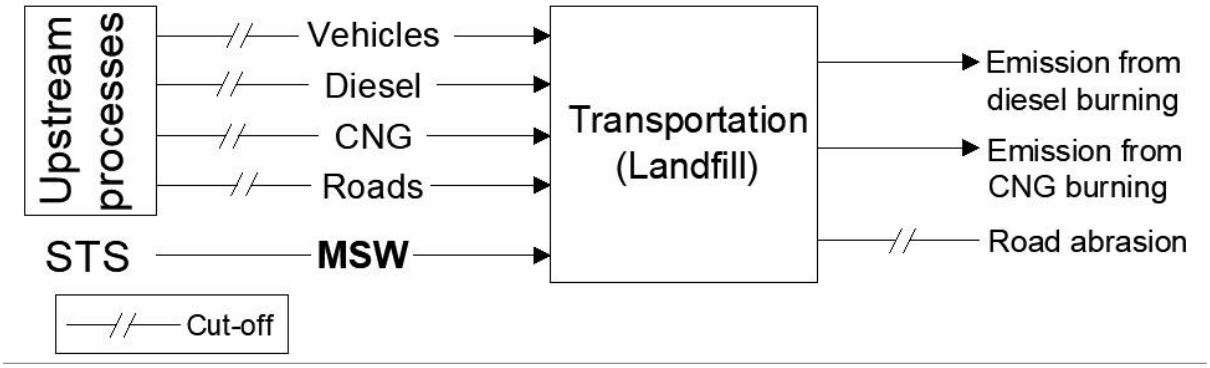


Figure 3.9: LCA scopes for transportation of waste to landfills

The impacts due to road abrasion while transporting is also excluded. The pollutants and emission factors are used according to the European Environmental Agency, 2021 guideline for road vehicles (Ntziachristos, et al. 2021).

3.5.4 Landfill

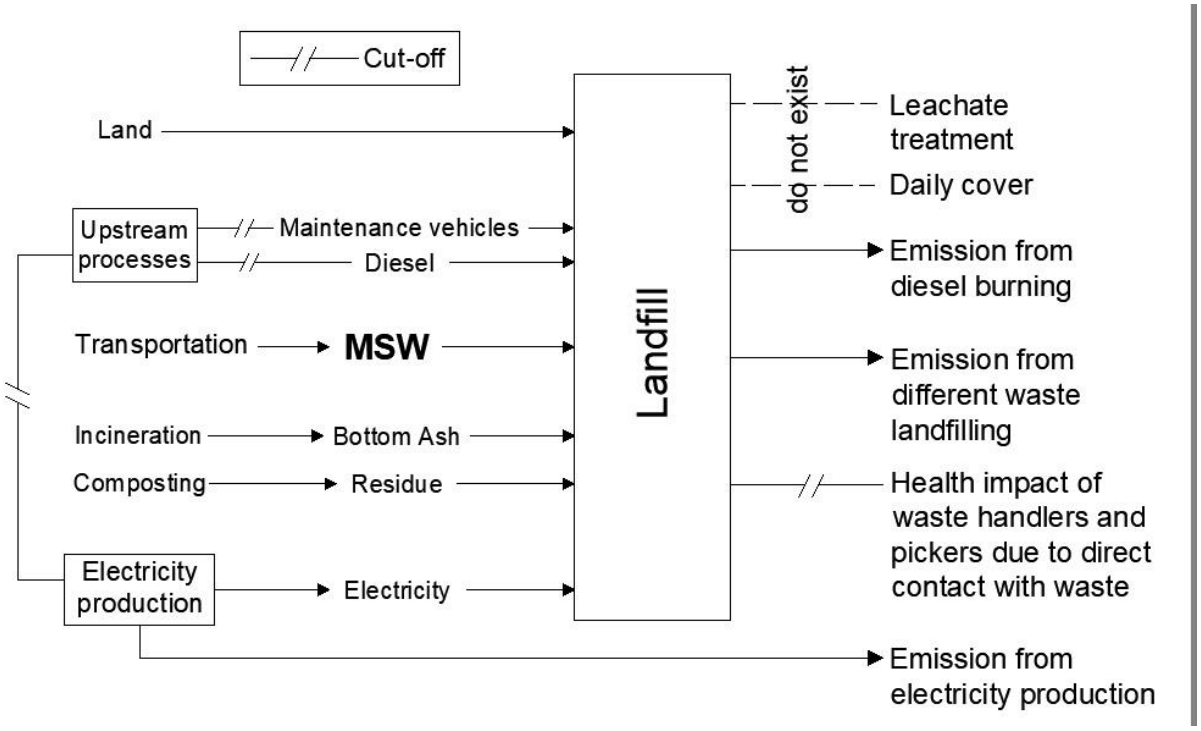


Figure 3.10: Scopes of landfilling operation and maintenance

After transportation to landfills, the waste is unloaded. Then the waste is dispersed and compacted with the help of landfill maintenance vehicles like excavators, bulldozers, wheel loaders etc. So, at this point the emissions will be due to the fossil fuel burning by these

maintenance vehicles and from the dumping of different types of waste in landfills with long-term and short-term impacts. To conduct LCA, the effect of diesel burning due to landfill compaction has been considered. The emission data of different types of wastes, such as organics, plastics etc. are used as input data in separate processes. The ash from incineration in alternative scenarios is also landfilled and the burden is provided in respective incineration process of different waste. Figure 3.10 illustrates the landfilling process analysis scopes.

The fuel emission, electricity consumption for landfill operation and maintenance and emission from the production of that amount of electricity from natural gas combined cycle power plant is considered. Land use for landfill is also considered depending on the waste quantity. The upstream process of manufacturing heavy equipment like bulldozers, excavators and processes related to diesel fuel supplying etc. are cut- off from the study. While estimating electricity, only output from the production of consumed electricity is considered. All the input like power plant facilities, land and raw materials for power generation is omitted except the use of water for plant cooling.

Matuail landfill has effective leachate treatment system. So, Matuail landfill is analyzed as sanitary landfill and relevant sanitary landfill data from ecoinvent is used. However, Aminbazar landfill has leachate treatment system, but no liner at the bottom is constructed. Therefore, the leachate treatment efficiency in Aminbazar is poor and considered unsanitary. When separate dataset for unsanitary and sanitary landfill emission from waste like organic, textile etc. are not available, a leachate treatment efficiency factor is applied on the generic leachate emission data.

3.5.5 Recycling

The recycling is performed to some extent by PCSP while collecting waste from households, roadside, hotels, markets and various other waste generation sources. Another phase of recyclable materials sorting is performed at STSs. Also, after the disposal of waste at landfills, the scavengers/ waste pickers (Tokai) sort out the recyclables. The combined recyclables quantity from PCSP, STS and landfills is then carried to different recycling facilities around different locations in Dhaka City (Matter, Dietschi and Zurbrügg 2013).

The burden from recycling process of different waste include the direct emission from recycling and save of emission of the same product when produced from virgin raw materials. The assumption here is that the recycled product will replace the virgin product therefore reducing the market demand of virgin products. The recycling process may be conducted into

multiple steps and all the steps are considered until the recycled product is usable and can serve the purpose as same as the virgin product. The upstream process of raw materials and elements like chemicals, land, factory facilities for virgin products production are avoided as inclusion of their upstream process can lead to complex output. Only water and electricity consumption and fuel emission are considered. Emission from net electricity production is also included in the scope of the analysis.

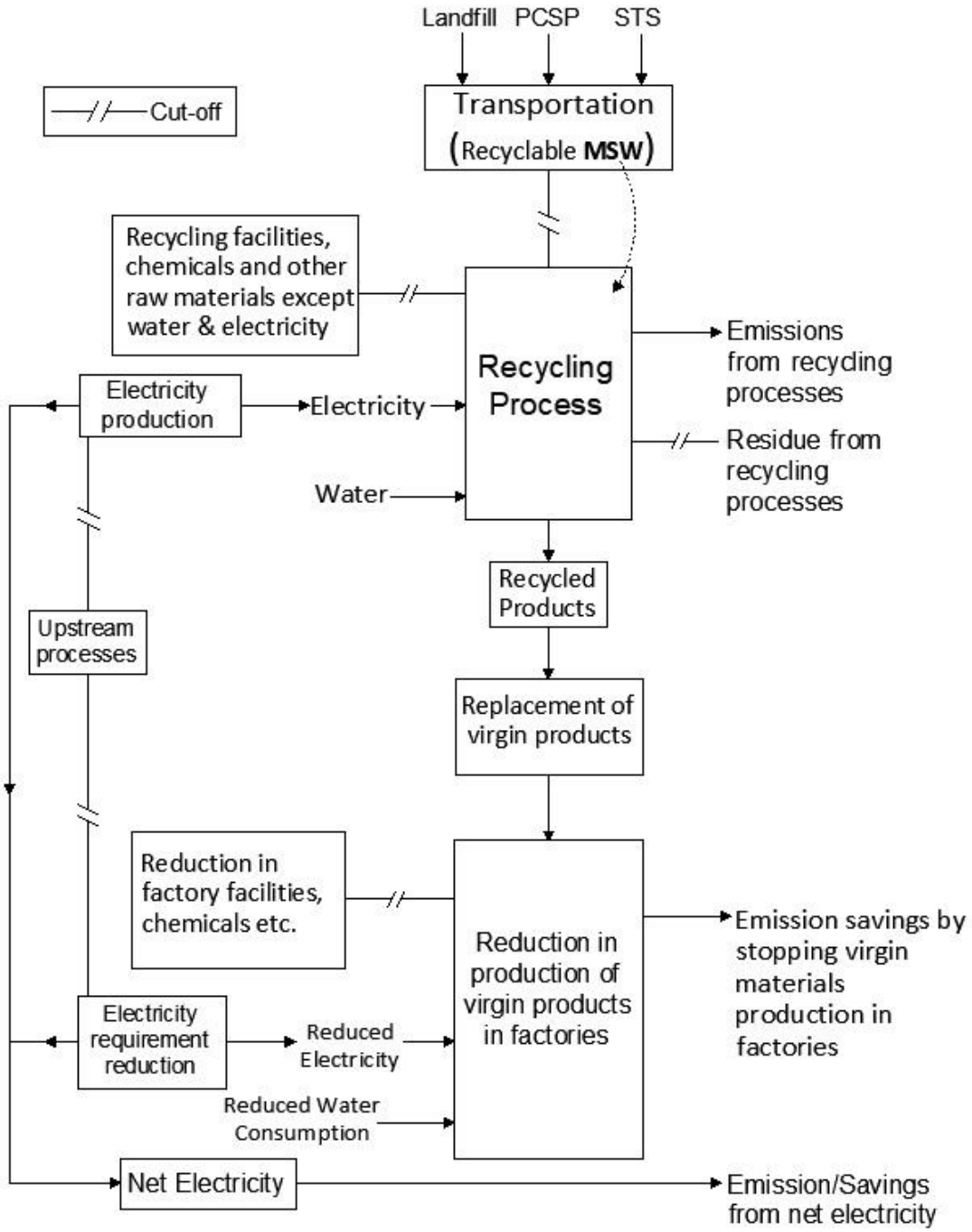


Figure 3.11: Scopes of recycling process

The transportation/ carriage of recyclables to recycling facilities is excluded from the study as the process of carrying, shop distance and number of paths for carrying the waste to recycling facilities can vary in numerous ways and without any specific study, assumptions will be vague. Also, no data is available on how far the recyclables are carried, how many workers involved, if any fossil fuel burned in this process and the impact of these recyclables on human health who is carrying and processing these items. Therefore, without considering the transportation of recyclable items, the net emissions/savings analysis and estimation from recycling process will be done in two phases:

- Calculating the process emissions during the making of new items from recyclables
- Subtracting the emissions that would have occurred during the preparation of the same quantity of new items from the virgin raw materials in those items specified industry

These two phases will be applied to main recyclable items i.e., paper, plastic and glass since their process emissions vary significantly while production from recyclables is compared to virgin raw materials. The scrap Aluminum (Al) and Steel (Fe) recyclables are generally melted, cleaned from impurities hence go through the same process as it is for the virgin raw materials to manufacture new products. For example, waste reinforcing steel cannot be used again as reinforcement in structures since their strength capacity may not remain the same and must be processed in the same way a raw steel scrap is processed to manufacture new reinforcing steel. Therefore, the net emission is independent in terms of materials either they are from recyclable part or raw resources. In this LCA, the net emissions from metals recycling are not analyzed for this reason. But this recycling is beneficial economically as the recyclable metals replace the Al, Fe and other such metals that are imported. The entire process is depicted in Figure 3.11.

3.5.6 Composting

Organic waste coming to landfill is sorted and separated for composting. The composting method is assumed to be windrow composting method and composting facility is assumed to be adjacent to the landfill site. The compost produced is used as fertilizers in crop production. The impact of composting is the reduction of landfill organic waste and its corresponding emissions. Another assumption is that this compost will replace nitrogen based chemical fertilizers. Therefore, environmental burden from equal chemical fertilizer production is reduced (Menikpura and Sang-Arun 2013). Net electricity associated burden from electricity

generation is considered taking count of all relevant processes. Also, the after-use emission from nitrogen-based fertilizer in the crop field is included in the LCI. The scopes of composting are illustrated in Figure 3.12.

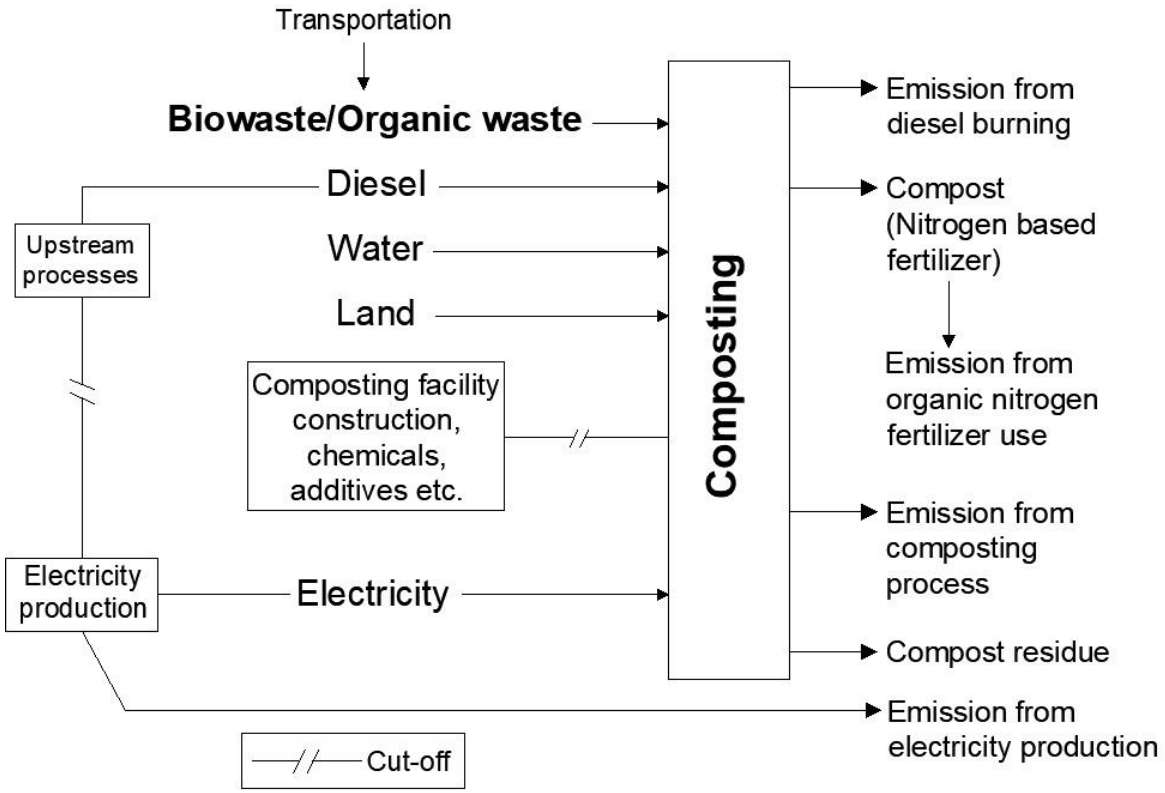


Figure 3.12: Scopes of composting process

GHGs emission will be mainly due to burning of fossil fuel during waste handling, composting process and degradation from organic waste. The carbon emissions are all biogenic except the emissions from operation and maintenance vehicles. Biogenic carbons are not taken as pollutants/responsible for GHGs emissions as per IPCC (IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National 2006). Land and net water consumption are considered.

3.5.7 Incineration

Waste incineration involves combustion of waste and generating energy. Incineration process starts with waste reception at waste incineration facility and ends with energy production, air emissions from incineration facility, liquid and solid emission form bottom ash and slag landfilling. The environmental burden will be the process specific emission from incineration. Also, there will be diesel emissions from ash landfilling. The net electricity remaining after using for in plant operation is assumed to be used for city power supply and replacing the

electricity from national grid. Several types of waste incineration cause different emissions. Therefore, for each type of waste incineration process LCI is formed separately. Land, water and oxygen requirements for incineration plant is considered. Remaining materials and elements like chemicals, cement, factory facilities construction upstream processes are cut-off from the study. The scopes are shown in following Figure 3.13.

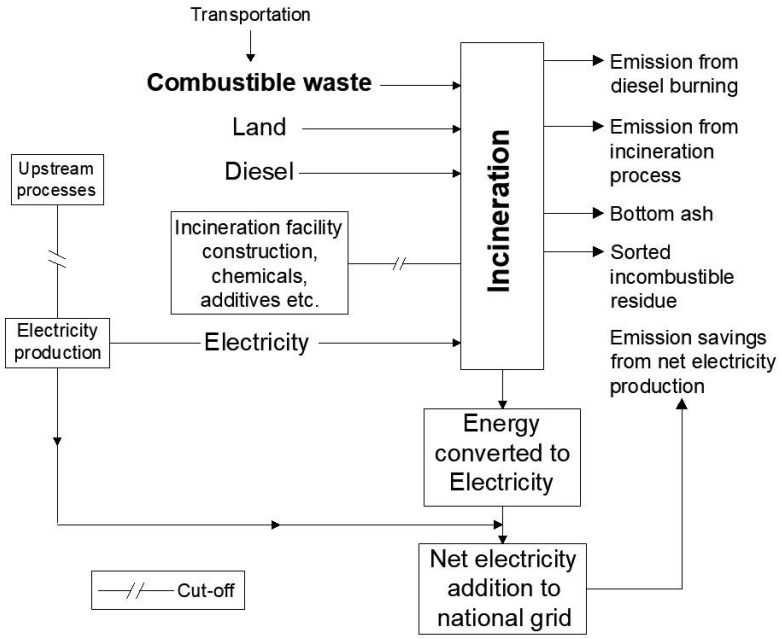


Figure 3.13: Incineration system scopes for LCA

3.6 System Boundary

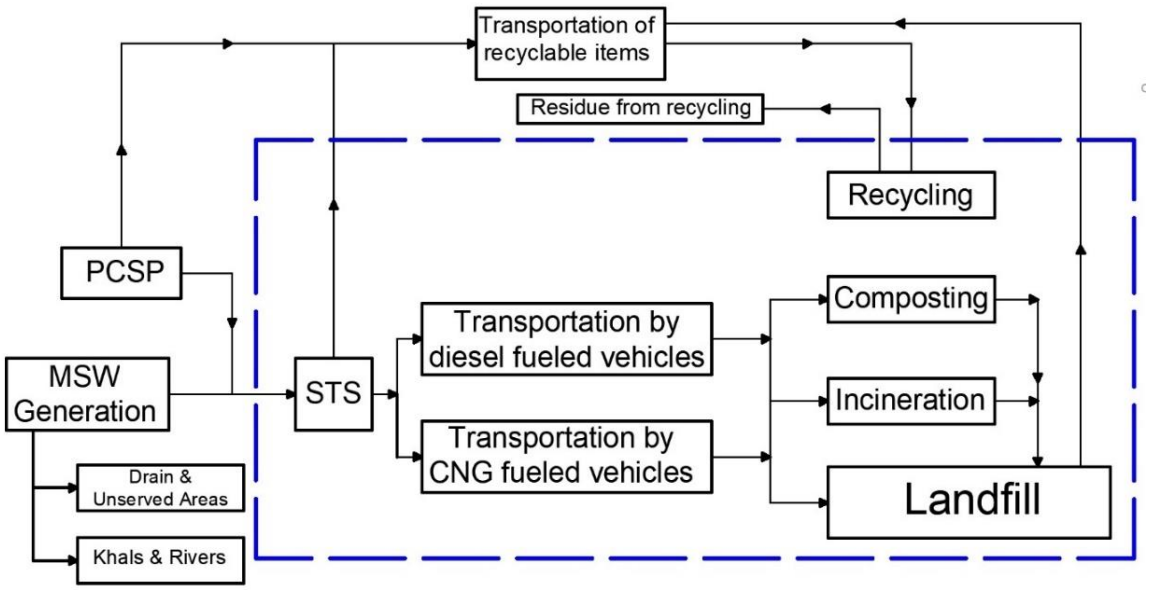


Figure 3.14: System boundary of this LCA

This study is a gate to grave LCA. As it is clear form Figure 3.14 that waste generation and PCSP waste collection is kept out of the study.

3.7 Functional Unit of LCA

The functional unit for LCA analysis is total yearly generated wastes combinedly in both city corporations in year 2020. The estimated quantity as per the World Bank report is 2359615 ton.

3.8 LCA Software and Database Selection

In this study of LCA openLCA software is used. The reasons for using the software are already discussed in literature review. To construct the LCI, ecoinvent database version 8 will be used which is free to use for academic purposes for non-OECD (Organization for Economic Co-operation and Development) countries. Cut off database is used for this study. It is easy to apply and focuses on the unit emissions. Instead of summing all the upstream process in single process, this approach links the upstream processes and provides the flexibility to apply cutoffs where necessary. This provides more control over the data and helps to assess as much upstream processes as required.

With openLCA software ecoinvent is the most preferable database suggested by LCA experts and scholars. The reason for this is ecoinvent LCI is well documented, offering free version to students of non-OECD countries. Ecoinvent has peer review process for datasets, covers a wide range of dataset from various industries and categories. For waste management LCA, ecoinvent offers dataset for dumping specific types of waste in unsanitary landfills in different climatic condition which makes it more region specific. Other significant waste management processes are also covered. Some other important features of ecoinvent database are the division of database according to allocation, cut-off, unit/system processes which really offers the user to get accustomed with the dataset easily and use these as per their considerations and necessity. There are other datasets like Gabi, ELCD, Product Environmental Footprint (EPF) etc. but none of these has that broad and specific range to cover a whole waste management scenario comprehensively. There are some datasets from Indian cities like Delhi that has higher possibility to match with the condition of Dhaka. One example is, both India and Bangladesh produce electricity from natural gas using the same technologies and the Indian dataset for producing electricity will be used to assess the environmental burden from electricity production related to Dhaka SWM. For these reasons, ecoinvent is used in this study. In some

cases, the ecoinvent dataset is not directly applied. The data from ecoinvent predefined processes is extracted, sorted and then modified as per necessity of this study and then applied to the processes made for LCI of the Dhaka city SWM study. All the data extraction and modification and preservation are performed with the help of excel spreadsheet.

3.9 Comparisons among Scenarios

To find the suitable approaches to SWM, it is mandatory to compare between scenarios and analyze each element. Also, it is important to understand how database and LCA tools can impact the LCIA results. The following comparisons will be performed in the result analysis section:

- **i.** Baseline B0 vs Alt. A1 vs Alt. A2 vs Alt. A3 vs Alt. A4 (Combined)
- **ii.** DNCC vs DSCC (Baseline)

3.10 LCI

In this step all the input and output data as per scopes of LCA will be analyzed. In all the process emission is calculated for high density areas as Dhaka is densely populated.

3.10.1 STS

The main data required for STS is the diesel quantity used by waste management pay-loaders and skid-loaders. To estimate emissions from diesel burning, the number of operational vehicles, their working hours and average diesel consumption estimation is necessary. There is no published data available to assess these quantities. So, the fuel consumption is estimated according to the following assumptions:

DNCC, total number of loaders = 11 nos. (Tabassum 2020)

DSCC the total number of loaders = 09 nos. (Verbal communication with DSCC)

Therefore, total vehicles = 20 nos.

Vehicles working duration = 8 hours/day on average.

From Tabassum (2020) the description and figure of dozers and payloaders from the background study, indicates that their bucket capacity is around 1 m^3 and operating weight is around 4500kg ~ 6000kg. These types of equipment have a tier 4 engine (Alibaba.com 2021). In Caterpillar Performance Handbook (2016) the hourly vehicle fuel consumption for tier 4 engine is provided. On that handbook, the fuel consumption is provided as 0.0 – 4.2 liters per

hour for low usage and 4.2 – 7.9 lit. (8.3 lit. in some engines) for medium usage (Caterpillar 2016). As exact vehicle model is available, for LCI analysis, it is assumed that 4.2 liters of diesel consumed per hour for average operating condition. Now, as the functional unit is taken for one year, the diesel consumption of one year is estimated and the data is provided in the following table:

Table 3.9: Diesel consumption at STSs

Item	**Unit**	**DSCC**	**DNCC**	**Combined**
Dozer/ Payloader	Nos.	9	11	20
Diesel Consumption	lit./hr./vehicle	4.2		
Working hrs.	hr./day	8		
Diesel Density	kg/lit.	0.832		
Diesel Consumption	kg/day	251.60	307.50	559.10
	kg/year	**91833**	**112240**	**204073**

Now from the diesel quantity, emissions related to diesel burning is estimated. To estimate the emission, EMEP/EEA, 2017 guideline for non-road mobile machinery is followed. Tier 1 approach for estimating the emission factor is adopted. Equipment category belongs to 1.A.2.g vii (mobile combustion in manufacturing industries and construction) (Winther, et al. 2017). The major pollutants are CH_4, CO, CO_2 (fossil), NOx, N_2O, SO_2, $PM_{2.5}$, PM_{10}, Heavy metals, Non-Methane Volatile Organic Carbon Compounds (NMVOCs) and Polycyclic Aromatic Hydrocarbons (PAHs). Speciation is applied to heavy metals only. NMVOCs and PAHs are not speciated due to their vast numbers and the average baseline characterization factor for NMVOCs and PAHs is provided in ReCiPe method. Therefore, for simplicity, the speciation is not conducted.

The quantity of SO_2 is calculated as per sulfur quantity present in diesel. In Bangladesh, the sulfur quantity was 500ppm after 2016 (DOE 2012). Therefore, the SO_2 emission factor can be estimated as:

E.F. (SO_2) = 2 x sulfur weight in fuel = 2 x 500 ppm = 1000 g/ton
Where, 1 ppm = 1 g/ton

Table 3.10 presents STS LCI for DNCC, DSCC and combined STS emissions:

Table 3.10:LCI for STS

Input		DSCC	DNCC	Combined
Diesel (in kg/year)		91833	112240	204073
Output	Emission factor (g/tonnes fuel)	From DNCC STS (kg)	From DNCC STS (kg)	From Combined STS (kg)
CH_4	8.30E+01	7.62E+00	9.32E+00	1.69E+01
CO	1.08E+04	9.89E+02	1.21E+03	2.20E+03
CO_2	3.16E+06	2.90E+05	3.55E+05	6.45E+05
N_2O	1.35E+02	1.24E+01	1.52E+01	2.75E+01
NH_3	8.00E+00	7.35E-01	8.98E-01	1.63E+00
NOx	3.28E+04	3.01E+03	3.68E+03	6.69E+03
SO_2	1.00E+03	9.18E+01	1.12E+02	2.04E+02
PM_{10}	2.10E+03	1.93E+02	2.36E+02	4.29E+02
$PM_{2.5}$	5.51E+03	5.06E+02	6.19E+02	1.13E+03
NMVOC*	3.38E+03	3.10E+02	3.79E+02	6.89E+02
PAH	3.32E+00	3.05E-01	3.73E-01	6.78E-01
Cadmium	1.00E-02	9.18E-04	1.12E-03	2.04E-03
Copper	1.70E+00	1.56E-01	1.91E-01	3.47E-01
Chromium	5.00E-02	4.59E-03	5.61E-03	1.02E-02
Nickel	7.00E-02	6.43E-03	7.86E-03	1.43E-02
Selenium	1.00E-02	9.18E-04	1.12E-03	2.04E-03
Zinc	1.00E+00	9.18E-02	1.12E-01	2.04E-01
*NMVOC = Non-Methane Volatile Organic Carbon				

This dataset is applied for all the scenarios LCA analysis. For alternative combined scenarios waste quantity in STSs remains same as baseline.

3.10.2 Transportation

Transportation dataset is divided into two parts: a) Diesel burning emission dataset, b) Compressed natural Gas (CNG) burning fuel dataset. Since no published data is available on yearly fuel consumption by transport vehicles, numerous assumptions are made to estimate the quantity.

It is important to quantify the waste carried from STSs of DNCC and DSCC separately to landfills. As waste reports provide vehicles data separately for each city corporation, those data will be used with the individual landfill quantities, not with the combined landfill waste quantity. Therefore, the following method is applied to estimate the individual landfill waste quantities.

i. Landfill waste quantification

In World Bank report (2021), out of 6465ton, 4700ton waste is disposed daily on the landfills. But the division of this total landfill quantity is not into individual landfills is not provided in thar report. To divide the 4700 ton into two landfills, the ratio of the average daily landfill waste is determined first. To obtain this ratio, the average daily waste data provided on city corporation waste reports 2019-2020 are used.

Average daily waste disposed in Aminbazar = 2750 ton (DNCC 2019-2020)
Average daily waste disposed in Matuail = 2540 ton (DSCC 2019-2020)

The ratio of DNCC:DSCC = 1.083:1

Using this ratio, 4700ton is divided into Aminbazar 2443ton and Matuail 2257ton. Now using these total landfill quantities, the quantity of distinct types of waste will be estimated as per their fraction.

ii. Diesel and CNG consumption

Now with the landfill quantities obtained, fuel consumption for carrying these quantities with various vehicles is determined. Following Table 3.11 shows the assumed values and estimation of fuel estimation:

Table 3.11: CNG and diesel consumption analysis

Item description	**DNCC**	**DSCC**	**Combined**	**Data Source**
Vehicles Number, nos.	Diesel Fueled Vehicles			(DNCC 2019-2020) (DSCC 2019-2020) (JICA 2009)
Container Carrier	29	44	73	
Arm Roll	8	12	20	
Compactor	46	58	104	
Open and Dump Truck	49	102	151	
	CNG Fueled Vehicles			
Container Carrier	15	30	45	
Total, nos.	**147**	**246**	**393**	
Average daily waste, ton	2443	2257	4700	As per analysis

Table 3.11: CNG and diesel consumption analysis continued

Item description	DNCC	DSCC	Combined	Data Source
Diesel density, kg/liter	0.832			
CNG density, kg/liter	0.77			
Diesel vehicle work mode, km/liter	3.00			(JICA 2009) (JICA 2011)
CNG vehicle work mode, km/liter	6.50			(JICA 2009) (JICA 2011)
Average load, ton/trip	4.80	3.98	-	(DNCC 2019-2020) (DSCC 2019-2020) (Yoshijima, et al. 2021)
Average trip distance, km/trip	16.25	16.25	-	As per analysis
Average trip, nos./(day*vehicle) (Average daily waste/ average load * total vehicle)	3.46	2.30	-	As per analysis
Diesel consumption, kg/year	$\frac{\text{Total diesel vehicle} * \text{average trip distance} * \text{average trip nos.} * 365 * \text{density of diesel}}{\text{work mode of diesel vehicle}}$			
	751863	818954	1570817	As per analysis
CNG consumption, kg/year	$\frac{\text{Total CNG vehicle} * \text{average trip distance} * \text{average trip nos.} * 365 * \text{density of CNG}}{\text{work mode of CNG vehicle}}$			
	36495	48585	85080	As per analysis

In the above Table 3.11, certain parameters are estimated from analysis, and some are derived from literature. Total number of vehicles are provided in DSCC and DNCC waste report without any mentioning of the number of vehicles driven by diesel and CNG (2019-2020). Upon verbal communication with DSCC, it was confirmed that most of the city corporation vehicles are driven by diesel and JICA provided few CNG driven vehicles. JICA 2009 and 2011 reports the total number of CNG Container Carrier (CC) vehicles is obtained as 45. In this study, it is assumed that 15 CC belongs to DNCC and 30 belongs to DSCC. In waste reports

the total number of CC for DNCC and DSCC is provided as 44 and 74 respectively. Therefore, remaining 29 and 44 CCs are assumed to be driven by diesel.

Universal diesel density 0.832 kg/liter is used for the analysis. The CNG density however depends on pressure and temperature. It is also expressed in equivalent liquid fuel density unit so that it is easier to compare its efficiency with diesel, petrol etc. 1 kg of CNG is energy equivalent to 1.39 liters of petrol and 1.18 liters of diesel. The density can also be calculated from the energy value of CNG.

The energy value of CNG = 50 MJ/kg (megajoules/kg).

Also, the energy value of CNG = 38.3 MJ/m^3

It can be written as 38.3 MJ/Liter as 1 m^3 or natural gas will have a volume of almost 1.032~1 liter when liquified under certain pressure and ambient temperature. So, the CNG density will be = 38.3/50 = 0.77 kg/Liter

The work mode is the mileage of the fuel, and the data is provided in JICA reports for both diesel and CNG. Average load per trip is provided in waste reports. Although, there are different waste carrying capacity vehicles like 3ton, 5ton, 7ton or more but the load is averaged for all vehicles for simplicity of calculation. The average trip distance from STSs to landfills is derived from JICA, 2009 report. In the report, the average travel distance for one vehicle per day is described as 32.5 kilometers. During that period, Dhaka City Corporation was undivided. 32.5 kilometers was found as the average distance for the waste vehicles to carry the waste from STS to landfills as per the JICA report analysis. Also, the 32.5 km diameter circular area comprised almost full of the Dhaka city area. But in 2011, Dhaka city corporation was divided into north and south zones. For each city corporation it is assumed that half of the previous 32.5 km i.e., 16.25 km is suitable to represent the average trip distance from DNCC and DSCC STSs to Aminbazar and Matuail respectively.

The next estimate is the average trip nos. per day per vehicle. Finally, with all the data yearly diesel and CNG consumption is estimated with the given formula in Table 3.11.

Emission factor of different pollutants from diesel and CNG burning obtained from EMEP/EEA (European Monitoring and Evaluation Program/European Environmental Agency), 2019 (last updated 2021) guideline for Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motorcycles (1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv).

iii. Diesel Emission

The emission factors for Heavy Duty Vehicles (HDVs) that use diesel fall on NFR 1.A.3.b.iii, HDV, Diesel 7.5-16t, EURO II technology category as per guideline. Tier 1,2 and 3 approaches are mixed for determining different emission factors. Typically, the waste carrying vehicles carries 3-12ton of waste. If summed up with their self-weight the total operating weight seems reasonable for adopting 7.5-16ton category from the guideline. Moreover, most of the diesel fueled vehicles engine that are currently operational belongs to EURO II technology which were proposed to change EURO III technology in 2019 as per DOE, 2012 report on vehicular emission standards of Bangladesh. As no exact data is available on the number of vehicles in different technology categories, for this study, EURO II emission factors are adopted for all diesel fueled vehicles.

Carbon dioxide emission factor as per guideline is 3.17 kg/kg of fuel. Typical diesel consumption for HDVs is also given in the guideline as 0.277 kg/km. Therefore, the emission factor in g/km for CO_2 will be 8.78E+02. Other emission factor is provided in gram/kilometer unit. So, all the factors are converted in the same unit to avoid error in the analysis.

Sulfur dioxide emission factor depends on the sulfur content of the fuel. Bangladesh imported diesel with 1000 ppm sulfur content before 2016. From 2106 the imported diesel has 500 ppm sulfur content. Therefore, the SO_2 emission factor as per guideline will be:

EF = 2*sulfur content = 2*500ppm = 1000ppm = 1000mg/kg fuel = 1000g/tonnes fuel = 0.0010kg/kg fuel

Typical diesel consumption as per guideline = 0.277 kg/km

Therefore, EF = 0.0010*0.277*1000 g/km = 0.277 g/km

Table 3-11 provides the emission factors and yearly pollutant emissions LCI associated with diesel burning. The yearly emission is obtained by the following formula:

$$\text{Yearly quantity (kg)} = \frac{emission\ factor\ (g/km) \times Yearly\ Fuel\ consumption\ (kg)}{Fuel\ Comsumption\ (kg/km) \times 1000(g/kg)}$$

The emission data from diesel burning is provided in Appendix B.

iv. CNG Emission

Emission factors of pollutants emitted by CNG burn are taken from EMEP/EEA emission category NFR 1.A.3.b.iii, EURO IV technology. Like diesel, tiers 1, 2 and 3 approach is mixed for determining emission factors. CNG vehicles are provided by JICA project to city

corporations and CNG is cleaner than diesel. These vehicles have EURO IV technology by default (Ntziachristos, et al. 2021).

The carbon dioxide emission factor as per guideline is 2.74 kg/kg of CNG. Typical diesel consumption for HDVs is also given in the guideline as 0.118 kg/km. Therefore, the emission factor in g/km for CO_2 will be 323.67g/km. There is no sulfur emission from CNG burn. Yearly emission is calculated using a similar formula as used in diesel dataset. Details are provided in the following Table 3.12:

Table 3.12: Pollutants from CNG burn

Item	Emission Factor, g/km	Yearly Emission, kg		
		DSCC	DNCC	Combined
CO	1.00E+00	4.12E+02	3.09E+02	7.21E+02
NOx	2.50E+00	1.03E+03	7.73E+02	1.80E+03
Pb	2.37E-05	9.76E-03	7.33E-03	1.71E-02
$PM_{2.5}$	5.00E-03	2.06E+00	1.55E+00	3.61E+00
CO_2	3.24E+02	1.33E+05	1.00E+05	2.33E+05
CH_4	5.73E-02	2.36E+01	1.77E+01	4.13E+01
NMVOC	4.50E-02	1.85E+01	1.39E+01	3.24E+01
PAH	1.06E-02	4.37E+00	3.29E+00	7.66E+00

The full LCI for transportation is the same in all the combined scenarios because the total waste carried from STS to landfills remains same and the other waste treatment facilities are assumed to stay adjacent to the landfill site.

3.10.3 Landfill Maintenance

The waste coming to landfills is compacted daily by chain dozer, payloader, excavator, wheel dozer etc. (DNCC 2019-2020, DSCC 2019-2020). These vehicles are all run by diesel. The factors are the same for STS LCI as these vehicles fall in the same non-road equipment category as per EMEP/EEA guideline. Additionally, electricity is consumed for landfill maintenance and operation. But there is no direct data available on yearly diesel and electricity consumption. However, the yearly fuel and electricity expenditure for landfills in fiscal year 2019-2020 is provided in waste reports. The total expenditure is divided by unit cost of diesel and electricity to estimate the yearly consumption. Although, there is no mention that only diesel comprised of the total fuel, there may be some lubricants and other auxiliary fuels, but diesel is the main fuel. So, only diesel emission is considered in this study. Diesel unit rate is taken as equal of 65 BDT/liter which was the market rate back in the year 2019-2020. Electricity rate taken from DPDC, 2017. The retail tariff rate is assumed to belong low voltage (LT) D2 class which is for streetlight, water pump and battery charging station. There was no specific category for landfill

or waste management in DPDC, 2017. Also, the landfill site has lights, water pump in leachate and office facilities. As there is no heavy equipment in operation, the electricity consumption is assumed like D2 low voltage class.

Generally, in LCA analysis there are two types of activities considered: i) land transformation, ii) land occupation. Land transformation is the change in land use pattern e.g., empty barren land or aquatic body suddenly sand filled and used for dump site. Land occupation is the ongoing activities for several periods that holds the natural restoration process of that land. Land occupation is also counted as the delay in the natural restoration process. In this study, both land transformation and occupation are considered for landfills.

Table 3.13: Consumption of diesel, electricity and land for baseline landfilling operation

Item	Aminbazar, DNCC	Matuail, DSCC	Combined
i. Diesel Consumption			
Fuel Cost, BDT/year	48000000	54500000	102500000
Diesel Unit Cost, BDT/liter	65 (Diesel unit rate, TBS, 2021)		
Diesel Consumption, kg/year	614400	697600	1312000
ii. Electricity Consumption			
Electricity Cost, BDT/year	2330000	2000000	4330000
Electricity Unit Cost, BDT/kWh	7.7 (Retail Electricity Rate, Category LT-D2, DPDC, 2017)		
Electricity Consumption, kWh/year	302597	259740	562338
iii. Land Use			
Incoming waste, ton/year	891800	823700	1715500
Land requirement parameter	20 ton/m^2 (ecoinvent database)		
i) Land Transformation, m^2 Ecoinvent Flow: Transformation, from wetland, inland (non-use)	44590 (11.01 acres)	41185 (10.18 acres)	85775 (21.19 acres)
ii) Land Occupation, m^2*year Ecoinvent Flow: Occupation, dump site	44590 (11.01 acres)	41185 (10.18 acres)	85775 (21.19 acres)

The existing field quantity of land transformed and occupied in Matuail and Aminbazar are not considered since these landfills have irregular height and managed inefficiently. So, it is not feasible to compare these land occupancy data with land requirements of other alternative waste treatment processes in standard condition. Therefore, just for this analysis purpose standard condition is assumed to estimate the land quantity. According to the ecoinvent life cycle inventories report no. 13: part II by Doka, 2009, in standard condition, 20 tons of waste will consume 1m^2 of area in a sanitary landfill with a landfill depth of 20m. The total waste quantity

in Matuail and Aminbazar is divided by 20 tons to estimate the total land area required in standard condition and the quantities in baseline and alternative scenarios are provided in Table 3.13 and Table 3.14. In alternative scenarios the waste quantity in landfills varies and the diesel, electricity and land consumption also change according to the quantity of waste. Following are these consumptions in alternative scenarios:

Table 3.14: Consumption of diesel, electricity and land for alternatives landfilling

Item	Alt. A1	Alt. A2, A3, A4
Diesel, kg/year	223352	94859
Land, m^2	14542	6137
Electricity, kWh/year	95196	40080

Both Matuail and Aminbazar are situated in low wetland. These low wetlands and not used for habitation, fishing, or any economic and social activities prior to landfill activities. So, the land is transformed from wetland to inland for landfilling purposes and the land is occupied as dump site till the end of landfill closure. To compare the landfilling practice with other waste treatment methods, both land transformation and land occupation need to be considered. Land occupation and transformation have different unit and characterization factors. As one year waste quantity is considered in this study, land occupation period also remains one year.

The environmental burden from production of the consumed electricity is considered as per scope of this LCA. Bangladesh produced around 66% electricity from natural gas in FY 2016-17 (Energypedia 2019). Also, most of the natural gas is used in combined cycle power plants. Therefore, for electricity burden LCI, the ecoinvent process output of "electricity production, natural gas, combined cycle power plant | electricity, high voltage | Cutoff, U – IN-DL" is followed. In this study, it is assumed that Bangladesh and India have the same technology and similar raw materials to produce electricity from natural gas in a combined cycle power plant. The rationale of this assumption is that as being neighboring countries Bangladesh and India has the similar trend/practice/technology to produce power. Database from Delhi city power plant is adopted. Water used in power plant cooling is considered. In alternative scenario A1 significant organic portion moved to composting from landfill. Therefore, the requirement is reduced as well as emissions due to reduced maintenance of landfill. In alternative A2, A3 and A4 the landfill waste quantity is further reduced due to waste incineration. The emissions from

yearly diesel burn and electricity consumption for baseline and alternative scenarios are provided in Appendix B.

3.10.4 Landfilling of Waste

The landfill waste contains decomposable organic waste, graphical paper, packaging paper or paperboard, plastic, textile, glass, metal or other inert and inorganics. Each of these items causes pollution at various levels. Therefore, a separate process is formed for analysis of the impact from individual waste category/types.

3.10.4.1 Organic/Biowaste Landfilling

Organic waste comprised of the most part of MSW. Baseline scenario is the existing percentage of organic waste disposed of into landfills. As per alternative scenarios scopes**,** the variation of organic waste landfilled, and its percentage with respect to generated waste is shown in Table 3.15.

Table 3.15: Organic waste landfilling quantities in DNCC, DSCC and different combined scenarios

Coverage, Unit	Baseline B0	Alternative A1	Alternative A2	Alternative A3	Alternative A4
Combined, %	62.24	1.87	1.87	1.87	1.87
Combined, Ton/year	1468725	44062	44062	44062	44062
DNCC, %	63.69	-	-	-	-
DNCC, Ton/year	769535	-	-	-	-
DSCC, %	60.72	-	-	-	-
DSCC, Ton/year	699190	-	-	-	-

The respective burden from organic waste LCI is taken from ecoinvent database for a landfill in Delhi, India. This landfill site in Delhi has a mean annual temperature of 24.65°C, mean annual precipitation of 1083mm/year and net infiltration of 649 mm/year (as per ecoinvent database). The ultimate average landfill height is 7 meters. The operation phase duration of the landfill is 15 years. The landfill emits landfill gas directly. A methane correction factor for landfill air emissions of 0.7057 is applied on the dataset. The reason for choosing landfill datasets from Delhi city is that Delhi and Dhaka have lots of cultural and climatic similarities. Both culture and climate have an impact on the composition of organic waste which is a major part of the total waste. The share of carbon is assumed to be 100% biogenic in organic waste.

As discussed in the landfill LCA scope, ecoinvent sanitary landfill dataset for paper, plastic and glass is used for Matuail and unsanitary landfill dataset is used for Aminbazar landfill.

Organic and textile datasets are not differentiated between sanitary and unsanitary landfill in ecoinvent. So, an average treatment deficiency factor is applied to the water emission outputs of the ecoinvent dataset of organic and textile waste landfilled. Following Table 3-16 shows the assumptions, based on which the deficiency factor is calculated.

Table 3.16: Average treatment deficiency of leachate treatment

Landfill name	Assumed Leachate Treatment Effectiveness	Total Landfilled Waste, ton/year	Average Treatment Effectiveness	Average Treatment Deficiency
Matuail	80%	823700	48.80%	51.20%
Aminbazar	20%	891800		

The emission data provided in ecoinvent is for 1kg of organic waste. It is recalculated for the estimated landfill quantities. Also, the water emissions are modified with leachate treatment deficiency factor. Following Table 3.17 presents the output data for baseline scenario:

Table 3.17: LCI for biowaste landfilling in baseline B0 crude condition

Ecoinvent process: treatment of biowaste, open dump | biowaste | APOS, S Modified – IN	
Quantity expressed in **kg/year** for all substances except heat (**MJ/year**)	
Category: Elementary flows/Emission to air/high population density Description: burden from direct release or incineration of landfill biogas	
Flow	**Emission Quantity**
Aluminium	4.94E+01
Arsenic	1.99E+00
Bromine	8.37E+01
Cadmium	6.40E-02
Calcium	2.81E+02
Carbon dioxide, biogenic	1.38E+08
Chromium	9.01E-03
Cobalt	1.59E-01
Copper	9.96E-03
Hydrogen chloride	5.74E+04
Hydrogen fluoride	3.15E+04
Iodine	7.68E-01
Iron	8.14E-01
Lead	1.44E-02
Magnesium	1.72E+02
Manganese	4.87E-01
Mercury	7.58E-01
Methane, biogenic	3.28E+07

Table 3.17: LCI for biowaste landfilling in baseline B0 crude condition, continued

Flow	Emission Quantity
Molybdenum	4.17E-03
Nickel	3.11E-02
Nitrogen oxides	2.17E+03
Potassium	2.53E+02
Selenium	5.21E-03
Silicon	1.97E+02
Sodium	5.49E+02
Sulfur dioxide	7.73E+04
Tin	4.66E-03
Zinc	2.42E-01
Vanadium	3.12E-02
Category: Elementary flows/Emission to soil/industrial Description: burden from short-term decomposition of waste (0-100a).	
Heat, waste	2.24E+09
Category: Elementary flows/Emission to water/ground water Description: burden from short-term leachate to groundwater in uncontrolled landfill in moist climate.	
Aluminium	1.01E+05
Ammonium, ion	7.71E+05
Arsenic, ion	7.27E+01
BOD5, Biological Oxygen Demand	2.48E+05
Boron	7.67E+03
Bromine	3.06E+03
Cadmium, ion	4.91E+00
Calcium, ion	5.74E+05
Chloride	2.04E+06
Chromium VI	1.85E+01
Cobalt	3.25E+02
COD, Chemical Oxygen Demand	1.05E+06
Copper, ion	1.78E+01
DOC, Dissolved Organic Carbon	9.57E+05
Fluoride	2.97E+03
Hydrogen sulfide	8.23E+03
Iodide	2.80E+01
Iron, ion	1.67E+03
Lead	2.21E+01
Magnesium	3.52E+05

Table 3.17: LCI for biowaste landfilling in baseline B0 crude condition, continued

Flow	Emission Quantity
Manganese	9.97E+02
Mercury	9.70E-01
Molybdenum	8.54E+00
Nickel, ion	6.38E+01
Nitrate	8.11E+04
Nitrite	4.20E+04
Nitrogen, organic bound	1.26E+06
Phosphate	3.92E+04
Potassium, ion	5.18E+05
Selenium	1.07E+01
Silicon	4.04E+05
Sodium, ion	1.12E+06
Sulfate	3.16E+05
Tin, ion	9.53E+00
TOC, Total Organic Carbon	9.57E+05
Vanadium, ion	6.40E+01
Zinc, ion	5.58E+02
Category: Elementary flows/Emission to water/ground water, long-term Description: Emissions from long-term leachate (>100a) directly from MSW landfill and indirectly via incineration of treatment sludge from leachate treatment.	
Aluminium	7.39E+06
Ammonium, ion	3.98E+05
Arsenic, ion	1.43E+03
BOD5, Biological Oxygen Demand	2.30E+07
Boron	7.67E-06
Bromine	1.40E+03
Cadmium, ion	9.85E+01
Calcium, ion	1.58E+07
Chloride	9.31E+05
Chromium VI	9.15E+00
Cobalt	3.42E+03
COD, Chemical Oxygen Demand	9.72E+07
Copper, ion	1.35E+04
DOC, Dissolved Organic Carbon	8.89E+07
Fluoride	1.32E+05
Heat, waste	3.82E+09
Hydrogen sulfide	7.22E+04

Table 3.17: LCI for biowaste landfilling in baseline B0 crude condition, continued

Flow	Emission Quantity
Iodide	1.28E+01
Iron, ion	4.48E+05
Lead	1.39E+04
Magnesium	1.76E+06
Manganese	2.23E+03
Mercury	5.11E+01
Molybdenum	4.55E+01
Nickel, ion	4.00E+03
Nitrate	4.19E+04
Nitrite	2.17E+04
Nitrogen, organic bound	6.51E+05
Phosphate	1.72E+05
Potassium, ion	2.11E+06
Selenium	3.85E+01
Silicon	2.12E+05
Sodium, ion	1.12E-03
Sulfate	2.77E+06
Tin, ion	5.98E+03
TOC, Total Organic Carbon	8.89E+07
Vanadium, ion	2.40E+02
Zinc, ion	4.31E+04

Similar data is constructed for combined alternatives and individual DNCC and DSCC LCI analysis. These data are provided in Appendix B.

3.10.4.2 Other Wastes in Landfills

Remaining landfill waste contains graphical and packaging paper, plastic, textile, glass and inert. Their respective quantity in different scenarios as described in scopes of this LCA and ecoinvent data source for these wastes are listed in Table 3.18. Graphical paper, paperboard, plastic and glass landfill emission dataset is provided separately for sanitary and unsanitary landfills. So, sanitary and unsanitary landfill dataset is used for Matuail and Aminbazar landfill respectively. For textiles the dataset is provided for unsanitary landfill. So, the provided data is directly used for Aminbazar landfill. For Matuail landfill, another set of data is prepared with the leachate treatment deficiency factor multiplied with water emission outputs. Datasets for both landfills are combined to form the unified LCI.

Table 3.18: Landfill percentage and quantity of different waste except biowaste

Graphical Paper Ecoinvent process: Aminbazar- treatment of waste graphical paper, unsanitary landfill, very wet infiltration class (1000mm) | waste graphical paper | Cutoff, U – GLO Matuail- treatment of waste graphical paper, sanitary landfill | waste graphical paper | Cutoff, U - RoW					
Unit	B0	A1	A2	A3	A4
Combined, %	1.08	1.08	0.054	0.054	0.054
Combined, Ton/year	25398	25398	1270	1270	1270
Packaging Paper/ Paperboard Aminbazar- treatment of waste paperboard, unsanitary landfill, very wet infiltration class (1000mm) | waste paperboard | Cutoff, U – GLO Matuail- treatment of waste paperboard, sanitary landfill | waste paperboard | Cutoff, U - RoW					
Combined, %	0.12	0.12	0.0059	0.0059	0.0059
Combined, Ton/year	2822	2822	141	141	141
Plastic (Mixed) Landfilling Aminbazar- treatment of waste plastic, mixture, unsanitary landfill, very wet infiltration class (1000mm) | waste plastic, mixture | Cutoff, U – GLO Matuail- treatment of waste plastic, mixture, sanitary landfill | waste plastic, mixture | Cutoff, U - RoW					
Combined, %	4.78	4.78	0.24	0.24	0.24
Combined, Ton/year	112880	112880	5644	5644	5644
Textile Landfilling Aminbazar- treatment of waste yarn and waste textile, unsanitary landfill | waste yarn and waste textile | Cutoff, U – IN Matuail- Same as ecoinvent process used for Aminbazar except modification in water emission					
Combined, %	0.92	0.92	0.046	0.046	0.046
Combined, Ton/year	21787	21787	1089	1089	1089
Glass Landfilling Aminbazar: treatment of waste glass, unsanitary landfill, very wet infiltration class (1000mm) | waste glass | Cutoff, U – GLO Matuail- treatment of waste glass, sanitary landfill | waste glass | Cutoff, U - RoW					
Combined, %	0.59	0.59	0.0295	0.0295	0.0295
Combined, Ton/year	14067	14067	703	703	703
Inert/Metal/Other Landfilling					
Combined, %	2.96	2.96	2.96	2.96	2.96
Combined, Ton/year	69821	69821	69821	69821	69821

Cutoff databases are selected to take count of the landfill related emissions only. Indian (IN) dataset is applied where available. Otherwise, global (GLO) and rest of world (RoW) dataset is applied. As per ecoinvent report, Bangladesh and the whole sub-continent falls in the very wet infiltration class where average infiltration is 1000mm (Doka 2018). Other waste categories include metal, alloys, cementitious and other materials. These are assumed to be inert. Inert substances have little environmental impact. However, aluminum and iron may be present in small amounts. Aluminum can be ignored as they have little chance to pollute the environment until reacting with reagent and producing toxic substances in high level and frequently. Steel product is also not harmful as they do not release ionized chromium normally (Chromium VI) until welded at 1200°C. No LCI is formed for inert landfill. It is kept as a dummy process just for picturing all the whole waste management scenario. For DNCC and DSCC baseline scenario analysis following data fraction will be used:

Table 3.19: Percentage and quantity of specific wastes for landfills excluding biowaste

Waste Item	DNCC, %	Aminbazar, ton/year	DSCC, %	Matuail, ton/year
Graphical Paper	1.69	20467	0.43	4931
Packaging Paper	0.19	2274	0.05	548
Plastic	3.87	46730	5.74	66150
Textile	0.99	11950	0.85	9837
Glass	0.92	11058	0.26	3009
Other	2.47	29786	3.48	40035

The emission LCI of these wastes landfilling processes are enlisted in Appendix B.

3.10.5 Recycling

3.10.5.1 Paper Recycling

Paper recycling can be categorized in four parts: 1) Writing, 2) Printing, 3) Newsprint, 4) Packaging. Frist two categories belongs to graphical paper, but their production from virgin raw materials have different environmental emissions.

1) Writing Paper

Paper recycling involves, the production of recycled materials, replacement of equal quantity of paper produced from virgin raw materials and reduction of its process output. Upstream processes of inputs from virgin material production are excluded except water and electricity as per scope.

i. Net environmental burden = Emission from recycling process – Emission from virgin material production
ii. Net electricity = Electricity consumption in recycling – Electricity consumption in virgin material production
iii. Net water consumption = Water consumption in recycling – Water consumption in virgin materials production

Both recycling and virgin raw materials production emissions are taken from ecoinvent dataset. Ecoinvent graphical paper production from recycling process mentioned that 0.903kg of wastepaper will produce 1kg of new paper by mixing with other raw pulp in small quantity. This parameter is followed to quantify the paper that can be produced yearly by recycling from actual wastepaper quantity. Additionally, this recycled quantity will replace equal quantity of virgin materials reducing emission from raw process. Recycled quantity and the percentage with respect to generated waste is estimated at the waste composition section. Paper production data is presented in the following Table 3.20 and emissions data are presented in Table 3.21.

Table 3.20: Recycled paper and production from recycled paper in particular paper categories

Paper	**Writing**	**Printing**	**Newsprint**	**Paperboard**
Recycled, kg	0.90	0.90	0.74	1.09
Produced, kg	1.00	1.00	1.00	1.00
Combined, recycled, ton/year	4608	10753	12289	3073
Combined, produced, ton/year	5103	11908	16562	2813

Table 3.21: Emission and water consumption by recycling and virgin material producing

Writing Paper Recycling Ecoinvent process: graphic paper production, 100% recycled | graphic paper, 100% recycled | Cutoff, U-RoW		
Output		
Category: Elementary flows/Emission to water/unspecified		
Flow	Unit, /year	Combined Scenario, Baseline and All Alternatives
AOX, Adsorbable Organic Halogen as Cl	kg	9.14E+00
BOD5, Biological Oxygen Demand	kg	9.51E+03

Table 3.21: Emission and water consumption by recycling and virgin material producing, continued

Flow	Unit, /year	Combined Scenario, Baseline and All Alternatives
COD, Chemical Oxygen Demand	kg	1.19E+04
DOC, Dissolved Organic Carbon	kg	3.96E+03
Nitrogen	kg	5.56E+03
Phosphorus	kg	1.01E+02
TOC, Total Organic Carbon	kg	4.76E+03
Virgin Writing Paper Production from Raw Materials Ecoinvent process: paper production, woodfree, uncoated, at non-integrated mill | paper, woodfree, uncoated | Cutoff, U - RoW		
Input		
Category: Elementary flows/Resource/in water		
Water, cooling, unspecified natural origin	m^3	-1.84E+05
Water, unspecified natural origin	m^3	-5.26E+04
Output		
Category: Elementary flows/Emission to water/surface water		
BOD5, Biological Oxygen Demand	kg	-1.63E+03
COD, Chemical Oxygen Demand	kg	-1.18E+04
DOC, Dissolved Organic Carbon	kg	-4.37E+03
Nitrogen	kg	-2.04E+02
Phosphorus	kg	-5.10E+01
Suspended solids, unspecified	kg	-2.55E+02
TOC, Total Organic Carbon	kg	-4.37E+03
Category: Elementary flows/Emission to air/unspecified		
Water	m^3	-7.91E+04
Water	m^3	-1.57E+05

Here "-ve" sign means this output is omitted and causing savings in environmental burden. Dataset is applicable for rest of the world (RoW) except European region. Municipal solid waste, ashes, hazardous waste, wood ash, sludge from pulp and paper is kept out of the study due to uncertainty of the disposal system and process may occur outside Dhaka city. The reason of choosing woodfree, uncoated paper production is that this category contains office papers

like business forms, copier, computer, stationery and book paper. In ecoinvent database description of mentioned that woodfree paper contains at least 90% fibers from chemical pulp. Also, coated paper has a coating of kaolin or calcium carbonate. The meaning of non-integrated mill is that the pulp required is bought from market for paper production. Since there is no data on what type of recycling facility Dhaka city has, all these above-mentioned conditions are assumed reasonable for a small paper recycling facility in Dhaka and the quality of the paper produced. The net electricity is calculated as followed in Table 3.22:

Table 3.22: Net electricity calculation from recycling process and virgin production process for writing paper

Unit	Electricity required producing graphic paper from recycling	Electricity required for producing woodfree uncoated paper from raw materials at non-integrated mill	Net Electricity
kWh in unit process, 1kg paper production	1.0092	-0.4802	0.529
kWh/year	5150391	-2450671	2699720

The emission from 2699720 kWh electricity production is estimated from electricity production from natural gas combined cycle power plant, Delhi. The net electricity production emissions as well as full LCI data for DNCC and DSCC writing paper recycling is provided in Appendix B.

2) Printing Paper

Printing paper is another category of graphic paper. So, the process flow and net burden calculations procedure is the same as the writing paper. The only difference is that wood containing lightweight coated (LWC) paper process flow is used as virgin printing paper production process. This sort of paper is predominately used for printing materials, magazines, journals that require higher quality than newsprint paper. This ecoinvent dataset description states that these paper mills contain an integrated mechanical pulp production and sometimes an integrated deinking equipment for recovered paper. The used sulfate pulp is usually purchased from outside. The paper quantity for recycling and newly produced paper is provided in Table 3-23. The details of emissions are provided in Appendix B.

3) Newsprint

The recycling process burden and savings from replacing raw newsprint calculation follows the same procedure as the other paper. There is difference in dataset of recycling and raw production from the other papers. The details are provided in Appendix B.

4) Packaging Paper

There are a variety of packaging paper available in real life. For simplicity, the ecoinvent recycling process for containerboard production, fluting medium is considered. Also, the containerboard produced is assumed to replace an equal quantity of containerboard produced by semichemical method in factory. Net water and electricity are also considered. Details are in Appendix B.

3.10.5.2 Plastic Recycling

Plastic recycling involves flake production from waste plastic by washing and cutting. Then the flake is converted to plastic granulate by another process. From different plastic granulates different plastic products are produced. In this study, the process emission for recycling process will be considered up to the production of granulates. Granulate production procedure is almost the same for different types of plastics. Therefore, no plastic category division is applied in plastic granulate production process. As per scope, the amount of granulate produced is assumed to replace the virgin granulates produced in industries which saves the burden from virgin granulate production. But different plastic granulates require different factory methods while produced in virgin condition. Therefore, the savings of environmental burden is calculated from each type of granulate production process as per their divided quantities. Net water and electricity are considered like other recycling processes. The quantity of plastic recycled, produced and corresponding ecoinvent processes are provided in the following Table 3.23 and 3.24:

Table 3.23: Plastic granulate produced from recycled waste plastic

Zone	**DSCC**		**DNCC**		**Combined baseline and alts'**	
Granulates	Plastic recycled	Granulates produced	Plastic recycled	Granulates produced	Plastic recycled	Granulates produced
PET	1.33E+04	1.29E+04	9.70E+03	9.45E+03	2.30E+04	2.24E+04
HDPE	5.67E+03	5.52E+03	4.14E+03	4.03E+03	9.81E+03	9.55E+03
PVC	6.64E+03	6.47E+03	4.85E+03	4.73E+03	1.15E+04	1.12E+04
LDPE	1.11E+04	1.08E+04	8.11E+03	7.90E+03	1.92E+04	1.87E+04
PP	7.60E+03	7.40E+03	5.55E+03	5.40E+03	1.31E+04	1.28E+04
PS	6.43E+03	6.27E+03	4.70E+03	4.57E+03	1.11E+04	1.08E+04
Total	**5.07E+04**	**4.94E+04**	**3.70E+04**	**3.61E+04**	**8.78E+04**	**8.55E+04**

All quantity is estimated in **ton/year.**

As per ecoinvent database,
1.03kg waste plastic produces 1kg plastic flake and
1.0001162 kg flake produces 1kg plastic granulate.
Produced granulates from recycled plastic is assumed to replace raw granulate in factories.

Table 3.24: ecoinvent process database used for different plastic recycling as well as production from virgin raw process LCI

Process	Ecoinvent process dataset
Recycling Processes	
Flake production	plastic flake production, consumer electronics, for recycling, by grinding/shredding, informal sector | plastic flake, consumer electronics, for recycling | Cutoff, U - IN
Granulate production	plastic granulate production, unspecified, recycled, informal sector | plastic granulate, unspecified, recycled | Cutoff, U - IN
Raw Production Process	
PET granulate production	polyethylene terephthalate production, granulate, bottle grade | polyethylene terephthalate, granulate, bottle grade | Cutoff, U - RoW
HDPE granulate production	polyethylene production, high density, granulate | polyethylene, high density, granulate | Cutoff, U - RoW
PVC granulate production	polyvinylchloride production, suspension polymerization | polyvinylchloride, suspension polymerized | Cutoff, U - RoW
LDPE granulate production	polyethylene production, low density, granulate | polyethylene, low density, granulate | Cutoff, U - RoW
PP granulate production	polypropylene production, granulate | polypropylene, granulate | Cutoff, U - RoW
PS granulate production	polystyrene production, general purpose | polystyrene, general purpose | Cutoff, U - RoW

Ecoinvent informal plastic recycling dataset of India is derived from the capital city of India, the New Delhi as per ecoinvent database description. New Delhi informal plastic recycling market is the biggest in South Asia. The raw material is collected from all parts of the country by an informal sector that consists of its large collection network of ragpickers and scrap dealers throughout the country. This is the most efficient collection channels as it reaches to every household in India, and they have efficient sorting techniques. Once the received plastics are segregated, cleaned and sorted, the plastics are grinded into smaller flakes. The grinding phase generally comprises of shredders that reduce bulk plastics into smaller flakes. The informal sector in India uses extrusion machines for granulation, and separate molding machines for molding and coloring of plastics from e-waste. The basic operation of granulation at all informal recyclers is same. Plastic flakes are fed into the extrusion machine through

hoppers and plastic in molten state pass through electrically heated barrels and passed through dye to take up the shape of wire. These are passed through the water bath to reduce its temperature and at the end of bath these wires are cut in the uniform size to produce granules. Database was verified and actual readings were taken related to electrical energy consumption by the informal sector. These datasets include activities started from sorting, grinding or shredding, preparing into smaller plastic flakes, palletization, molding and coloring. The existing informal practice of plastic recycling in Bangladesh as described in World bank, 2021 report is very much like the practice described in ecoinvent process for India. Therefore, recycling datasets presents an accurate scenario. The factory production of raw granulates is a typical dataset that is usable for rest of the world (RoW). LCI for raw granulate production and emission/savings from net electricity production are provided in Appendix B. LCI for recycling process is provided in the following Table 3.25:

Table 3.25: LCI data for plastic recycling

Output from plastic flake production				
Category: Elementary flows/Emission to air/high population density				
Flow	Unit, /year	Combined Baseline and All Alternatives	DSCC	DNCC
Particulates, > 10 um	kg	2.65E+02	1.53E+02	1.12E+02
Particulates, > 2.5 um, and < 10um	kg	7.12E+01	4.11E+01	3.00E+01
Input for plastic granulate production				
Category: Elementary flows/Resource/in water				
Water	m^3	3.65E+04	2.11E+04	1.54E+04
Output from plastic granulate production				
Category: Elementary flows/Emission to air/high population density				
Benzene, ethyl-	kg	1.00E-01	6.00E-02	4.00E-02
Carbon dioxide, fossil	kg	1.91E+06	1.10E+06	8.04E+05
Carbon disulfide	kg	4.00E-02	2.00E-02	2.00E-02
Carbon monoxide, fossil	kg	1.69E+03	9.76E+02	7.13E+02
Methane, dichloro-, HCC-30	kg	1.10E-01	7.00E-02	5.00E-02
Nitrogen oxides	kg	6.86E+03	3.96E+03	2.89E+03
Particulates, > 10 um	kg	8.97E+01	5.19E+01	3.79E+01

Table 3.25: LCI data for plastic recycling, continued

Flow	Unit, /year	Combined Baseline and All Alternatives	DSCC	DNCC
Particulates, > 2.5 um, and < 10um	kg	3.59E+02	2.07E+02	1.51E+02
Sulfur dioxide	kg	5.28E+01	3.05E+01	2.23E+01
Toluene	kg	1.50E-01	8.90E-02	6.10E-02
Water	m^3	9.94E+03	5.74E+03	4.19E+03
Category: Elementary flows/Emission to water/unspecified				
Water	m^3	2.66E+04	1.54E+04	1.12E+04

Following Table 3.26 provides the net electricity saved by the plastic recycling process:

Table 3.26: Net electricity savings from plastic recycling

Unit	Combined Baseline and All Alternatives	DSCC	DNCC
kWh/year	-16294674	-9418467	-6876207

3.10.5.3 Glass Recycling

Glass recycling involves production of glass cullet from unsorted glass and producing glass from cullet. Glass is recyclable and can be recycled endlessly. But due to contamination is it difficult to produce clean cullet which makes the whole glass recycling process challenging (Jacoby 2019). Food scraps, dust, glue, labels and chemicals contaminate glass. In this study, these limitations are overlooked and assumed that glass is sorted, and cullet prepared following typical process. Then the cullet is used to produce white packaging glass by mixing with chemicals, silica sand etc. Also, savings in burden calculated from the raw production of white packaging glass in factory of equal recycled quantity. Raw materials other than water is not considered. Water consumption and other emission LCI data is in the Appendix B. Glass produced from recycled quantity is provided in the following Table 3.27:

Table 3.27: Quantity of glass recycled and produced from recycling

Item	DNCC	DSCC	Combined	Database, kg
Recyclable Glass, ton/year	6185	8472	14657	1.08
Glass Cullet, ton/year	5727	7844	13571	1.00
White Glass, ton/year	10047	13762	23809	1.75

3.10.5.4 Metal Recycling

It is assumed that the remaining materials after paper, plastic and glass recycling are metals, alloys etc. No LCI is formed but kept as dummy process. Details are discussed in "waste management components scope: recycling" section of this chapter.

3.10.6 Composting

Composting dataset is applicable for Alternative scenarios A1, A2 and A3. Composting process inventory is formed using ecoinvent database. Additionally, diesel and net electricity production consumption is considered. Table 3.28 provides the organic waste composted, compost produced, diesel consumption and net electricity saved from composting process in alternative scenarios.

Table 3.28: Quantity of organic waste composted, compost produced, diesel consumption and net electricity saved from composting process

Item	Alt. A1	Alt. A2	Alt. A3
Organic/Biowaste, ton/year	1424664	1424664	712332
Compost, ton/year	356166	356166	178083
Diesel, kg/year	2991793	2991793	1495897
Net electricity, kWh/year	-2975964	-2975964	-1487982

As alternative A1 and A2 has similar quantities of organic waste therefore these scenarios will have the same environmental burden. Alternative A3 has half the quantity composted in alternative A1 and A2. Therefore, the input land and water consumption will be half. The emissions from diesel and net electricity saving will be half as well from alternative A1 and A2.

The produced organic compost is assumed to be used as nitrogen fertilizer and replace urea (H_2NCONH_2) therefore, urea production will count as savings. The reason of replacing urea fertilizer is that Bangladesh mostly requires urea fertilizer rather than any other fertilizer. In fiscal year 2017 the demand for urea fertilizer was 2.7 million out of total 5 million tons demand and the domestic production of urea was 0.878 million tons (ECRL 2017). Since the new organic compost will replace urea, there will be a two-way reduction in environmental burdens. Firstly, factory production or urea will be reduced due to this replacement. Although the demand is much higher and there is less chance of replacement but to make this assessment simple and to understand the impact on the environmental burden this replacement is assumed. Secondly, the reduction of burden from after use of this replaced urea in crops field. According

to Chandini et al. (2019) plant take around 50% of nitrogen from N fertilizer applied. The rest 2-20% is volatilized, 15-25% emits at ground and reacts with organic compounds in soil and 2-10% emits to surface and groundwater. Therefore, for this study it is assumed from 1kg of urea, there will be 0.5 kg plant uptake, 0.2 kg volatilization, 0.2 kg emitted to soil, 0.1kg emitted to groundwater. To calculate the nitrate and ammonia quantity, chemical relationships among these substances need to be discussed.

Urea is converted to ammonia by the following hydrolysis reactions (3.1), (3.2) and (3.3):

$$NH_2 - CO - NH_2 + 2H_2O \xrightarrow{Urease\ enzyme} (NH_4)_2CO_3 \dots\dots\dots\dots (3.1)$$

$$(NH_4)_2CO_3 + H^+ \longrightarrow 2NH_4^+ + CO_2 \uparrow + H_2O \dots\dots\dots\dots (3.2)$$

$$2NH_4^+ + OH^- \Longleftrightarrow 2NH_3 \uparrow + H_2O \dots\dots\dots\dots (3.3)$$

Here, 1 mole of urea produces 2 moles of volatile ammonia.

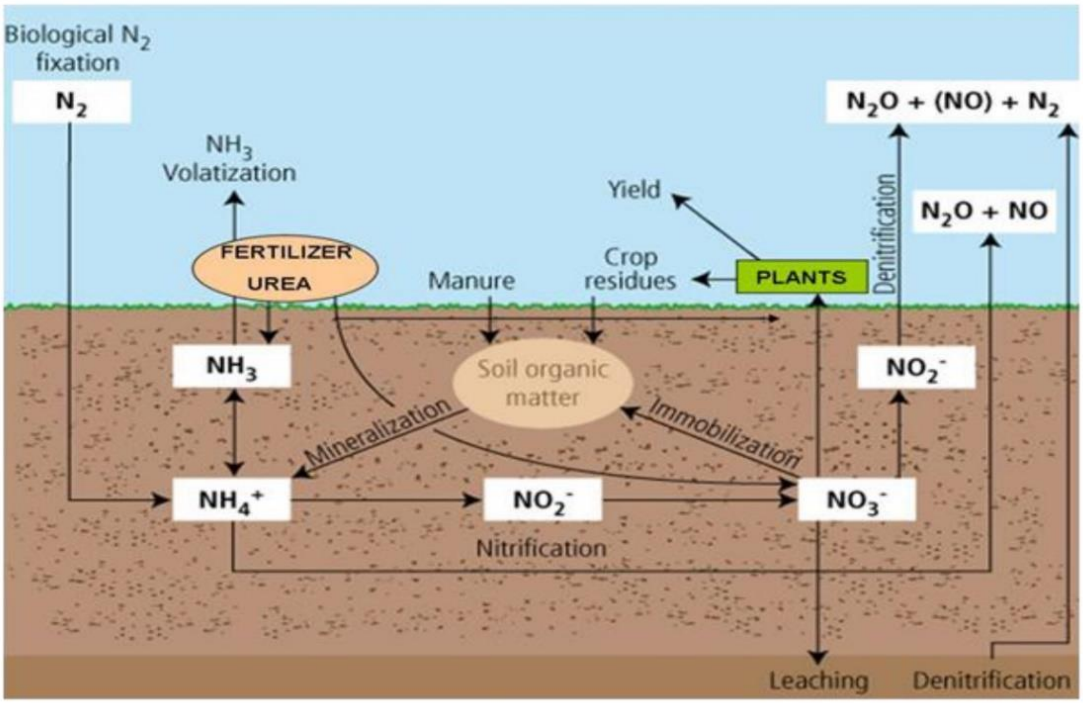


Figure 3.15: Flow of nitrogen fertilizer (Garnica, et al. 2012)

The ammonium ion can also be oxidized to form nitrate by nitrification process as shown in equation (3.4) and (3.5). Therefore, 1 mole of urea is responsible for producing 2 moles of nitrate. Following equations show the nitrification process from ammonium ion:

$$2NH_4^+ + 3O_2 \xrightarrow{Nitrosomonas} 2NO_2^- + 2H_2O + 4H^+ \dots\dots\dots\dots (3.4)$$

$$2NO_2^- + O_2 \xrightarrow{Nitrobacter} 2NO_3^- \ldots\ldots\ldots\ldots (3.5)$$

Now based on the above assumptions and equations, the reduction of environmental burden from using urea is calculated as per following Table 3.29:

Table 3.29: After use burden savings LCI calculations from reduced urea use on field

Urea flow	**After use**	**Plant intake**	**Volatilization**	**Emission to soil**	**Emission to groundwater**
by weight %	100%	50%	20%	20%	10%
Alt. A1, A2, ton/year	-356166	-178083	-71233	-71233	-35617
Alt. 03, ton/year	-178083	-89041	-35617	-35617	-17808
Ecoinvent output data					
Flow	Unit, /year	Alt. A1, A2	Alt. A3	Category	
Ammonia	kg	-40396305	-20198152	Elementary flows/Emission to air/high population density	
Nitrate	kg	-147068167	-73534083	Elementary flows/Emission to soil/agricultural	
Nitrate	kg	-73534083	-36767042	Elementary flows/Emission to water/ground water, long-term	
Calculation method					
Molar Mass	Urea, 60.06 g/mol		NH_3 17.03 g/mol	NO_3^- 62.00 g/mol	
Equivalent mole	1 mole		2 moles	2 moles	

$$Output\ Quantity\ (kg) = -\frac{Urea\ replaced\ (kg) \times Urea\ Percentage\ flowing\ \times Output\ substance\ molar\ mass\ \left(\frac{g}{mol}\right) \times Output\ substance\ mole\ produced\ per\ mole\ of\ urea\ \left(\frac{mol}{mol}\right)}{Molar\ mass\ of\ urea\ \left(60.06\frac{g}{mol}\right)}$$

Example: NH_3 produced $= -\frac{712331782.63\times(\frac{20}{100})\times 17.03\times 2}{60.06} = -20198152.28\ kg\ (Alt.03\ scenario)$

The emission from composting process is adapted from ecoinvent dataset industrial composting. The inputs for urea production in factory facilities are not considered except water and electricity. Additionally, the emission savings from reduction in factory production of urea is calculated based on the ecoinvent dataset as per following Table 3.30:

Table 3.30: LCI for composting and emission savings from reduced urea production

Flow	Unit, /year	Alt. A1, A2	Alt. A3
Composting			
Ecoinvent process used: treatment of biowaste, industrial composting | biowaste | Cutoff, U - RoW			
Output			
Category: Elementary flows/Emission to air/high population density			
Ammonia	kg	9.97E+05	4.99E+05
Carbon dioxide, biogenic	kg	2.14E+08	1.07E+08
Dinitrogen monoxide	kg	3.56E+04	1.78E+04
Hydrogen sulfide	kg	7.49E+05	3.75E+05
Methane, biogenic	kg	1.42E+06	7.12E+05
Category: Elementary flows/Emission to air/unspecified			
Water/m^3	m^3	8.55E+05	4.27E+05
Urea Production			
Ecoinvent process used: urea production | urea | Cutoff, U - RoW			
Input			
Category: Elementary flows/Resource/in water			
Water, cooling, unspecified natural origin	m^3	-4.67E+07	-2.33E+07
Category: Elementary flows/Resource/in ground			
Water, unspecified natural origin	m^3	-8.19E+04	-4.10E+04
Output			
Category: Elementary flows/Emission to air/high population density			
Ammonia	kg	-1.85E+05	-9.26E+04
Carbon dioxide, fossil	kg	2.61E+08	1.31E+08
Particulates, > 2.5 um, and < 10um	kg	-1.10E+05	-5.52E+04
Category: Elementary flows/Emission to air/unspecified			
Water/m^3	m^3	-1.87E+07	-9.33E+06
Category: Elementary flows/Emission to water/surface water			
Ammonium, ion	kg	-5.96E+04	-2.98E+04
Nitrogen	kg	-1.53E+05	-7.66E+04
Category: Elementary flows/Emission to water/unspecified			
Water/m^3	m^3	-2.87E+07	-1.43E+07
"-ve" indicates savings in environmental burden			

The emissions from diesel burning during the composting process and emissions savings from net electricity production are provided in Appendix B.

Data of land quantity transformed and occupied by one composting facility is provided in ecoinvent process *"composting facility construction, open | composting facility, open | Cutoff, U"*. For 1 kg organic composting 7.41E-09 fraction of one composting facility would be required. Therefore, the total composting facility required for composting waste in different scenarios are calculated using a unitary method. Then the estimated total plant facility required

is multiplied with the provided land transformation and occupation quantity of one composting facility in the above-mentioned dataset.

For example,
Land occupation for 01 composting facility = 18800 m^2*a (square meter * per annum)
Composting facility required for 01 kg of organic waste = 7.41E-09 items
Composting facility required for 1424664 ton = 7.41E-09*1424664*1000 = 10.55 items
So, total land occupation by the 1424664 ton = 10.55*18800 = 198467 m^2*a

Similarly, all the land transformation and occupancy data for composting are calculated, and the summary is provided in the following Table 3.31:

Table 3.31: Land use data in composting process

Flow	Unit, /year	Alt. A1, A2	Alt. A3
Output			
Category: Resource/land			
Occupation, construction site	m^2*a	7.92E+03	3.96E+03
Occupation, industrial area, built up	m^2*a	1.98E+05	9.92E+04
Transformation, from wetland, inland (non-use)	m^2	7.92E+03	3.96E+03
Transformation, to industrial area, built up	m^2	7.92E+03	3.96E+03

3.10.7 Incineration

Incineration introduced in alternative A2, A3 and A4. The incineration inventory is prepared according to the scope described in LCA components scope section. Ecoinvent dataset for incineration of biowaste, paper, plastic, textile and glass are applied. Each waste item emits different types of pollutants in different quantities resulting separate LCI for each process.

3.10.7.1 Biowaste Incineration

In alternative scenario A2 biowaste is not incinerated. In alternative scenario A3 and A4, 712332 ton and 1424664ton (half as used in alt. A3) biowaste is incinerated respectively. Oxygen and water required as input for incineration process. Land transformation and occupation for incineration facility as well as land required for residual materials produced after treatment are considered. The dataset from ecoinvent database is modified as per the waste quantity incinerated. The Swiss dataset for municipal incineration of biowaste with fly ash extraction is used. The incineration process description is provided in ecoinvent as follows: “average Swiss MSWI plants in 2010 (grate incinerators) with electrostatic precipitator for fly ash (ESP), wet flue gas scrubber and 25% SNCR, 42.77% SCR-high dust, 32.68% SCR-low

dust -DeNOx facilities and 0% without DeNOx (weighted according to mass of burnt waste, representing Swiss average). Efficiency of iron scrap separation from slag: 58%. Efficiency of non-ferrous scrap separation from slag: 31%. The technology mix for this dataset includes a filter ash treatment (FLUWA) of a share of 46.22%. Gross electric efficiency technology mix 15.84% and Gross thermal efficiency technology mix 28.51%". Diesel consumption is considered for handling waste and moving bottom ashes to nearby landfill. Net electricity is considered. LCI data from biowaste incineration is provided in Table 3.32.

Table 3.32: Incineration LCI of biowaste

Flow	**Unit, /year**	**Alt. A3**	**Alt. A4**
Biowaste Incineration			
Ecoinvent process: treatment of biowaste, municipal incineration with fly ash extraction | biowaste | Cutoff, U – CH CH = Switzerland			
Input			
Elementary flows/Resource/in ground			
Water, unspecified natural origin	m^3	6.12E+08	1.22E+09
Elementary flows/Resource/in air			
Oxygen	kg	3.42E+08	6.85E+08
Output			
Category: Elementary flows/Emission to air/high population density			
Aluminium	kg	5.06E+00	1.01E+01
Ammonia	kg	4.49E+02	8.99E+02
Arsenic	kg	9.73E+00	1.95E+01
Benzene	kg	2.96E+01	5.93E+01
Benzene, hexachloro-	kg	6.20E-02	1.24E-01
Benzene, pentachloro-	kg	1.57E-01	3.13E-01
Benzo(a)pyrene	kg	6.60E-04	1.32E-03
Bromine	kg	1.86E+00	3.72E+00
Cadmium	kg	4.37E-02	8.74E-02
Calcium	kg	1.07E+05	2.13E+05
Carbon dioxide, biogenic	kg	3.68E+08	7.35E+08
Carbon monoxide, biogenic	kg	5.04E+04	1.01E+05
Chromium	kg	4.34E+00	8.68E+00
Cobalt	kg	5.65E+00	1.13E+01
Copper	kg	1.02E+00	2.05E+00
Cyanide	kg	7.96E+03	1.59E+04
Dinitrogen monoxide	kg	3.71E+04	7.41E+04
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	5.93E-05	1.19E-04
Heat, waste	MJ	3.17E+09	6.33E+09
Hydrogen chloride	kg	1.42E+03	2.84E+03
Hydrogen fluoride	kg	8.38E+02	1.68E+03

Table 3.32: Incineration LCI of biowaste, continued

Flow	Unit, /year	Alt. A3	Alt. A4
Iodine	kg	1.90E-02	3.79E-02
Iron	kg	6.68E-01	1.34E+00
Lead	kg	9.50E-01	1.90E+00
Magnesium	kg	1.85E+03	3.70E+03
Manganese	kg	5.10E-01	1.02E+00
Mercury	kg	1.23E+00	2.47E+00
Methane, biogenic	kg	4.45E+02	8.89E+02
Molybdenum	kg	3.27E-01	6.54E-01
Nickel	kg	4.23E+00	8.46E+00
Nitrogen oxides	kg	1.42E+05	2.85E+05
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.35E+03	2.70E+03
Particulates, < 2.5 um	kg	3.54E+03	7.08E+03
Particulates, > 2.5 um, and < 10um	kg	1.78E+01	3.56E+01
Phenol, pentachloro-	kg	1.29E-02	2.58E-02
Phosphorus	kg	7.13E+02	1.43E+03
Potassium	kg	1.07E+04	2.15E+04
Selenium	kg	3.70E+00	7.41E+00
Silicon	kg	3.87E+01	7.74E+01
Sodium	kg	7.65E+03	1.53E+04
Sulfur dioxide	kg	9.91E+03	1.98E+04
Tin	kg	3.25E-03	6.49E-03
Toluene	kg	5.93E+01	1.19E+02
Vanadium	kg	3.95E+01	7.90E+01
Water/m3	m^3	9.65E+05	1.93E+06
Zinc	kg	2.43E+01	4.85E+01
Category: Elementary flows/Emission to water/ground water, long-term			
Aluminium	kg	4.79E+06	9.59E+06
Antimony	kg	5.75E-01	1.15E+00
Arsenic, ion	kg	7.58E+02	1.52E+03
BOD5, Biological Oxygen Demand	kg	2.45E+05	4.89E+05
Boron	kg	5.25E+03	1.05E+04
Bromine	kg	1.93E+02	3.87E+02
Cadmium, ion	kg	1.38E+01	2.75E+01
Calcium, ion	kg	1.15E+07	2.30E+07
Chloride	kg	3.13E+05	6.26E+05
Chromium VI	kg	2.83E+02	5.67E+02
Cobalt	kg	2.72E+03	5.44E+03
COD, Chemical Oxygen Demand	kg	7.48E+05	1.50E+06
Copper, ion	kg	1.05E+04	2.11E+04
DOC, Dissolved Organic Carbon	kg	2.96E+05	5.92E+05

Table 3.32: Incineration LCI of biowaste, continued

Flow	Unit, /year	Alt. A3	Alt. A4
Fluoride	kg	8.29E+04	1.66E+05
Iron, ion	kg	1.91E+05	3.82E+05
Lead	kg	8.12E+03	1.62E+04
Magnesium	kg	1.63E+06	3.26E+06
Manganese	kg	2.12E+03	4.25E+03
Mercury	kg	9.14E+00	1.83E+01
Molybdenum	kg	1.92E+02	3.83E+02
Nickel, ion	kg	3.32E+03	6.65E+03
Nitrate	kg	8.91E+04	1.78E+05
Phosphate	kg	6.31E+04	1.26E+05
Potassium, ion	kg	1.56E+06	3.12E+06
Selenium	kg	2.38E+02	4.77E+02
Silicon	kg	1.83E+06	3.67E+06
Sodium, ion	kg	6.10E+05	1.22E+06
Sulfate	kg	2.23E+06	4.45E+06
Thallium	kg	7.03E-01	1.41E+00
Tin, ion	kg	3.30E+03	6.59E+03
TOC, Total Organic Carbon	kg	2.96E+05	5.92E+05
Vanadium, ion	kg	7.28E+02	1.46E+03
Zinc, ion	kg	1.62E+04	3.25E+04
Category: Elementary flows/Emission to water/surface water			
Aluminium	kg	4.61E+02	9.23E+02
Antimony	kg	3.13E-01	6.27E-01
Arsenic, ion	kg	4.99E+02	9.98E+02
BOD5, Biological Oxygen Demand	kg	7.51E+04	1.50E+05
Boron	kg	6.59E+01	1.32E+02
Bromine	kg	3.46E+03	6.92E+03
Cadmium, ion	kg	1.52E-02	3.05E-02
Calcium, ion	kg	2.43E+05	4.87E+05
Chloride	kg	2.11E+06	4.22E+06
Chromium VI	kg	8.21E+01	1.64E+02
Chromium, ion	kg	6.45E-01	1.29E+00
Cobalt	kg	5.16E-01	1.03E+00
COD, Chemical Oxygen Demand	kg	7.67E+04	1.53E+05
Copper, ion	kg	9.70E-01	1.94E+00
DOC, Dissolved Organic Carbon	kg	3.35E+04	6.69E+04
Fluoride	kg	3.62E+04	7.23E+04
Heat, waste	MJ	1.06E+09	2.12E+09
Iodide	kg	3.33E+01	6.67E+01
Iron, ion	kg	7.85E+00	1.57E+01
Lead	kg	7.86E-01	1.57E+00
Magnesium	kg	1.33E+04	2.65E+04

Table 3.32: Incineration LCI of biowaste, continued

Flow	Unit, /year	Alt. A3	Alt. A4
Manganese	kg	3.35E-01	6.69E-01
Mercury	kg	2.31E-01	4.63E-01
Molybdenum	kg	4.14E+01	8.27E+01
Nickel, ion	kg	2.28E+00	4.56E+00
Nitrate	kg	3.19E+04	6.39E+04
Phosphate	kg	1.05E+03	2.09E+03
Potassium, ion	kg	5.90E+05	1.18E+06
Selenium	kg	6.19E+01	1.24E+02
Silicon	kg	5.89E+03	1.18E+04
Sodium, ion	kg	3.07E+05	6.13E+05
Sulfate	kg	3.81E+05	7.61E+05
Thallium	kg	1.17E-03	2.35E-03
Tin, ion	kg	4.49E+00	8.98E+00
TOC, Total Organic Carbon	kg	3.35E+04	6.69E+04
Vanadium, ion	kg	2.74E+00	5.47E+00
Water	m^3	2.07E+05	4.14E+05
Zinc, ion	kg	2.21E+00	4.43E+00

To calculate the land requirement three items from incineration input is considered. One is for incineration facility; another is for slag landfill and the other is for residual landfill. The transformation and occupation data due to road network and traffic in ecoinvent dataset are not taken into consideration as the incineration facility will be adjacent to the landfill area.

Following Tables 3.33 and 3.34 show the process of estimation of land requirement for each facility and final estimated value for this study as per discussed criteria:

Table 3.33: Facilities requirement in biowaste incineration

Item	Municipal waste incineration facility	Slag landfill	Residual material landfill
Land area required for 01 item of each facility, m^2			
Occupation, construction site	1.50E+04	-	-
Occupation, industrial area, built up	1.20E+05	-	-
Transformation, from wetland, inland (non-use)	3.00E+03	3.75E+03	1.80E+04
Transformation, to industrial area, built up	3.00E+03	-	-
Facilities required for 01kg of waste (items) as per ecoinvent	2.50E-10	2.50E-10	5.48E-11
Adjustment in facilities required for 01kg of biowaste (items) due to lower calorific value	5.64E-10	5.73E-10	1.24E-10

Table 3.34: Final estimated land use in biowaste incineration

Item	Alt. A3	Alt. A4
Municipal waste incineration facility		
Occupation, construction site, m^2*a	6.03E+03	1.21E+04
Occupation, industrial area, built up, m^2*a	4.82E+04	9.65E+04
Transformation, from wetland, inland (non-use), m^2	1.21E+03	2.41E+03
Transformation, to industrial area, built up, m^2	1.21E+03	2.41E+03
Slag landfill facility		
Transformation, from wetland, inland (non-use), m^2	1.53E+03	3.06E+03
Residual material landfill facility		
Transformation, from wetland, inland (non-use), m^2	1.59E+03	3.18E+03

In ecoinvent dataset the lower heating value of organic waste is considered as 4.29 MJ/kg. But in this study the calorific value of organic waste is considered 1.9 MJ/kg as per World Bank data. Therefore, low energy value will produce more ash and less energy. So, the incineration facility, slag and residue landfill facility need to be increased with the decrease in calorific value of organic waste. The requirement of these facilities in alt. A3 and alt A4 are therefore calculated by taking this criterion into account.

The diesel required for handling ash from incineration plant to landfill is calculated following the ecoinvent process. It is assumed that landfill and incineration facility will be placed alongside. Therefore, the diesel consumption will start from collecting the waste from incineration plant and placing to landfill. In ecoinvent dataset for incineration the diesel consumption is not provided directly. The ecoinvent dataset for treatment of different waste in unsanitary landfill, very wet infiltration class the diesel consumption for 1kg waste distribution and compaction is given as 0.046738 MJ. This value will be used for this LCA study as Bangladesh falls under very wet category as per ecoinvent and landfill practice is also unsanitary. The calorific value of diesel is 45.5 MJ/kg of diesel. Therefore, for per ton waste handling the diesel consumption will be 1.0272 kg. This unit consumption is multiplied with total residual bottom ash, slag and cement quantity emitted from any incineration process to calculate the diesel consumption for individual processes. The total ash, slag and cement quantity is adjusted according to calorific value of the organic waste.

Table 3.35: Diesel consumption estimation for ash, slag and cement handling from incineration

Item	Ecoinvent	Adjusted value as per calorific value of organic waste	Alt. A3, quantity/year	Alt. A4, quantity/year
Biowaste, kg	1.00E+00	1.00E+00	7.12E+08	1.42E+09
Slag, kg	1.36E-01	3.06E-01	2.18E+08	4.36E+08
Residue, kg	2.46E-02	5.54E-02	3.95E+07	7.90E+07
Cement, kg	9.82E-03	2.22E-02	1.58E+07	3.16E+07
Total ash (Slag + Residue + Cement), kg	1.70E-01	3.84E-01	2.73E+08	5.47E+08
Diesel Consumption	1.0272kg/ton of waste			
kg	1.75E-04	3.94E-04	2.81E+05	5.62E+05

Based on this consumption the diesel burning emissions are calculated. The relevant unit emission is not provided in the ecoinvent incineration process. Hence, the emission from diesel burn is calculated following the same method that is applied for STS and landfill equipment diesel burning emission based on the EMEP/EEA, 2017 guideline for non-road mobile machinery. Equipment category belongs to 1.A.2.g vii (mobile combustion in manufacturing industries and construction) (Winther, et al. 2017). Tier 1 approach is applied. Quantities are provided in Table 3.35. Emissions values are provided in Appendix B.

Net electricity for incineration is calculated differently from the other treatment process. As incineration is a waste to energy (WtE) process, energy will be produced form combustion of waste. Some energy will be required to start the initial ignition process. Also, some energy will be required to run the incineration plant. All these energy requirements are calculated in the form of electricity. Therefore, the net energy produced from incineration process can be written as the net electricity produced. This net electricity will reduce the equivalent amount of electricity produced in natural gas – combined cycle power plant.

The energy produced from waste incineration depends on the calorific value of that waste. In ecoinvent database for incineration of biowaste, the lower heating value of biowaste is provided as 4.289 MJ/kg with 65% moisture content. This heating value and moisture content is obtained from literature reference where the study is conducted on Switzerland. However, this biowaste characteristics will vary in Bangladesh specially in Dhaka as the climatic conditions and other factors that influence waste composition and characteristics like lifestyle, culture is not the same. So much emphasis is placed on heating value as this property is solely responsible for

energy production and the most important indicator of incineration plant efficiency. Also, biowaste is the major waste fraction in Dhaka MSW.

In US, the average heating value of food waste is given as 3.95 MJ/kg of waste with 70% moisture content (Harrison, et al. 2000). The food waste average heat value in Toronto, Canada is 4 MJ/kg as per Assamoi (2012). Finnveden et al. (2000) mentioned that in Sweden the lower heating value (LHV) of 8.4 MJ/kg in biomass. All these data suggest significant variation in biomass heating value. Islam et al. (2016) studied the sewage sludge energy values in raw and coal mixed condition. Sludge sample was taken from Pagla Sewage Treatment Plant (PSTP), Narayanganj, Dhaka. The study reveals that the sewage sludge has LHV of 1.7 MJ/kg in unadulterated condition. According to World Bank, (Rand, Haukohl and Marxen 2000) report for requirement of municipal solid waste incineration, the lower calorific value of food and organic waste is 1.912 MJ/kg with 66% moisture content. JICA, (CDMP 2005) analyzed the MSW of Dhaka in Bangladesh University of Engineering and Technology (BUET) laboratory and found 50.93% moisture content in 2.22 ton generated organic waste collected from different areas of Dhaka and 74.18% in 3.43 ton collected organic waste from Matuail landfill, Gabtoli and Uttara dump site. This data produce a weighted average of approximately 65% moisture content. Considering these above references, data from World Bank report is found closely representative to the characteristics of Dhaka MSW. An adjusted value of 1.9 MJ/kg is adopted for this analysis. The net electricity and net thermal energy production from 1kg biowaste with LHV of 4.289 MJ/kg is given as 0.41 MJ/kg and 1.0041 MJ/kg respectively in ecoinvent. Here net means the remaining energy after using the energy produced from waste for in plant incineration operation. Therefore, both the net energy will change as per the adopted LHV of 1.9MJ/kg. Furthermore, the net thermal energy is converted to net electricity energy with 80% efficiency assumption. Then the net energy in MJ/kg is converted to kWh/kg. This net energy value is then multiplied with total biowaste incinerated to obtain the yearly electricity production. The net value obtained from these above calculations, the emission savings from equal electricity production in power plant is estimated. Net electricity production quantity and LCI values are provided in Appendix B.

3.10.7.2 Graphical Paper Incineration

The incineration of graphical paper is considered in alternative scenarios A2, A3 and A4. All the alternatives have equal quantity as 95% of the waste graphical paper going to landfill is now diverted to incineration and the 5% is assumed to be disposed of landfill. From ecoinvent database, process emission from graphical waste incineration in Switzerland is used for this

study. The lower heating value is given as 14.12 MJ/kg of graphical paper. This value is almost same to other available literature and there is no significant variation found (Kreith and Tchobanoglous 2002, Rezaei, et al. 2020, Rand, Haukohl and Marxen 2000, Assamoi and Lawryshyn 2012). The produced net electricity, net thermal energy, bottom ash, residue and cement for unit graphical paper waste incineration is provided in ecoinvent dataset. Diesel consumption, land requirement and net electricity are calculated by similar processes as biowaste incineration. Diesel and net electricity amount are provided in Table 3.36. The emission data are provided in Appendix B.

Table 3.36: Diesel and net electricity produced from graphical paper incineration

Item	Diesel, kg/year	Net Electricity, kWh/year
Alt. A2, A3, A4	2985.67	30428212

3.10.7.3 Packaging Paper Incineration

LCI of waste packaging paper incineration process is formed similarly as waste graphical paper incineration. Diesel and net electricity amount are provided in Table 3.37 and emission data are in Appendix B.

Table 3.37: Diesel and net electricity produced from waste packaging paper/paperboard incineration

Item	Diesel, kg/year	Net Electricity, kWh/year
Alt. A2, A3, A4	53.43	3866453

3.10.7.4 Plastic Incineration

Plastic incineration has the highest upper and lower heating value of 34.05 MJ/kg and 30.79 MJ/kg as per ecoinvent dataset for plastic incineration. The net electric energy is 3.93 MJ/kg. Net thermal energy is 7.66 MJ/kg which is converted to electricity. Among the combustible waste plastic has the highest potential for incineration. In Table 3.38, the diesel consumption data and net electricity produced from plastic incineration is provided.

Table 3.38: Diesel and net electricity produced from waste plastic (mixed) incineration

Item	Diesel, kg/year	Net Electricity, kWh/year
Alt. A2, A3, A4	4222	299605443

In following Table 3.39, LCI for plastic incineration process data as well as the emission from diesel burning during the incineration process and emissions savings from produced net electricity through the incineration process are provided.

Table 3.39: LCI of waste plastic (mixed) incineration process

Flow	Unit, /year	Alt. A2, A3, A4
Plastic Incineration		
Ecoinvent process: treatment of waste plastic, mixture, municipal incineration with fly ash extraction | waste plastic, mixture | Cutoff, U – CH		
Input		
Category: Elementary flows/Resource/in ground		
Water, unspecified natural origin	m^3	3.94E+05
Category: Elementary flows/Resource/in air		
Oxygen	kg	2.66E+08
Category: Elementary flows/Resource/land		
Municipal waste incineration facility		
Occupation, construction site	m^2*a	4.02E+02
Occupation, industrial area, built up	m^2*a	3.22E+03
Transformation, from wetland, inland (non-use)	m^2	8.04E+01
Transformation, to industrial area, built up	m^2	8.04E+01
Slag landfill		
Transformation, from wetland, inland (non-use)	m^2	1.90E+01
Residual material landfill		
Transformation, from wetland, inland (non-use)	m^2	6.73E+01
Output, due to incineration process		
Category: Elementary flows/Emission to air/high population density		
Aluminium	kg	1.63E-02
Ammonia	kg	1.86E+02
Antimony	kg	3.44E-03
Arsenic	kg	1.49E+00
Barium	kg	7.32E+01
Benzene	kg	1.61E+00
Benzene, hexachloro-	kg	3.37E-03
Benzene, pentachloro-	kg	8.51E-03
Benzo(a)pyrene	kg	3.58E-05
Bromine	kg	3.50E+00
Cadmium	kg	4.14E+00
Carbon dioxide, fossil	kg	2.48E+08
Carbon monoxide, fossil	kg	2.74E+03
Chromium	kg	3.57E+00
Cobalt	kg	5.75E+00
Copper	kg	2.91E+00
Cyanide	kg	2.10E+03
Dinitrogen monoxide	kg	9.78E+03
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	3.22E-06
Heat, waste	MJ	2.66E+09

Table 3.39: LCI of waste plastic (mixed) incineration process, continued

Flow	Unit, /year	Alt. A2, A3, A4
Hydrogen chloride	kg	1.11E+03
Hydrogen fluoride	kg	9.92E+00
Iron	kg	6.68E-01
Lead	kg	3.85E+00
Manganese	kg	1.53E+00
Mercury	kg	2.41E+00
Methane, fossil	kg	2.42E+01
Nickel	kg	2.59E+00
Nitrogen oxides	kg	5.88E+04
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	7.33E+01
Particulates, < 2.5 um	kg	1.92E+02
Particulates, > 2.5 um, and < 10um	kg	9.66E-01
Phenol, pentachloro-	kg	7.01E-04
Selenium	kg	2.51E+00
Sodium	kg	1.20E+03
Strontium	kg	8.86E-01
Sulfur dioxide	kg	1.60E+03
Thallium	kg	4.00E-02
Tin	kg	1.71E-03
Titanium	kg	8.30E+01
Toluene	kg	3.22E+00
Vanadium	kg	6.12E+02
Water/m3	m3	3.66E+05
Zinc	kg	3.75E+01
Category: Elementary flows/Emission to water/ground water, long-term		
Aluminium	kg	1.87E+04
Antimony	kg	1.74E+03
Arsenic, ion	kg	1.16E+02
Barium	kg	1.36E+04
Beryllium	kg	4.70E+01
BOD5, Biological Oxygen Demand	kg	1.65E+05
Bromine	kg	3.63E+02
Cadmium, ion	kg	1.30E+03
Calcium, ion	kg	1.54E+04
Chloride	kg	2.45E+05
Chromium VI	kg	2.16E+02
Cobalt	kg	2.77E+03
COD, Chemical Oxygen Demand	kg	5.03E+05
Copper, ion	kg	2.99E+04
DOC, Dissolved Organic Carbon	kg	1.99E+05

Table 3.39: LCI of waste plastic (mixed) incineration process, continued

Flow	Unit, /year	Alt. A2, A3, A4
Fluoride	kg	9.81E+02
Iron, ion	kg	1.91E+05
Lead	kg	3.29E+04
Manganese	kg	6.34E+03
Mercury	kg	1.78E+01
Nickel, ion	kg	2.02E+03
Nitrate	kg	2.35E+04
Selenium	kg	1.61E+02
Silicon	kg	3.70E+04
Sodium, ion	kg	9.60E+04
Strontium	kg	8.85E+03
Sulfate	kg	3.61E+05
Thallium	kg	3.07E+01
Tin, ion	kg	1.74E+03
Titanium, ion	kg	2.99E+04
TOC, Total Organic Carbon	kg	1.99E+05
Vanadium, ion	kg	8.50E+03
Zinc, ion	kg	2.51E+04
Category: Elementary flows/Emission to water/surface water		
Aluminium	kg	6.83E+00
Antimony	kg	8.45E+02
Arsenic, ion	kg	7.43E+01
Barium	kg	7.92E+00
Beryllium	kg	3.11E-02
BOD5, Biological Oxygen Demand	kg	5.05E+04
Bromine	kg	6.50E+03
Cadmium, ion	kg	1.44E+00
Calcium, ion	kg	2.56E+01
Chloride	kg	1.65E+06
Chromium VI	kg	6.22E+01
Chromium, ion	kg	5.31E-01
Cobalt	kg	5.21E-01
COD, Chemical Oxygen Demand	kg	5.17E+04
Copper, ion	kg	2.75E+00
DOC, Dissolved Organic Carbon	kg	2.25E+04
Fluoride	kg	4.28E+02
Heat, waste	MJ	6.74E+08
Iron, ion	kg	7.19E+00
Lead	kg	3.18E+00
Manganese	kg	9.78E-01
Mercury	kg	4.52E-01
Nickel, ion	kg	1.37E+00

Table 3.39: LCI of waste plastic (mixed) incineration process, continued

Flow	Unit, /year	Alt. A2, A3, A4
Nitrate	kg	8.42E+03
Selenium	kg	4.19E+01
Silicon	kg	8.34E+01
Sodium, ion	kg	4.83E+04
Strontium	kg	5.79E+00
Sulfate	kg	6.16E+04
Thallium	kg	2.84E-02
Tin, ion	kg	2.37E+00
Titanium, ion	kg	2.04E+01
TOC, Total Organic Carbon	kg	2.25E+04
Vanadium, ion	kg	3.35E+01
Water	m^3	1.35E+05
Zinc, ion	kg	3.42E+00
Output, due to diesel burning emissions		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	3.38E-02
Cadmium	kg	4.22E-05
Carbon dioxide, fossil	kg	1.33E+04
Carbon monoxide, fossil	kg	4.55E+01
Chromium	kg	2.11E-04
Copper	kg	7.18E-03
Methane, fossil	kg	3.50E-01
Nickel	kg	2.96E-04
Nitrogen oxides	kg	1.39E+02
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.43E+01
PAH, polycyclic aromatic hydrocarbons	kg	1.40E-02
Particulates, < 2.5 um	kg	2.33E+01
Particulates, > 2.5 um, and < 10um	kg	8.88E+00
Selenium	kg	4.22E-05
Sulfur dioxide	kg	4.22E+00
Zinc	kg	4.22E-03
Savings from reduced electricity production that is added by incineration process		
Input		
Category: Elementary flows/Resource/in water		
Water, cooling, unspecified natural origin	m^3	-1.50E+07
Output		
Category: Elementary flows/Emission to air/high population density		
Acenaphthene	kg	-2.01E-03
Acetaldehyde	kg	-2.03E+00
Acetic acid	kg	-3.07E+02
Arsenic	kg	-1.04E-01

Table 3.39: LCI of waste plastic (mixed) incineration process, continued

Flow	Unit, /year	Alt. A2, A3, A4
Benzene	kg	-2.29E+00
Benzo(a)pyrene	kg	-1.34E-03
Beryllium	kg	-6.26E-03
Butane	kg	-2.35E+03
Cadmium	kg	-5.73E-01
Carbon dioxide, fossil	kg	-1.37E+08
Carbon monoxide, fossil	kg	-5.57E+03
Chromium	kg	-7.27E-01
Cobalt	kg	-4.36E-02
Dinitrogen monoxide	kg	-2.48E+03
Ethane	kg	-3.47E+03
Formaldehyde	kg	-8.18E+01
Hexane	kg	-2.01E+03
Lead	kg	-2.61E-01
Manganese	kg	-1.98E-01
Mercury	kg	-1.74E-01
Methane, fossil	kg	-2.46E+03
Nickel	kg	-1.09E+00
Nitrogen oxides	kg	-6.46E+04
PAH, polycyclic aromatic hydrocarbons	kg	-2.03E+01
Particulates, < 2.5 um	kg	-1.24E+03
Pentane	kg	-2.91E+03
Propane	kg	-1.79E+03
Propionic acid	kg	-4.05E+01
Selenium	kg	-1.24E-02
Sulfur dioxide	kg	-1.45E+03
Toluene	kg	-3.80E+00
Category: Elementary flows/Emission to air/unspecified		
Water/m^3	m^3	-2.49E+05
Category: Elementary flows/Emission to water/unspecified		
Water/m^3	m^3	-1.52E+07

3.10.7.5 Textile Incineration

In ecoinvent, the higher and lower heating value for textile are provided as 19.78 MJ/kg and 14.45 MJ/kg respectively. The total net electric energy and thermal energy quantity is provided in Table 3.45. Detailed emission LCI data is provided in Appendix B.

Table 3.40: Diesel and net electricity produced from waste textile incineration

Item	Diesel, kg/year	Net Electricity, kWh/year
Alt. A2, A3, A4	1141	26699806

3.10.7.6 Glass Incineration

Glass incineration is recommended for recycling or landfill by ecoinvent database as the heating value is 0.1423 MJ/kg and the lower heating value is 0.04602 MJ/kg which is very low for incineration. However, for this study 95% of glass that is going to landfill in baseline scenario is considered for incineration in alternative scenarios like the other combustible materials. Emission LCI is provided in Appendix B. Table 3.47 shows the net electricity production and diesel consumption value in the incineration process.

Table 3.41: Diesel and net electricity produced from waste glass incineration

Item	Diesel, kg/year	Net Electricity, kWh/year
Alt. A2, A3, A4	15869	29697

3.10.8 Other Process LCI

Other LCI processes include the waste going to drain, khals, rivers and unserved areas. These are not within the scope, so these are just kept as dummy processes.

3.11 LCIA

The next step is piloting the impact assessment of scenarios. For impact assessment a suitable method is selected based on the following discussion:

3.11.1 Selection of LCIA Method

For this LCA study with openLCA software, the ReCiPe2016, Midpoint and Endpoint, Hierarchist LCIA methods are followed. There are multiple reasons behind this choice.

i. ReCiPe is designed for both midpoint and endpoint categories so the midpoint results will be in harmony with the endpoint results as the characterization factors are weighted accordingly.
ii. In endpoint, the damage to human health and ecosystems can be determined.
iii. If compared with other LCIA methods, ReCiPe2016 is a state-of-the-art method than most other methods and it covers major categories in midpoint which is only limited to a few categories in some other methods.
iv. It is an improved version of the ReCiPe2008 which can be adapted for a broader range of pollutants. Also, the pathway is more organized than the previous versions.
v. Its hierarchist version is suitable for comparative analysis for implication of certain technologies within reasonable timeframe as it is based on most common policy principles with regards to time frame.

Although there are number of limitations, it is suitably balanced for comparative analysis. COD and BOD5 is added as per ReCiPe 2008 method report by Goedkoop, et al. (2013). COD marine eutrophication characterization factor is added as 0.05 kg N equivalent/kg. BOD5 is assumed to be 50% of COD which is the theoretical thumb rule. Therefore, the characterization factor of BOD5 is assumed to be 0.025 kg N equivalent/kg.

3.11.2 LCIA Categories

Midpoint categories used in this LCIA are: 1) Fine particulate matter formation, 2) Freshwater ecotoxicity, 3) Freshwater eutrophication, 4) Global warming, 5) Human carcinogenic ecotoxicity, 6) Human non-carcinogenic ecotoxicity, 7) Land use, 8) Martine ecotoxicity, 9) Marine eutrophication, 10) Ozone formation, Human health, 11) Ozone formation, Terrestrial ecosystems, 12) Stratospheric ozone depletion, 13) Terrestrial acidification, 14) Terrestrial ecotoxicity, 15) Water consumption.

At endpoint, global warming is divided into three subcategories: 1) Freshwater ecosystems, 2) Terrestrial ecosystems, 3) Human health. The first two divisions are assigned to estimate the impacts on species on water and land separately. The third one is the impact on human life. Also, water consumption is divided in three subcategories- i) Aquatic ecosystems, ii) Human health, iii) Terrestrial ecosystem.

Some categories like fine particulate matter formation, human carcinogenic and non-carcinogenic toxicity, tropospheric ozone formation (human health) have direct impact on human health, but their pathways are not known to have impact on species loss. Therefore, these categories are only considered for impact on human health. Other categories impacting the environment and ecosystem are considered as responsible for species loss.

3.12 Data Structure in openLCA

openLCA offers great control over LCA study. It is possible to change data structures, elements, process, parameters or projects that can be applied with immediate effect, if the LCA model is formed properly. The analysis with openLCA starts with the creation of a new database named “Dhaka_MSW”. Therefore, Ecoinvent LCI Cutoff database version 3.8 is imported under this database and then modified as per necessity. LCA software follows certain data structures to form an LCA model. In openLCA the data structure can be categorized in various layers as per modelling steps. A flow chart of data structure is shown in Figure 3.16. The process starts with definition of unit, flow properties, indicators, parameters, and other

technical parts necessary to form a flow. Flow is used to create processes and then processes are structured by LCI inputs and outputs. Final steps involve the impact analysis which can be conducted on individual process, product system or project report analysis stage. From the above shown data structure flow chart only the steps and features necessary to model this LCA study are discussed in the following sections.

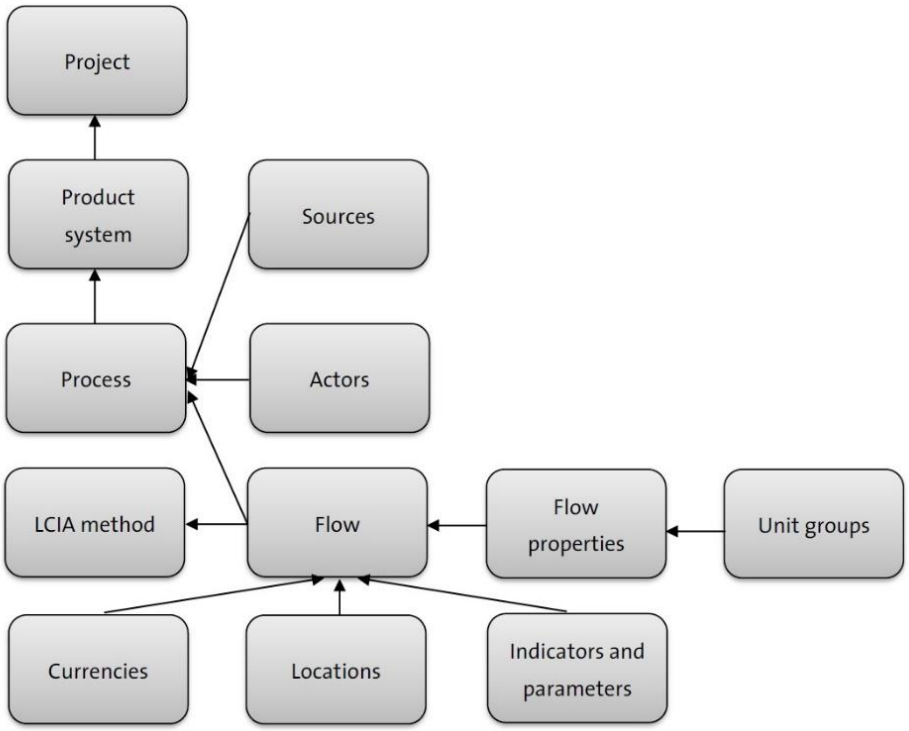


Figure 3.16: Data structure of openLCA modelling (Ciroth, et al. 2020)

3.12.1 Unit Groups

Unit groups are basic units for various quantity measurements like weight, distance, area, number of items, volume, energy etc. For this LCA study no new unit is created. The unit groups are found under “Background data” of the navigation panel on the left in openLCA software.

3.12.2 Flow Properties

Flow properties are basic technical and economic properties that are the property of a material or process. For example: Area, Volume, Items*Length, Mass*Time etc. For this study only technical flow properties are used as per necessity and no new flow is generated.

3.12.3 Flow

Flows are items, products or services on which processes are built up. For this LCA the necessary flow is created and process is created using these flows. Flows are also used to link

up among processes. Each flow should be defined according to their flow properties like mass, volume, time etc. There are many defaults flow in openLCA as well as ecoinvent database in various categories. These flows are named in a way that they match the way it is described in impact characterization of LCIA methods.

3.12.4 Process Buildup

Process is the system where certain input materials/flow is given as input to produce certain materials as output with their corresponding emissions. For this study a child category is created named "SWM Dhaka". Then this category is divided into combined, DNCC and DSCC SWM sub-categories. Under "Combined SWM" the scenarios' (Baseline, Alt. 01, Alt. 02 etc.) folders are created. On each scenario the processes related are created with their reference flow. For example, 'Biowaste Landfilling' process is created with flow "Biowaste, Landfilled" as reference. Therefore, the input and output data are provided to form the process. Figure 3.17 shows a snap from the openLCA software with process folder and name at the left side on the navigation panel and on the middle to right side the main input and output window is shown for the selected process on the left.

For processes where ecoinvent default dataset is not used like transportation and landfill maintenance the pollutants flows categorized in openLCA or ecoinvent database is used and the value is provided according to the LCI analysis. The data obtained from ecoinvent has the flow categorized in the way it is described in impact characterization. So, not much editing was necessary. Some waste outputs which have the probability to be linked with default process provider in ecoinvent when running LCIA operation, like municipal solid waste, hazardous waste from recycling, are omitted as almost all these types are beyond the scope of this study. If necessary, these can be used by defining new flows if it is necessary to avoid linkage with its upstream waste producing process. All the processes under a scenario are linked up with final scenario process. Figure 3.18 shows the linked inputs from other processes that formed alternative scenario A1.

In this study, Microsoft excel is used processing data with formula, keeping backup, pasting, and exchanging data with processes inputs and outputs.

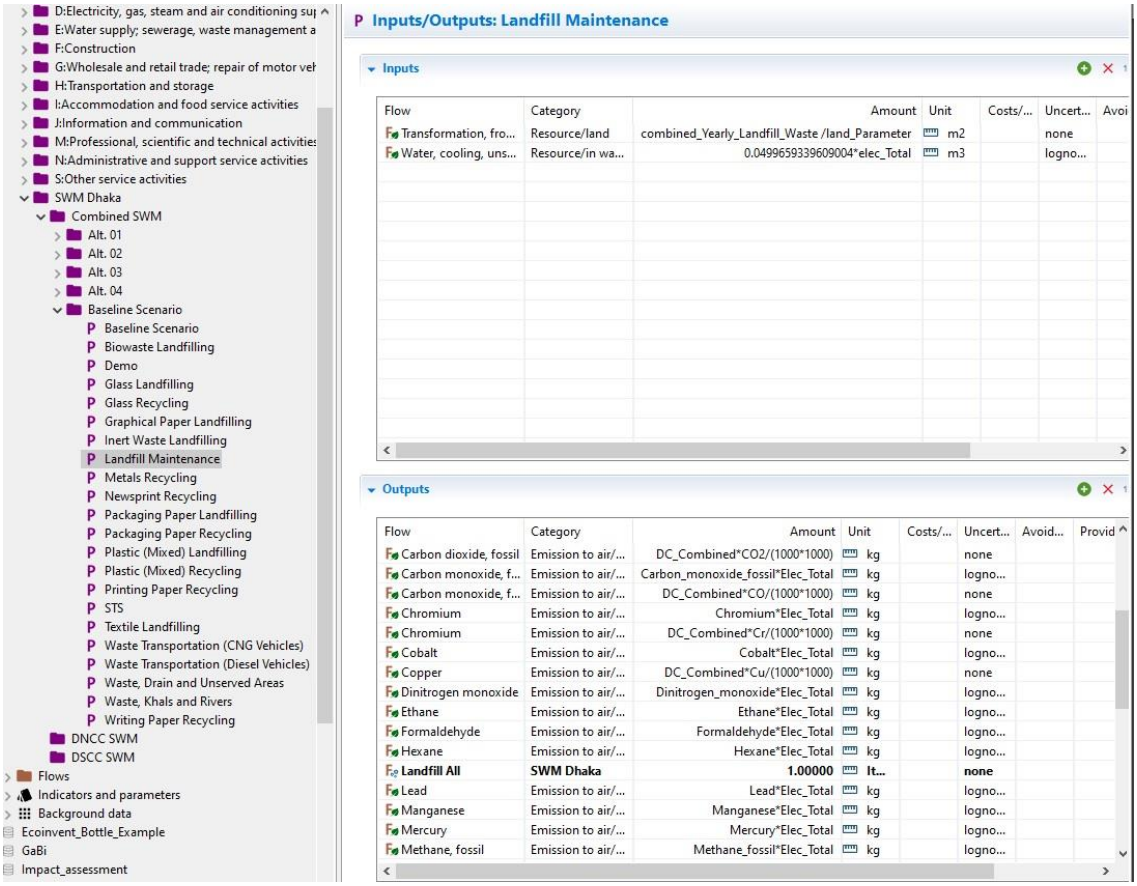


Figure 3.17: LCI formation by input and output of a process

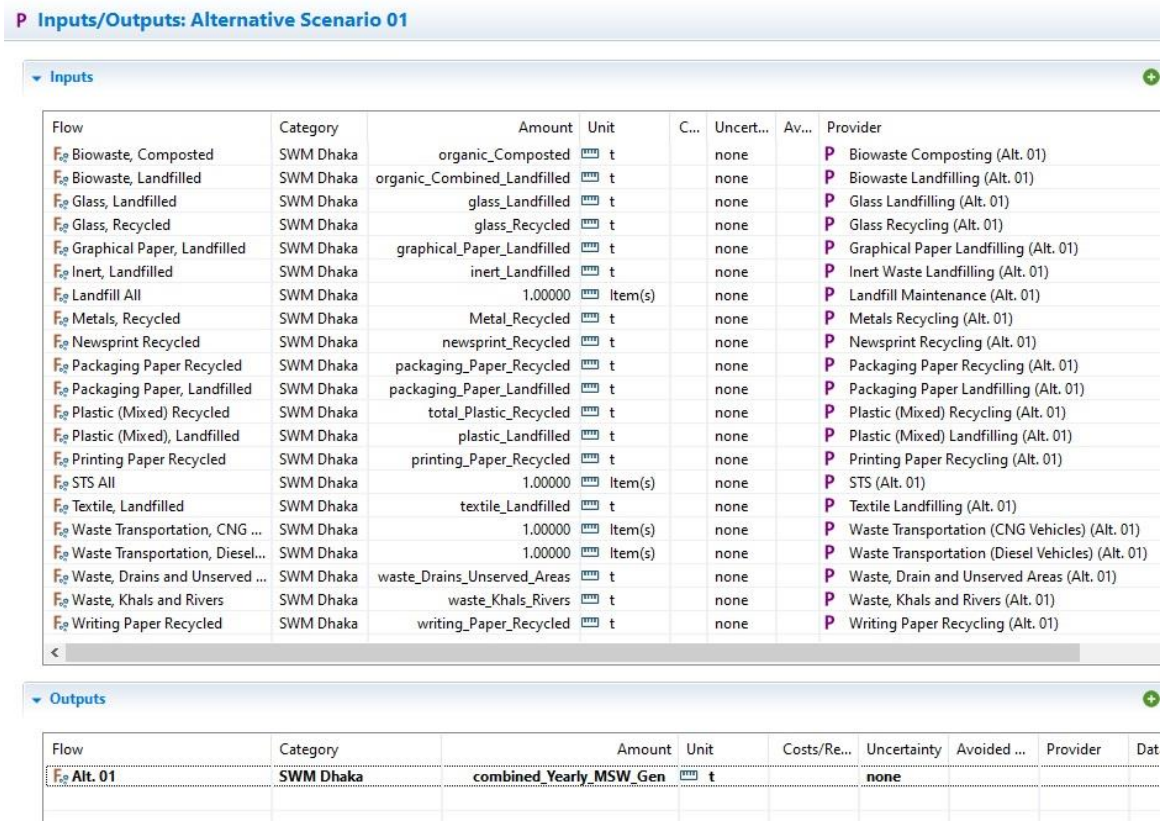


Figure 3.18: Linking the processes to final scenario

3.12.5 Product System

The product system combines the process networks that are necessary to calculate the inventory results and impact assessment. LCIA operation can be run directly for individual process or in product system. In a product system the target amount of functional unit can be changed. In this study as all the process is custom made, these are linked to their default providers and system process is created. The model graph is generated as per process link and providers. Processes are linked automatically. Calculate button is the option for running LCIA. Figure 3.19 shows the model graph for baseline scenario.

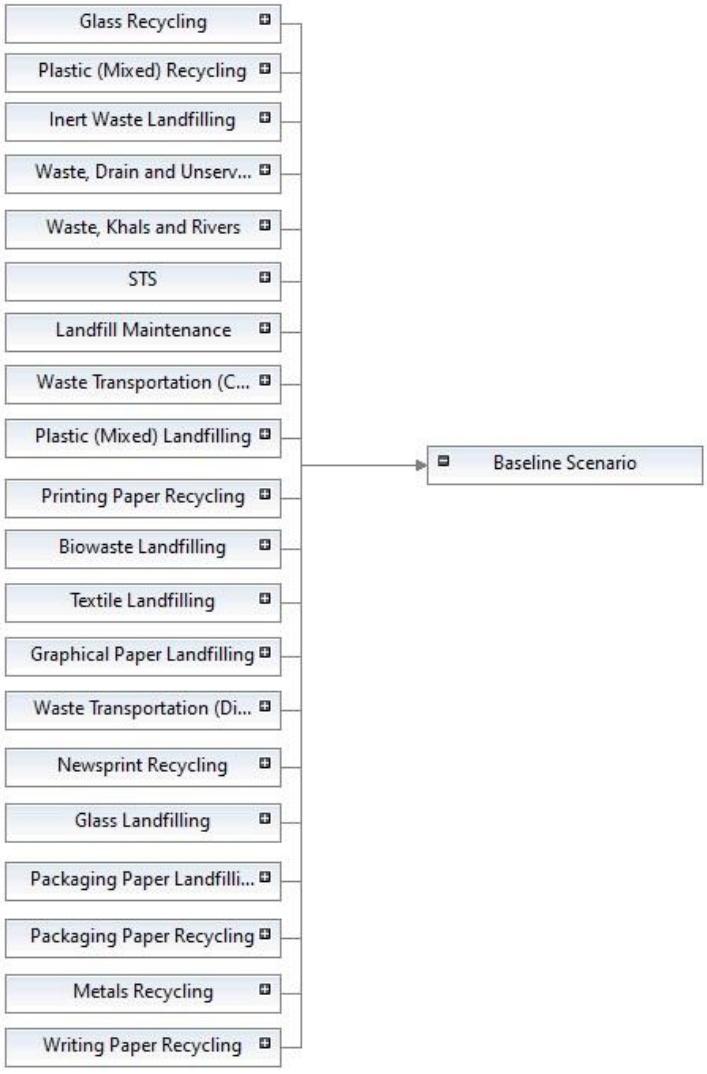


Figure 3.19: Model graph formation in product system of a scenario

3.12.6 Project

Project is created to compare between product systems. On project LCIA is run on different product systems with necessary impact categories as per requirement. In this study “Dhaka

SWM LCA Project" is created under which all the scenarios are included and run for impact analysis. Report shows the results of LCIA. All the impact variants value is provided on the report by summing the burden from the individual processes in a product system. Then the result is compared. In openLCA it is possible to view dynamic single indicator results. A sample project window is shown in Figure 3.20.

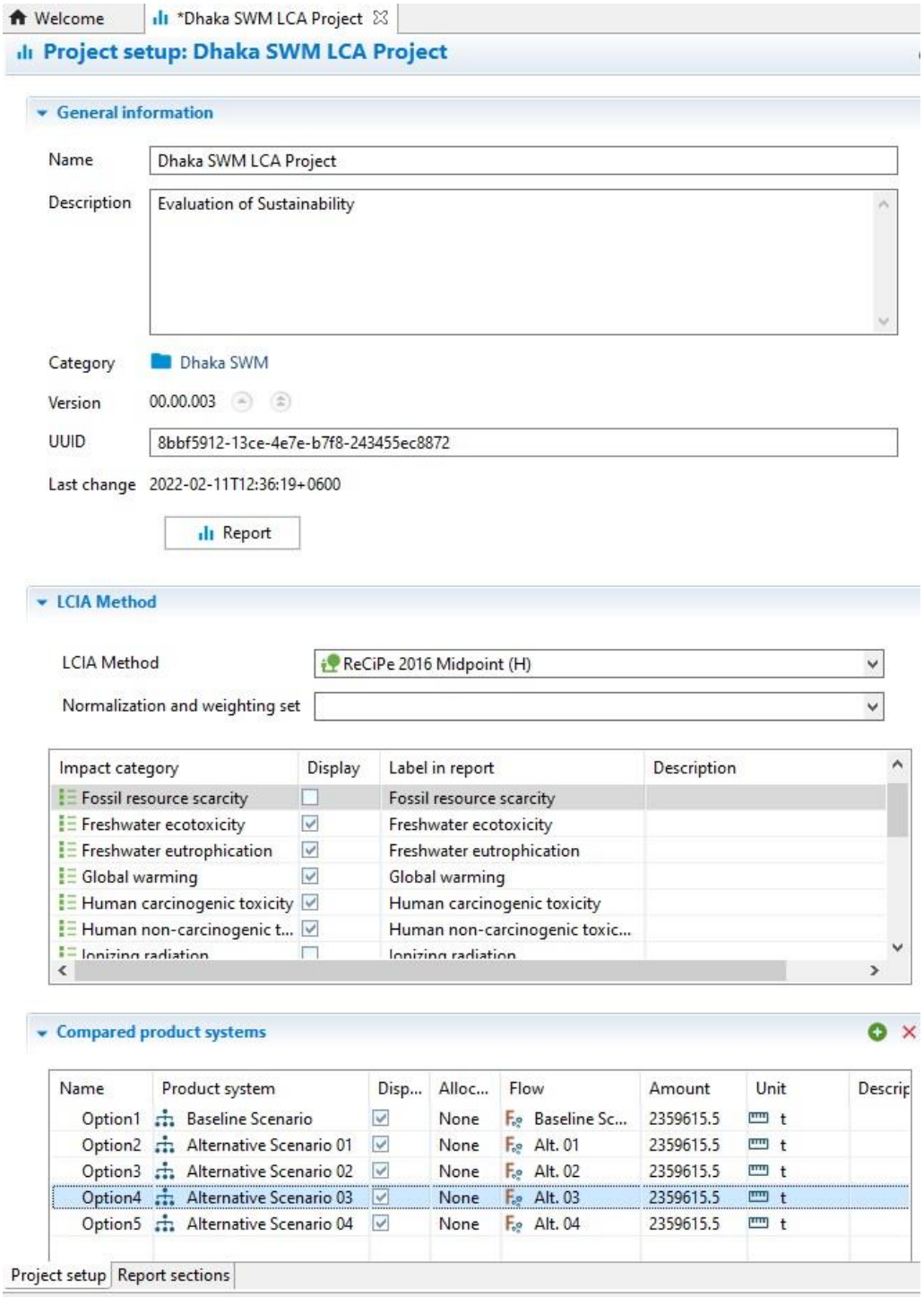


Figure 3.20: Project setup in openLCA

3.12.7 Parameters

There are three types of parameters which are very useful to use, especially when conditions like waste quantity, waste vehicles nos., different waste percentage etc. can vary and result or LCA will change accordingly. It may not be feasible all the time to change all dependent values when these data changes. Therefore, parameters are created, and these are integrated with the emissions value as formula in processes so that one change in a parameter will change all the data depending on it. There are three types of parameters available in openLCA. Three types of example parameters defined in this study is enlisted in the below Table 3.42:

Table 3.42: Different parameters example used for LCA

Name	Value	Unit	Type
Combined_Yearly_MSW_Gen	2359569	ton/year	Global
Organic_Combined_Landfill_Fraction	0.62	fraction	Process- Input
Organic_Combined_Landfilled	combined_Yearly_MSW_Gen *Organic_Combined_Landfill_Fraction	ton/year	Process-Dependent
	1468725	ton/year	

Here, the global parameter combined MSW quantity generated is defined globally by value and this data is available to use anywhere in the database. The organic combined waste landfill fraction is necessary for calculation of organic waste landfill quantity only. Therefore, the fraction is defined in process parameter. The total yearly organic waste landfill quantity is dependent to the fraction of organic waste and total quantity of MSW generated. Therefore, it is defined as dependent parameter where the formula combines a global and local process parameter. Throughout this whole LCA study parameters are created when it is applicable. The basic hierarchy for parameters is shown in Figure 3.21 below:

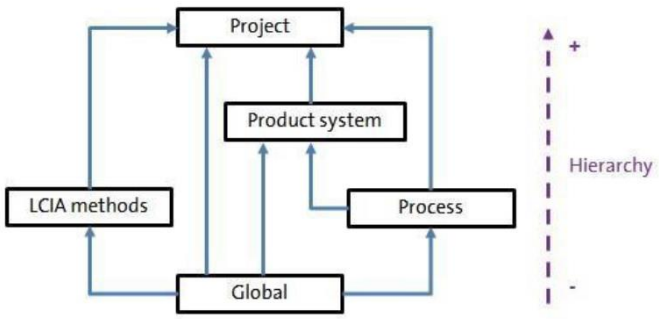


Figure 3.21: Hierarchy of parameter (Ciroth, et al. 2020)

3.12.8 Impact Assessment

Impact assessment has several tabs. In the general information tab, the top five contributing process under a scenario in a particular pollution category is shown graphically. The next tab shows the inventory results, where it is possible to check whether the LCA is done according to the intended quantity of waste in different processes. Impact analysis tab is the detail impact analysis result chart for different impact categories showing pollutants and their quantity, impact factor and contribution in the specific impact category. The results are extracted from product systems LCIA and project LCIA report.

It is possible to run impact assessment operation in quick mode and detail analysis mode. Quick mode takes less time and offers only the basic assessment data. The advanced options provided in details analysis are process details, contribution tree and Sankey diagram. On the process results, both the direct and the total upstream contributions are displayed. This analysis will be run on final scenarios processes. All the processes of landfilling, recycling and others are linked to the final scenarios. Therefore, there will be no direct emission on the final scenarios, but total emission is the summation from all linked processes. The contribution tree breaks down the final scenarios to different process contributions in certain impact categories. Sankey diagrams provide contribution of several processes under a scenario graphically.

Chapter 4
RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the life cycle impact assessment result is demonstrated through detailed analysis of different scenarios and components of Dhaka MSWM in different pollution categories. Graphical representation from openLCA software is used to analyze the environmental burdens

4.2 Comparison of Combined Scenarios: Baseline B0 vs. alt. A1 vs. A2 vs. A3 vs. A4

4.2.1 Midpoint Overall Analysis Result

The midpoint environmental burden of baseline and alternative scenarios are analyzed by ReCiPe2016 Midpoint Hierarchist LCIA method. The results from different pollution categories are shown in Table 4.1 with their respective values.

Table 4.1: LCIA result of baseline and alternatives in various midpoint categories

Indicator	Unit	B0	A1	A2	A3	A4
Fine particulate matter formation	kg $PM_{2.5}$ eq	1.11E+04	-9.49E+06	-9.49E+06	-4.73E+06	2.64E+04
Freshwater ecotoxicity	kg 1,4-DCB*	3.14E+07	2.00E+07	1.47E+07	2.02E+07	2.58E+07
Freshwater eutrophication	kg P eq	7.00E+04	2.39E+03	2.31E+03	2.35E+04	4.47E+04
Global warming	kg CO2 eq	1.18E+09	1.57E+08	1.49E+08	7.83E+07	7.72E+06
Human carcinogenic toxicity	kg 1,4-DCB	1.21E+06	4.09E+05	2.65E+06	5.90E+06	9.14E+06
Human non-carcinogenic toxicity	kg 1,4-DCB	1.03E+09	5.48E+08	3.18E+08	5.67E+08	8.17E+08
Land use	m^2a crop eq	3.84E+05	2.45E+05	2.13E+05	1.57E+05	1.00E+05
Marine ecotoxicity	kg 1,4-DCB	4.26E+07	2.69E+07	1.95E+07	2.70E+07	3.44E+07
Marine eutrophication	kg N eq	9.78E+06	-5.56E+06	-8.77E+06	-4.12E+06	5.30E+05
Ozone formation, Human health	kg NOx eq	4.83E+03	6.57E+04	1.12E+05	1.91E+05	2.69E+05
Ozone formation, Terrestrial ecosystems	kg NOx eq	-5.73E+03	5.58E+04	1.01E+05	1.79E+05	2.58E+05
Stratospheric ozone depletion	kg CFC11 eq	-5.07E+00	3.86E+02	7.17E+02	9.19E+02	1.12E+03
Terrestrial acidification	kg SO2 eq	1.43E+04	-7.76E+07	-7.76E+07	-3.88E+07	5.78E+04
Terrestrial ecotoxicity	kg 1,4-DCB	-3.51E+06	-5.21E+05	1.28E+08	1.41E+08	1.54E+08
Water consumption	m^3	-5.82E+06	-5.28E+07	-7.04E+07	-5.16E+07	-3.28E+07
*DCB = Dichlorobenzene						

Individual pollutants emissions are multiplied with their corresponding characterization factor. Each pollution category has a specific unit which is used to commonly express all the different burden in a single unit. Therefore, multiplying with the characterization factor converts the pollutants emissions to a common expressible unit so that all the emissions can be calculated in the same unit for that specific category. This conversion is done for every process under a scenario to estimate the process environmental burden for that impact category. Then all these burdens from different processes under that scenario are accumulated to calculate the net impact value of that scenario in that certain impact category. Similarly, this process is followed for other scenarios and impact categories and following values are obtained.

Now these values here have positive and negative signs. Here, positive sign means the addition of this impact to the environment which means responsible for pollution whereas negative means savings in environmental pollution. There is no single scenario that is the worst in all categories. There has been wide variation among the least desirable and most expected strategy if compared in all categories. It is rather better to express these data graphically so that a rational strategy for Dhaka city MSWM can be determined.

In Figure 4.1 the midpoint categories results are demonstrated in a clustered column chart. For each category all the scenarios are clustered. The maximum positive or negative emission value among scenarios for a certain category is taken as 100%. Then the rest of the scenarios are expressed in percentage of this maximum fraction. When pollution/stress occurs, the value lies in the positive Y-axis and when the emission value is negative (which is reduction in environmental burden) the value lies in negative Y-axis.

Similarly, each scenario is placed depending on its corresponding side from zero line and their order of analysis. For example, in freshwater ecotoxicity, all the scenarios have positive value, hence polluting the environment. Now, baseline B0 scenario has the highest value of 3.14E+07 kg 1,4-DCB. Now, this is assumed 100% or maximum and other scenarios impacts are expressed in both direction (pollution and savings / positive and negative burden) with respect to this maximum value as its percentage. Since there is no negative value on other scenarios, nothing falls under the zero line. Alternative A1, A2, A3 and A4 are 63.68%, 46.61%, 64.26% and 81.92% of the maximum baseline 100% value of 3.14E+07 kg 1,4-DCB. Another example is the burden graph for marine eutrophication. Alt. A1, A2, A3 have negative value and the baseline B0 with alt. A4 lies above the zero line. Among these, baseline has the highest value. So, the other scenarios saving, and burden percentages are calculated with respect to the baseline scenario.

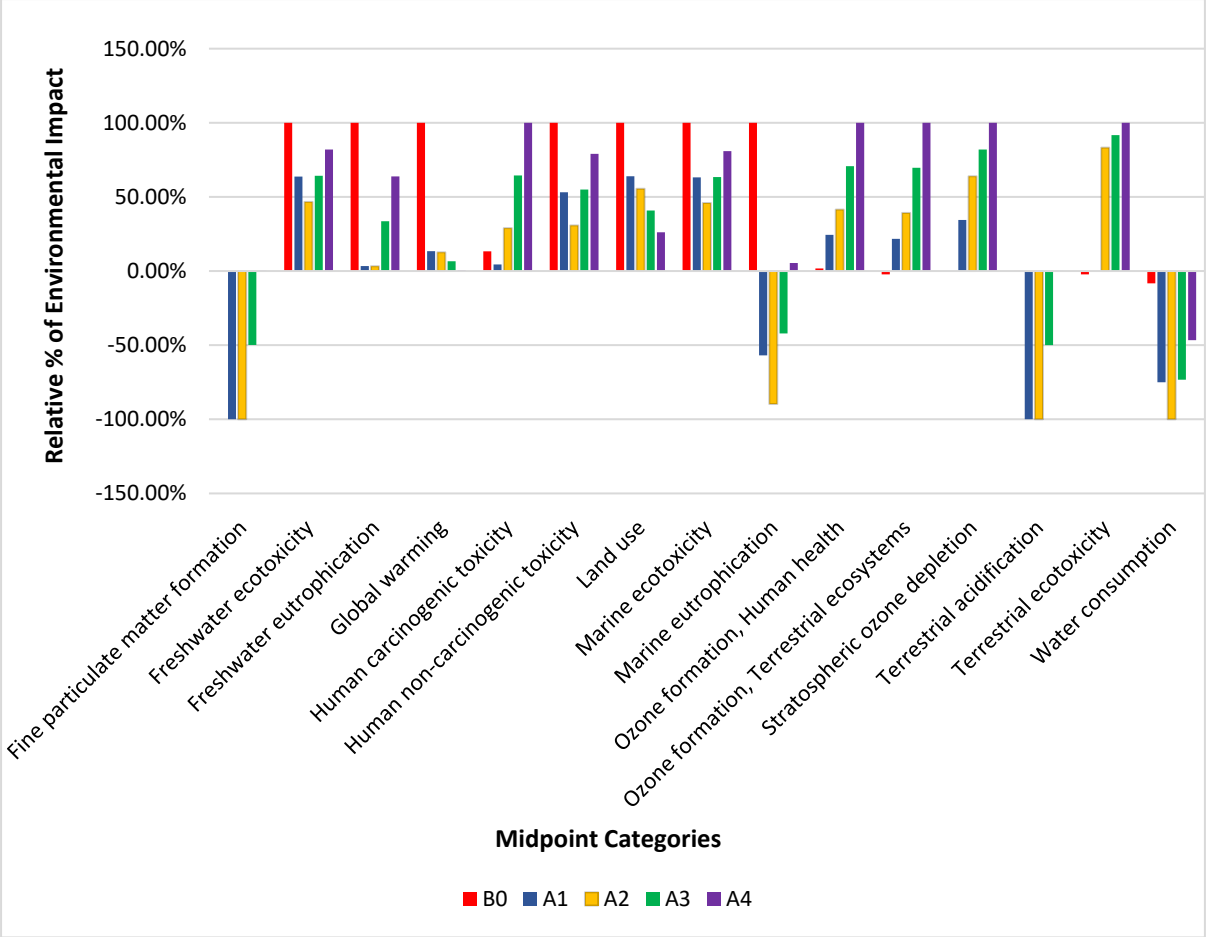


Figure 4.1: Relative result of different scenarios in various midpoint impact categories

In most categories the alternative scenario A2 has the highest value of savings rather than other scenarios. From the above graph, it is also clear that comparison among alternative A1, A2 and A3 is difficult from overall pollution or environmental burden perspective as their rank varies in different scenarios. Therefore, it is convenient to discuss these impact categories separately and find the suitable strategy respectively. The impact values along with their graphical demonstration are discussed in the following sections.

4.2.2 Midpoint Impact Analysis Result of Various Categories

4.2.2.1 Fine Particulate Matter Formation

In this category, kg equivalent particulate matter size less than 2.5 µm produced or saved is the analysis parameter. Both baseline and alternative A4 have positive burden value whereas other alternatives have negative environmental burden. Among them, alternative A1 and A2 have the same and highest savings in environmental burden. Alternative A3 burden saving value is almost as half as alternative A1 and A2. Therefore, alternative scenarios A1 and A2 are the two

most environmentally friendly condition. Comparison among scenarios is graphically presented in Figure 4.2.

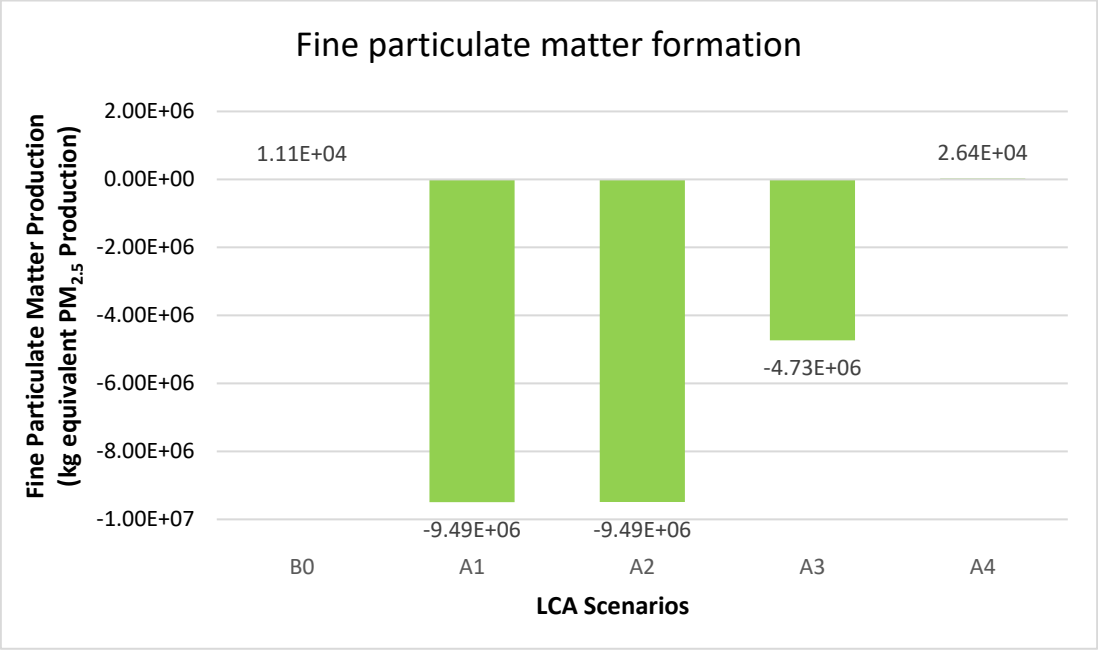


Figure 4.2: kg equivalent $PM_{2.5}$ production burden from baseline and alternatives

The main responsible pollutants are sulfur dioxide, nitrogen oxides, ammonia and all the particulate matter that is less than 2.5 µm in size. In baseline B0 scenario, the emission from biowaste landfilling and landfilling contributes mostly to the particulate matter formation. There are some savings from plastic recycling process, but it is not enough to suppress the positive environmental burden which causes pollution. Similarly, in alternative scenario A4 the positive emission from biowaste incineration is far greater than the savings from plastic recycling.

In alternative scenario A1, A2 and A3 biowaste composting process produced organic fertilizer. This organic fertilizer reduced urea use in the crop field. As a result, the ammonia volatilization to air occurred from using urea in crop fields is reduced. Due to this ammonia reduction, the formation of particulate matter in air is greatly saved. Therefore, saving the environment from potential pollution. Major process contributors in each scenario are shown in Appendix D.

4.2.2.2 Freshwater Ecotoxicity

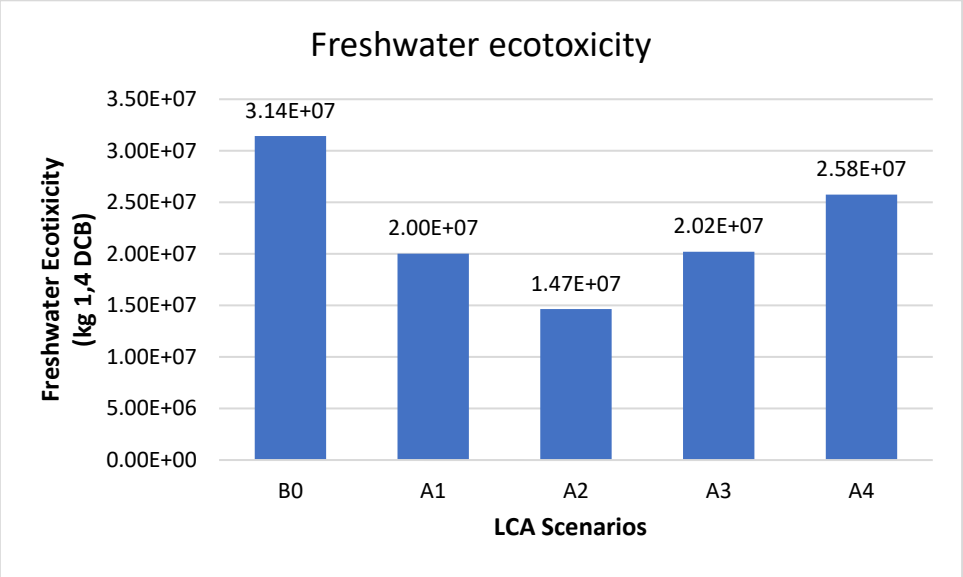


Figure 4.3: Fresh water ecotoxicity value of baseline and alternatives in kg 1,4 DCB

Metal ions like zinc, copper, nickel etc. are the main stressors which is emitted to water for long term. All the scenarios pollute the environment in this category as they add positive burden to the environment as shown in Figure 4.3. Baseline scenario has the highest value due to biowaste and plastic landfilling as this process emit metals ions responsible for ecotoxicity. The least burden is calculated on alternative scenario 02 where the emission is majorly occurred by plastic incineration process. So, in this category alternative 02 is the most suitable choice. Other alternatives burden in this category is governed by plastic landfilling, plastic and biowaste incineration.

4.2.2.3 Freshwater Eutrophication

Phosphate and phosphorus are the main stressors causing eutrophication to freshwater found in this LCA. The amount of phosphate emission from biowaste landfilling in baseline scenario is way higher than other scenarios as demonstrated in Figure 4.4.

Very little is emitted from 3% of total organic waste that is landfilled in alternative A1 and A2. Due to reduction in landfilling of other wastes in alternative A2 the net positive burden becomes the lowest. Biowaste incineration then again increased the pollution in alternative A3 and A4. Phosphate emission can pollute the ground water in both short and long periods. Also, emission of phosphorus and phosphate causes pollution in surface water.

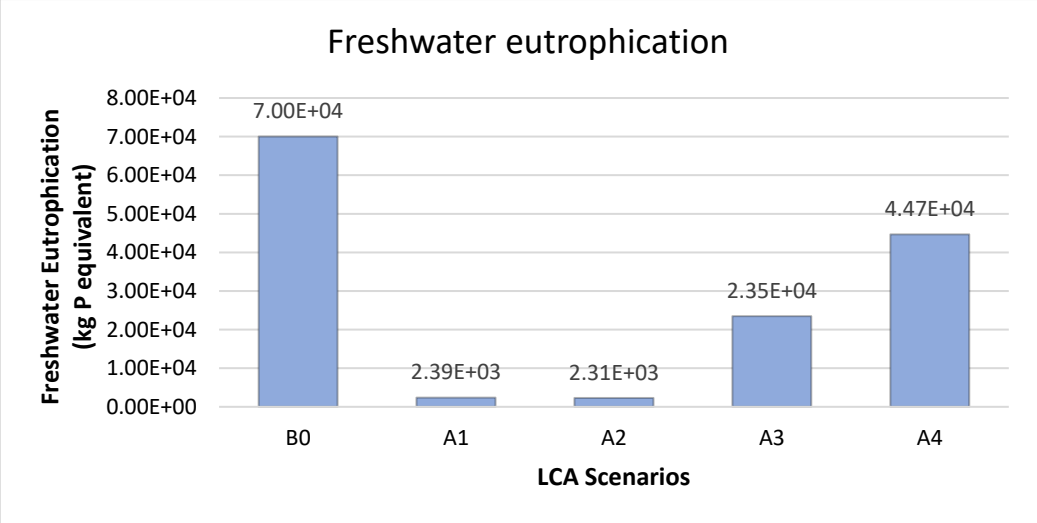


Figure 4.4: Freshwater eutrophication from baseline and alternatives, kg P equivalent

4.2.2.4 Global Warming

Baseline scenario emits the most GHGs among all. Biogenic methane gas emission from biowaste landfilling is the main stressor in baseline scenario. Therefore, the current practice can be considered as the worst in this category. From the remaining scenarios, alternative A4 has the least emission of GHGs.

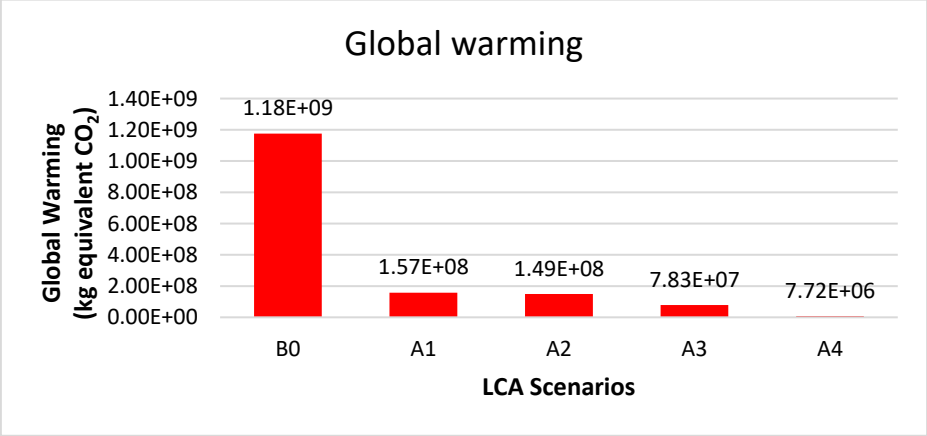


Figure 4.5: Global warming potential of different scenarios expressed in kg equivalent CO_2

In baseline scenario, methane emissions from biowaste landfilling are mainly responsible for global warming. In alternative A4, the GHGs emission from plastic incineration and biowaste landfilling are mostly responsible for emission whereas incineration of biowaste, graphical paper and recycling of plastic and newsprint contribute to reduction in GHGs resulting the lowest net value of global warming potential. In alternative scenario A1, most contribution comes from graphical paper landfilling and biowaste composting and landfilling. Also, there are reductions in GHGs from plastic and other materials recycling.

In alternative A2, the GHGs are emitted mostly from plastic incineration and biowaste composting. Due to 95% reduction of graphical paper, textile, and plastic landfilling quantity in alternative A2 than alternative A1, the contribution from these waste landfilling mostly curtailed, and the net emission becomes marginally lower than alternative A1. In alternative scenario A3, everything remained same as alternative A2 except the GHGs emissions from biowaste composting as the composting quantity becomes half the quantity in alternative A2. Also, biowaste incineration contributes to the reduction in GHGs emissions causing a net global warming potential value almost half as alternative A2. Alternative A4 is the most suitable option obtained from the analysis in this category.

4.2.2.5 Human Carcinogenic Toxicity

Carcinogenic toxicity is responsible for causing cancer in the human body. The main stressors are chromium VI, nickel and arsenic ion as these elements are responsible for causing cancer. Biowaste, plastic, glass and graphical paper landfilling causing emission of these elements in groundwater for long term. But the emission is more intense in plastic incineration. So, the emission is lowest in alternative A1 where no incineration occurs. Pollution is gradually increased in alternative A2, A3 and A4 with the increase in waste incineration quantity. Incineration emits pollutants to not only in ground water in the long term but also in surface water with short term effect. Toxicity is expressed in kg equivalent to 1,4 dichlorobenzene or in short 1,4-DCB.

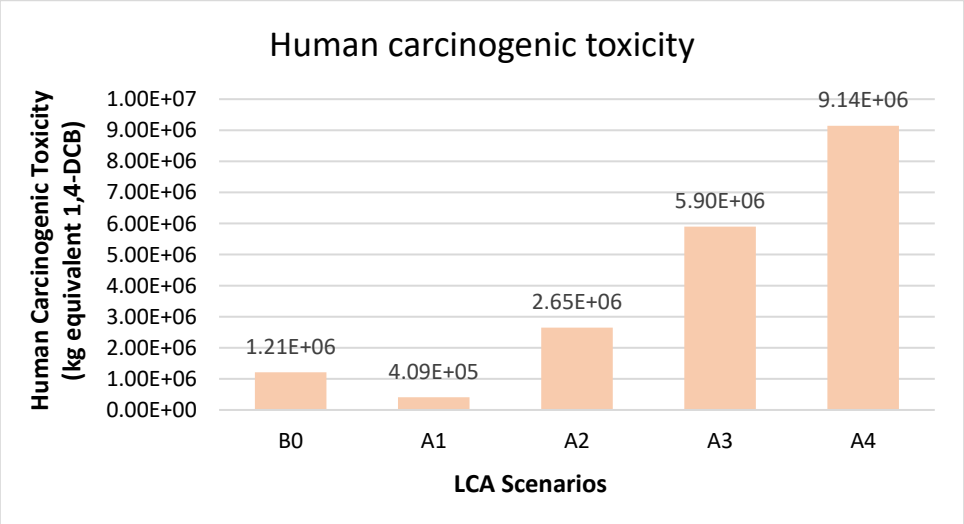


Figure 4.6: Human carcinogenic toxicity in kg equivalent 1,4-DCB

4.2.2.6 Human non-Carcinogenic Toxicity

In this category, pollution caused by the baseline scenario B0 is the highest. The main stressors behind toxicity are ionized and neutral forms of zinc, arsenic, lead, barium, cadmium which are mostly emitted to ground water in long term from biowaste and plastic landfilling. As landfilling is highest in baseline, the emissions are also highest in baseline. In other scenarios, the quantity varies according to the amount of landfilled waste. In alternative scenarios A2, A3 and A4 biowaste and plastic incineration emits metal ions causing toxicity in groundwater, but it is not as acute as landfilling. Alternative A1 scenario has higher quantity of landfilling than A2, but no incineration occurs, therefore pollution is higher than alternative A2. As the incineration increases in alternative A3 and A4 the pollution again rises from alternative A2. In this category alternative A2 is the most suitable alternative.

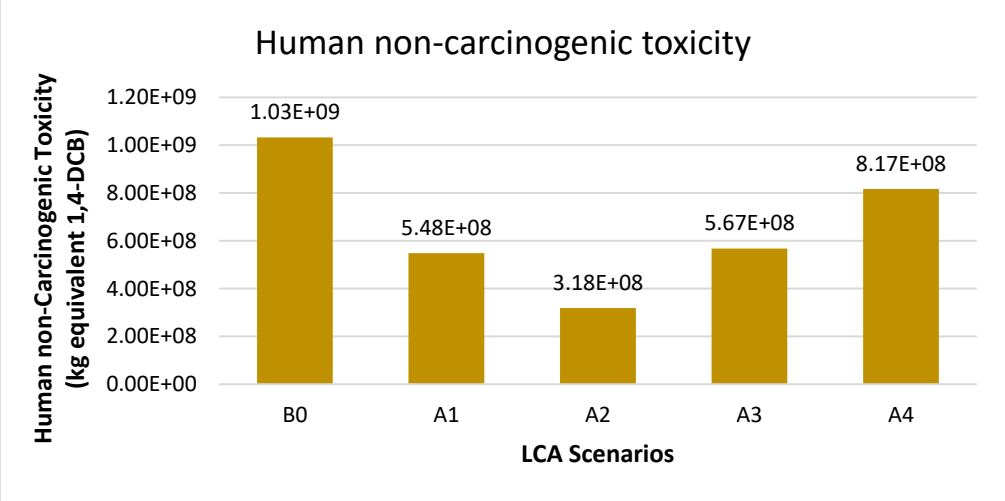


Figure 4.7: Human non-carcinogenic toxicity emission expressed in kg equivalent 1,4-DCB

4.2.2.7 Land Use

The land use in this LCA study is measured as the area required in square meter equivalent to crop field per annum. The land use impact is calculated by factoring the new land area that is transformed for an initiation of a treatment process like how much land required for a standard landfill facility or how much incineration or composting plant area required at start. Also, the land occupied for one year by the waste in landfill or incineration plant etc. as the waste quantity is considered here is accumulated in one year. The land use graph shown in Figure 4.8 demonstrates that baseline B0 is the worst scenario as no volume reduction occurs and land occupancy is high due to lack of volume reducing treatment.

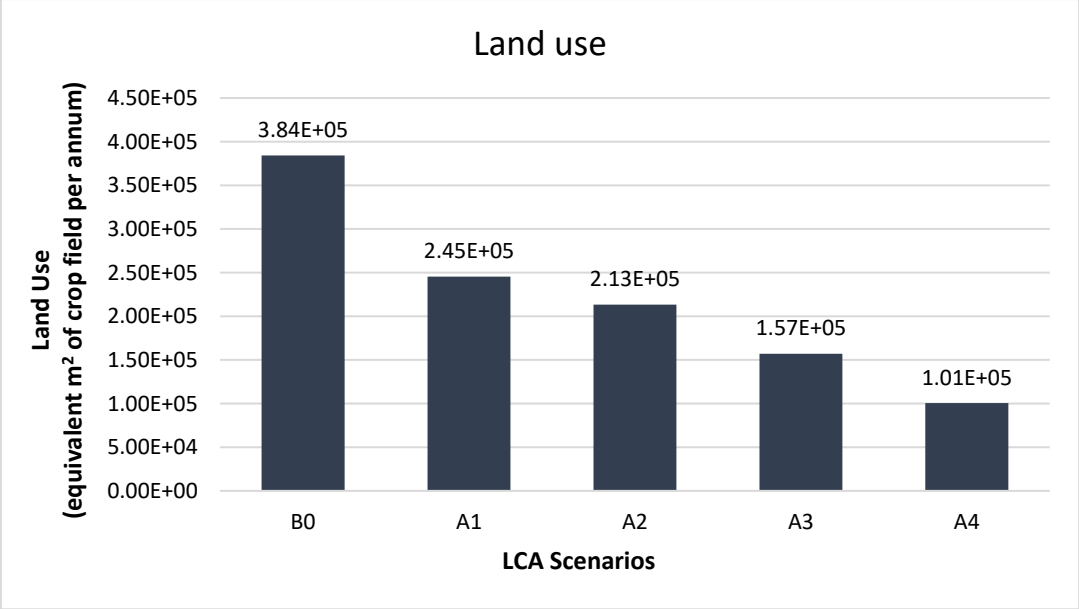


Figure 4.8: Land use in baseline and alternatives expressed in equivalent m^2 of crop field per annum

In alternative A1, with the introduction of composting, the land use is significantly reduced as the major organic portion is recovered as fertilizer. In alternative A2 to A4 the with the increase in total incineration quantity the waste volume further reduced as the process produces energy converting the waste mass. The incineration process is said to reduce waste mass by 75% and volume by 90%. Following Table 4.2 shows the land that requires transformation for initiation of different waste treatment methods. The land required for unit organic waste is extracted from the ecoinvent database and modified for incineration based on the organic waste lower heating value as lower heating value will produce more ash causing higher requirement in landfill area.

Table 4.2: Land use reduction comparison in incineration and composting

Waste Treatment Methods	Landfill, both sanitary & unsanitary	Composting	Incineration
Land area transformation for 1 kg organic waste as per ecoinvent, m^2	5.00E-05	1.11E-05	3.44E-06
Modified Land area transformation for unit organic waste, m^2	No modification	No modification	5.88E-06
Area reduction % compared to landfill	-	77.77%	88.24%

The land quantity reduction in composting method is around 78% while reduction due to incineration is around 88%. Although, this land requirement difference between composting and incineration may seem significant but it is not applicable in long term waste management scenario. Composting produces a small quantity of ash or byproducts. As soon as the composts

are packed, new waste can occupy the same area. Although, typical composting process is a month-long procedure, therefore enough land should be readily available for frequent daily disposal of waste. However, incineration requires a landfill facility as the bottom ash, slag and cement need to be deposited or disposed of unless reused in construction. The use of the incineration byproducts as construction materials need pretreatment and go through subsequent procedure for quality control depending on the quality of waste. Also, after a certain period, the cumulative burden from ash will increase the requirement of land. An approximate analysis about land exhaustion in organic waste incineration and organic waste composting is shown in Table 4.3 below. Organic waste quantity is considered according to scenario A3 whereas the total organic waste quantity considered for waste treatment is divided into two equal parts for composting and incineration.

Table 4.3: Land exhaustion analysis between incineration and composting

Item	Incineration	Composting
Quantity of organic waste, ton	½ of the total organic waste considered for treatment = 7.12E+05ton, scenario A3	½ of the total organic waste considered for treatment = 7.12E+05ton, scenario A3
Total Land Transformation for 7.12E+05ton waste, m^2	4185	7918
Total Land Transformation for 10 years with the same rate of waste treatment per year, m^2	32238	7918
Remarks	The required land quantity composed of two parts, first one is basic incineration plant facility which is 1.07E+03 m^2 and the remaining land quantities are 1.53E+03 m^2 and 1.59E+03 m^2 for slag and residual landfill respectively. While calculating the requirement for 10 years only the slag and residual landfill is multiplied by 10 whereas the basic incineration facility remains the same. The landfill area transformed become non-reusable for any further treatment purpose	The land quantity required for one-year remains reusable for many years

From the above analysis it can be concluded that, in the first years the land transformed by incineration process will be below the land quantity required in composting process. As time advances, the land requirement for incineration becomes significantly higher. Even if the area is doubled for composting in 10 years the required land for composting will still be less than

that of incineration. The incineration plant facility also needs to be extended if the waste quantity rises significantly.

4.2.2.8 Marine Ecotoxicity

Marine environment ecotoxicity is caused by ions of heavy metals like zinc, copper, nickel, vanadium etc. and metals like antimony, barium etc. in this analysis.

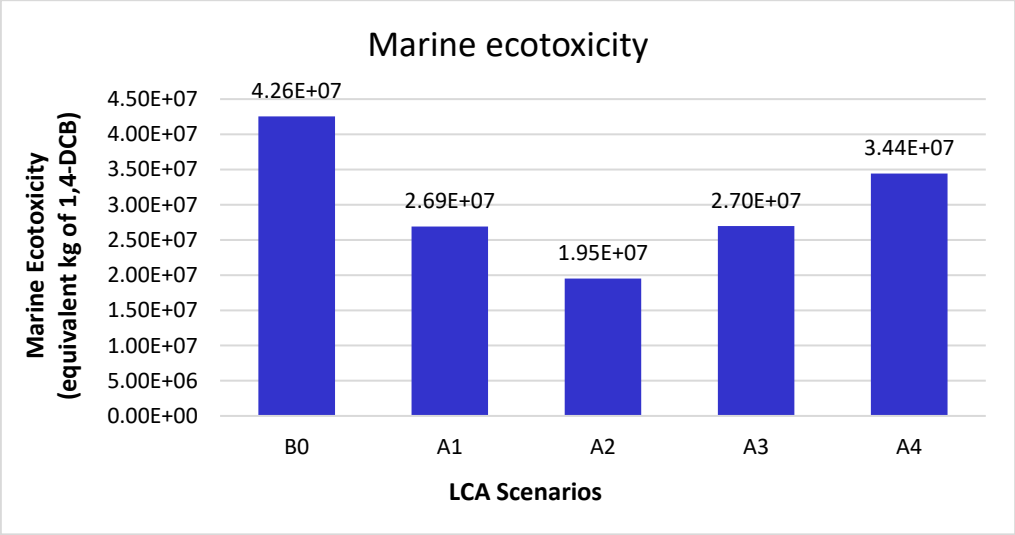


Figure 4.9: Ecotoxicity in marine environment expressed in equivalent kg of 1,4-DCB

Long term emissions of these heavy metal ions to ground water cause pollution. As the landfilling quantity is the highest in baseline the pollution is also the highest in baseline condition. Plastic landfilling is mostly responsible in alternative A1 for causing toxicity in marine environment. In alternative A2 plastic incineration is causing the most contribution to toxicity, but the level of toxicity is slightly lower than alternative A1 and lowest if compared to other scenarios. In alternative scenarios A3 and A4, biowaste incineration is added to this toxicity level causing a higher burden than alternative A2. It can also be summarized that the level of toxicity in incineration is not as acute as exhibited in landfilling. Alternative A2 is the most suitable option for this impact category. Graphical presentation is provided in Figure 4.9.

4.2.2.9 Marine Eutrophication

Baseline scenario is the most polluting scenario in marine eutrophication category mainly due to COD release from biowaste and plastic landfilling. This positive emission is greatly encountered by biowaste composting in alternative A1 which is the result of reduction of nitrate emissions from after use of chemical fertilizers. In alternative A2, the decrease in landfilling caused the lowest impact among scenarios. In alternative A3, quantity of organic waste in composting reduced which result less savings than alternative A2. In alternative A4, the burden

turns positive as no composting occurred ad landfill occurred in very small quantity. Alternative A2 is the most suitable option in this category. Figure 4.10 shows the summary of the impact in different scenarios.

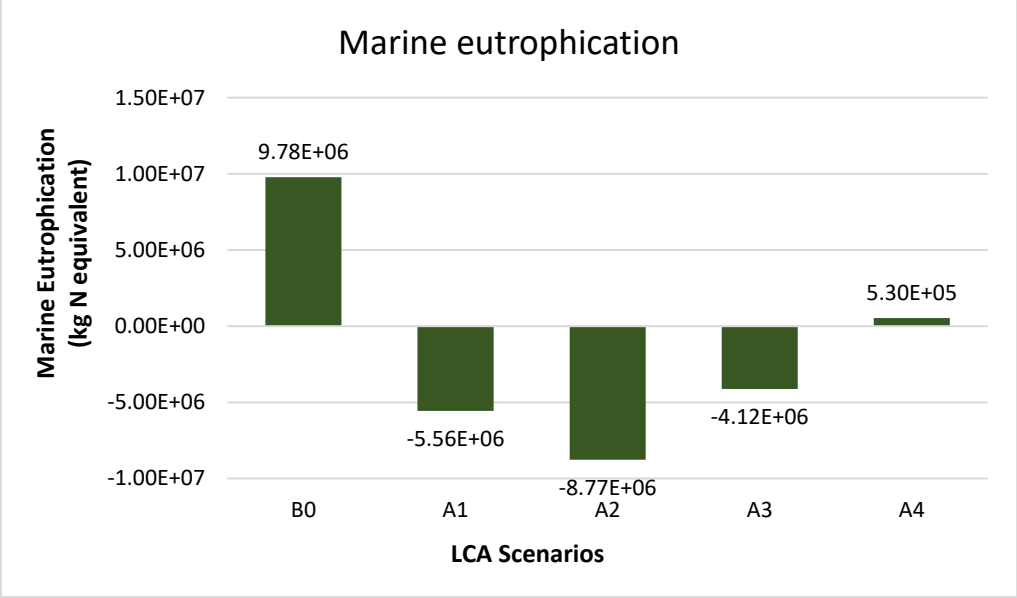


Figure 4.10: Burden in marine eutrophication expressed in kg N equivalent

4.2.2.10 Ozone Formation, Human Health

NOx and NMVOCs are major stressors in this category which is responsible for ozone formation in troposphere causing damage to ecosystem balance. This category follows the same pattern as ozone formation, terrestrial ecosystems impact category. The only differences are that the impact factor of NMVOC is 0.29 kg NOx eq/kg in terrestrial ecosystems whereas for human health it is 0.18 kg NOx eq/kg and ethene impact factor changes from 0.585 kg NOx eq/kg in terrestrial ecosystems to 0.363 kg NOx eq/kg. As a result of this value change the net value changed in all categories. In baseline, the value changed negative to positive due to drastic change in ethene impact factor which is saved by plastic recycling procedure. Still baseline burden remains the lowest among other scenarios in this category. The comparison is presented graphically in Figure 4.11.

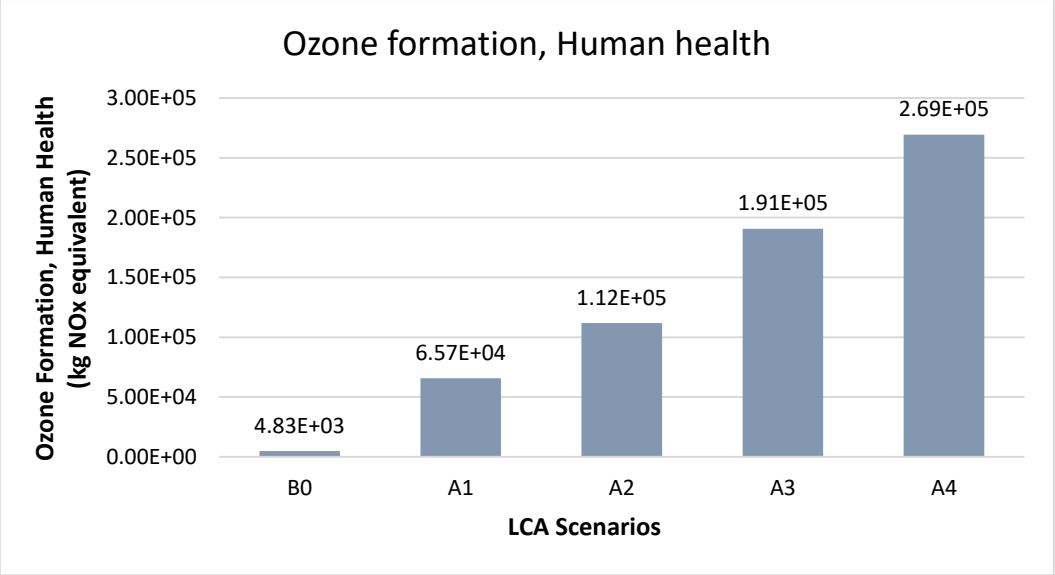


Figure 4.11: Ozone formation burden to human health expressed in kg NOx equivalent, baseline and alternatives

4.2.2.11 Ozone Formation, Terrestrial Ecosystems

In baseline B0, the stressors are emitted from landfill, transportation and STS are lower than the savings from recycling process of paper and plastics resulting the lowest and negative net emission. In alternative A1, composting produces significant amount of NOx that overrides savings through plastic recycling process causing the net lowest positive emission. In alternative A2, textile incineration adds up to the emission of alternative A1 causing a slightly upper net positive value. In alternative A3, NOx emission from biowaste incineration is much higher which escalated with the increase of organic waste incineration quantity in alternative A4. Figure 4.12 presents the comparison graphically.

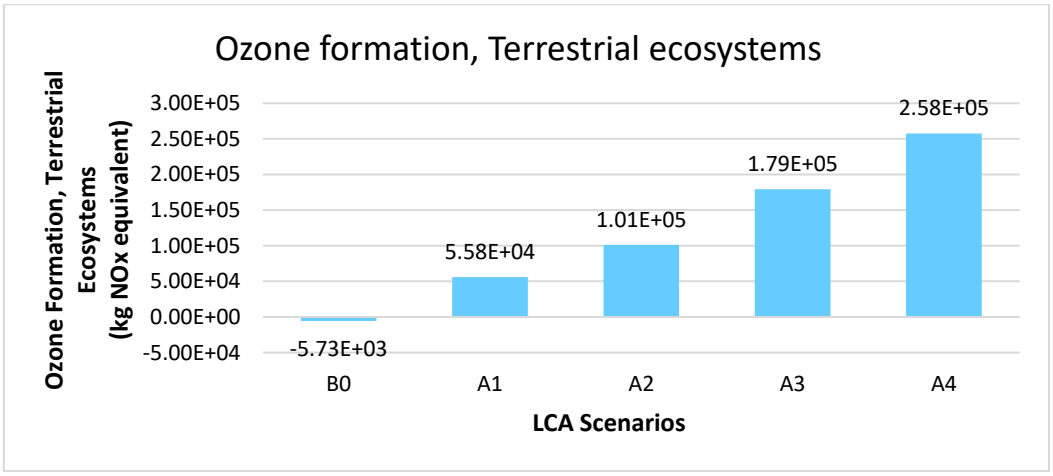


Figure 4.12: Ozone formation burden to terrestrial ecosystems expressed in kg NOx equivalent, baseline and alternatives

4.2.2.12 Stratospheric Ozone Depletion

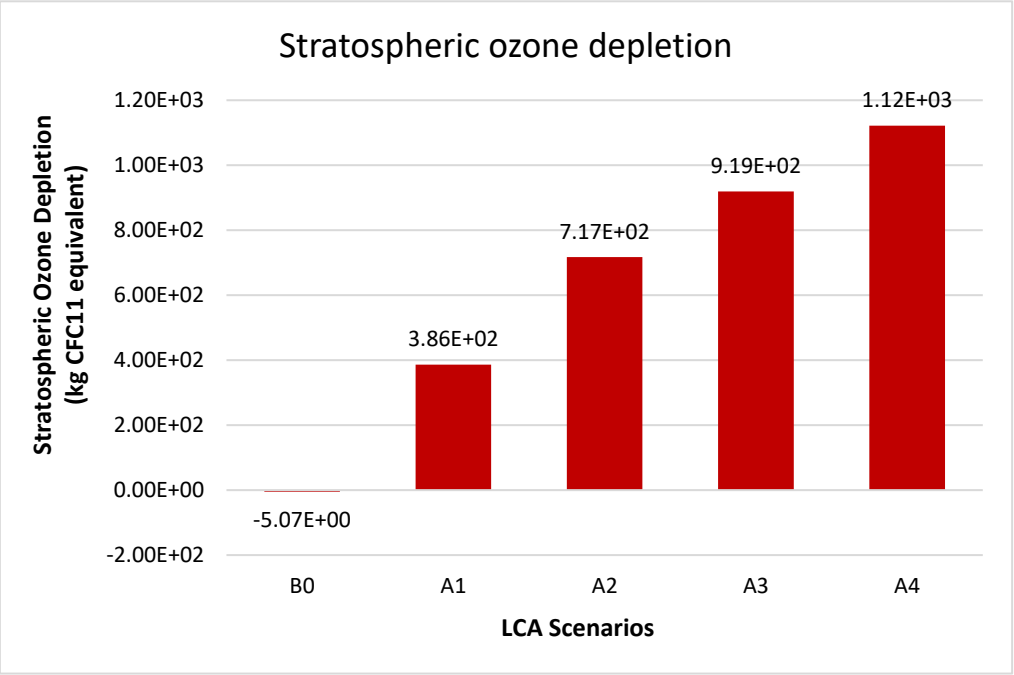


Figure 4.13: Good ozone depletion in stratosphere in baseline and alternatives, kg CFC11 equivalent

Baseline B0 is the most suitable option for reducing stratospheric ozone depletion as there is no significant process causing any positive emission. The recycling process of paper, glass, plastic reduced dinitrogen monoxide which is a major CFC stressor. In alternative scenario A1, A2 and A3 composting process produced significant amount of dinitrogen monoxide. In alternative A2, A3 and A4 incineration of textile, biowaste, plastic and paper add significant dinitrogen monoxide to the environment. Figure 4.13 demonstrates the bar diagram of different scenarios.

4.2.2.13 Terrestrial Acidification

Biowaste landfilling, landfill maintenance, transportation of waste from STS to landfills emits NOx and SOx from fuel burning and landfilling which cause acidification to air in baseline scenario. Composting process saves huge quantities of ammonia emissions to air from reduction of the after use of chemical fertilizer. In alternative scenario A1 and A2 the equal composting quantity causing equal save in acidification as shown in Figure 4.14. In alternative A3, the savings were reduced due to a reduction in composting quantity. In alternative A4, biowaste incineration causes a positive burden while plastic recycling cause savings in NOx and SOx emission although it is much lesser than the positive burden from incineration. Alternative A1 and A2 are the two most suitable choices in this category.

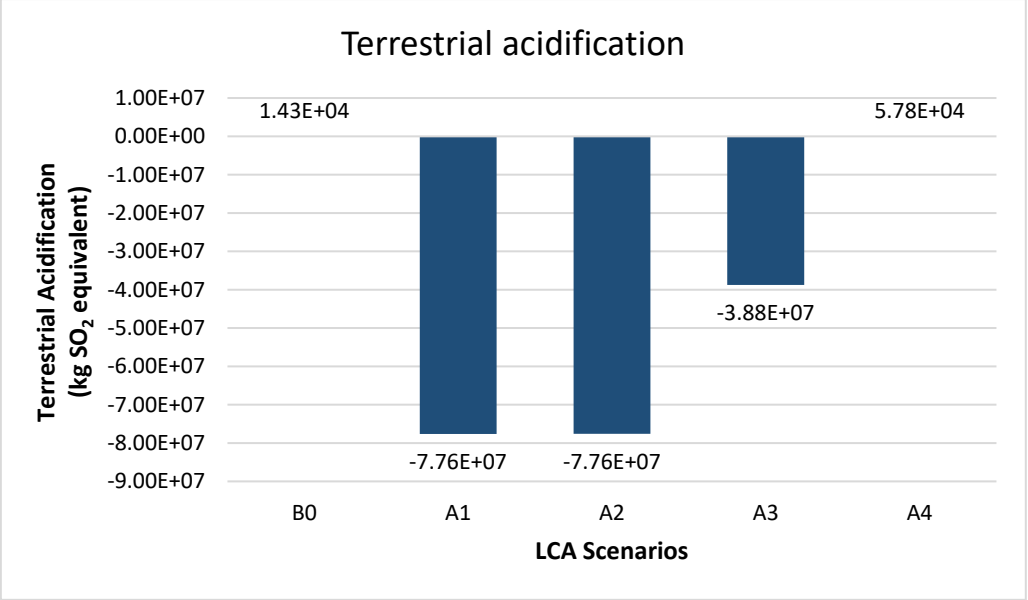


Figure 4.14: Terrestrial acidification from baseline and alternatives, kg SO_2 equivalent

4.2.2.14 Terrestrial Ecotoxicity

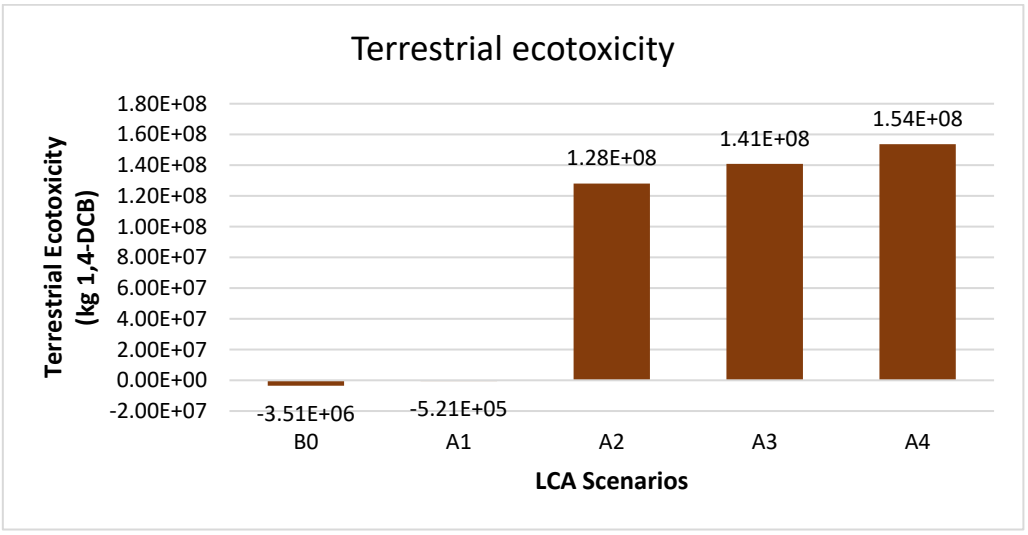


Figure 4.15: Terrestrial ecotoxicity from baseline and alternatives, kg 1,4-DCB

In terrestrial ecotoxicity category, heavy metals like copper, zinc, lead, chromium are the main stressors. Baseline scenario has positive emissions of these metals mainly due to landfilling operation. On the contrary recycling causes savings in emission of these metals into air by larger quantity. Therefore, in baseline and alternative A1 the net value is negative. Due to composting although the load on landfilling reduced but the burden remains higher than baseline. Here higher burden means lower savings in ecotoxicity. However, when incineration is introduced in alternative A2, A3 and A4, the impact value greatly increases due to vanadium emission from plastic and biowaste incineration. In this category baseline remains the least polluting MSWM option. Values are presented in Figure 4.15.

4.2.2.15 Water Consumption

Water consumption is mostly saved by alternative scenario A2 among others. Water savings are directed by recycling, composting, and incineration processes. Indirect savings in electricity caused by reduction of electricity during raw/ virgin materials production. This reduced electricity will reduce water consumption in electricity power plants. The burdens are presented in Figure 4.16.

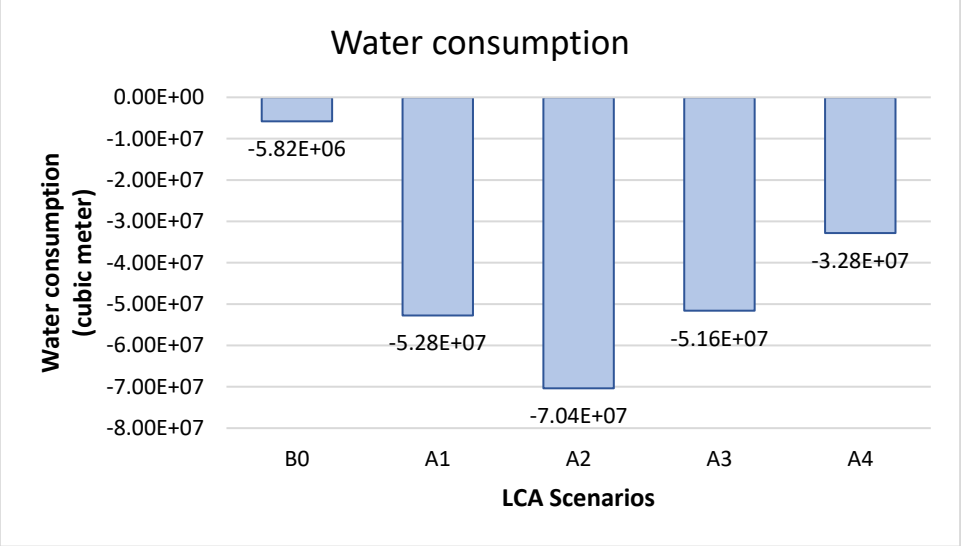


Figure 4.16: Water consumption in cubic meter, baseline and alternatives

4.2.3 Power Production from Incineration

The analysis of power produced from incineration is important to understand the possible contribution to the Dhaka city electricity supply. Alternative A2, A3 and A4 has incineration of different waste and the calculation for electricity production from these scenarios are provided in the following Table 4.4-

Table 4.4: Net electricity generation from waste incineration in different scenarios

Waste type	A2, kWh/year	A3, kWh/year	A4, kWh/year
Organic	-	106350310	212700620
Graphical paper	30428212	30428212	30428212
Packaging paper	3866453	3866453	3866453
Plastic	299605443	299605443	299605443
Textile	26699806	26699806	26699806
Glass	29697	29697	29697
Total	**360629612**	**466979922**	**573330233**

Alternative A4 has the highest net electricity production annually which is quite reasonable as this scenario has the highest waste quantity burning. According to the data of PGCB, the yearly electricity consumption of Dhaka city was around 96,00,000 MWh as an average in year 2016 (Istiaque and Khan 2018). The net electricity produced in A4 is only 5.96% of the total electricity required in 2016. A2 and A3 covered 3.76% and 4.86% of the total requirement respectively.

4.2.4 Endpoint Analysis Result

The endpoint analysis is the reflection of midpoint results which can be broadly discussed into two categories. One is impact to human health expressed in disability adjusted life years, DALY and the other one is the loss of species due to the pollution per year. DALY is the loss of healthy life years due to pollution. Following Table 4.5 shows the sum of DALY and species loss per year result obtained from impact analysis.

Table 4.5: LCIA result of baseline and alternatives at endpoint

Unit	B0	A1	A2	A3	A4
DALY	1.33E+03	-5.82E+03	-5.91E+03	-2.87E+03	1.68E+02
Species. yr	3.29E+00	-1.67E+01	-1.70E+01	-8.66E+00	-3.22E-01

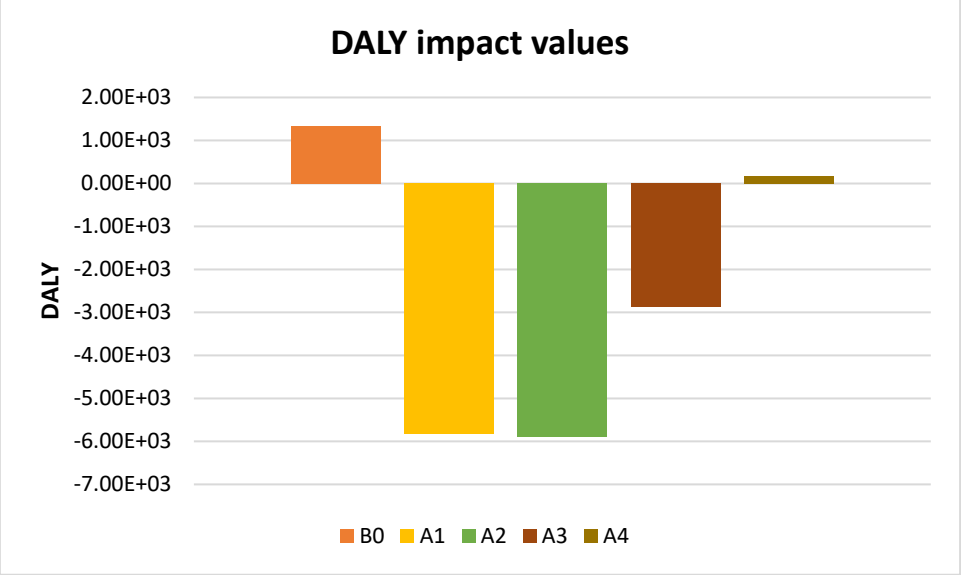


Figure 4.17: DALY LCIA values for different scenarios

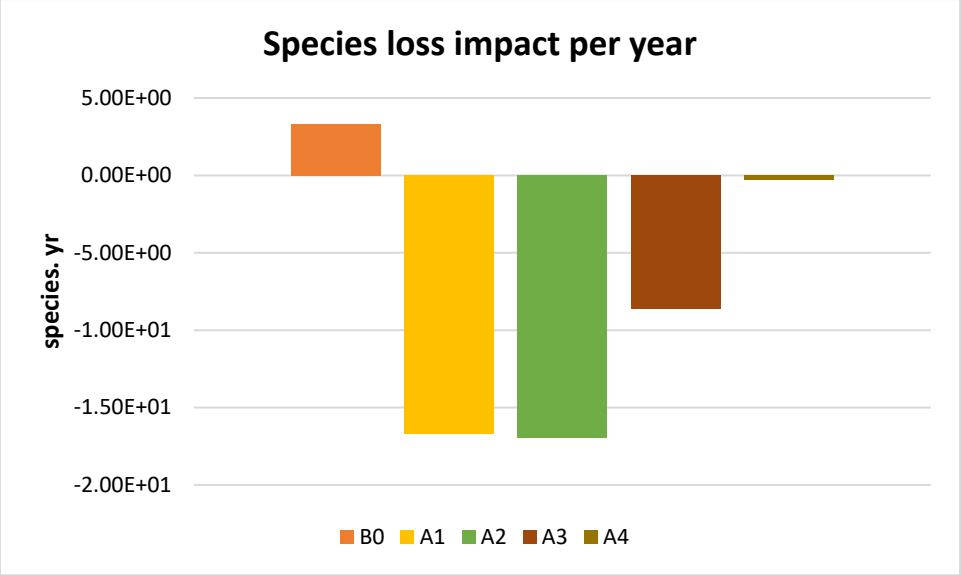


Figure 4.18: Species loss per year for different scenarios

Above Figure 4.17 and 4.18 showing the data presented in Table 4.5 in column charts. The combined result shows that scenarios A1, A2 and A3 are reducing the disabilities and increasing the life span of human while B0 and A4 are causing some adjustment in life years due to disability. Scenarios A1 and A2 are the two most environmentally friendly options. Similar pattern is obtained in species loss per year except scenario A4 saving small quantity of species. The contribution of each midpoint categories in DALY and species loss per year is shown in Table 4.6. The midpoint categories contribution to endpoint in baseline B0 scenario is presented graphically in Figure 4.19 and Figure 4.20.

Table 4.6: Endpoint LCIA results, combined scenarios

Indicator	Unit	B0	A1	A2	A3	A4
Fine particulate matter formation	DALY	6.95E+00	-5.97E+03	-5.97E+03	-2.98E+03	1.66E+01
Freshwater ecotoxicity	species. yr	2.18E-02	1.39E-02	1.01E-02	1.40E-02	1.78E-02
Freshwater eutrophication	species. yr	4.69E-02	1.60E-03	1.55E-03	1.57E-02	2.99E-02
Global warming, Freshwater ecosystems	species. yr	8.99E-05	1.20E-05	1.14E-05	5.99E-06	5.91E-07
Global warming, Human health	DALY	1.09E+03	1.46E+02	1.38E+02	7.28E+01	7.27E+00
Global warming, Terrestrial ecosystems	species. yr	3.29E+00	4.41E-01	4.17E-01	2.19E-01	2.15E-02
Human carcinogenic toxicity	DALY	4.02E+00	1.36E+00	8.80E+00	1.96E+01	3.03E+01

Table 4.6: Endpoint LCIA results, combined scenarios, continued

Human non-carcinogenic toxicity	DALY	2.36E+02	1.25E+02	7.26E+01	1.29E+02	1.86E+02
Land use	species. yr	2.30E-03	1.99E-03	1.81E-03	1.51E-03	1.20E-03
Marine ecotoxicity	species. yr	4.47E-03	2.83E-03	2.05E-03	2.83E-03	3.62E-03
Marine eutrophication	species. yr	1.85E-03	-1.52E-02	-1.55E-02	-7.71E-03	1.12E-04
Ozone formation, Human health	DALY	4.39E-03	5.98E-02	1.02E-01	1.73E-01	2.45E-01
Ozone formation, Terrestrial ecosystems	species. yr	-7.38E-04	7.20E-03	1.30E-02	2.31E-02	3.32E-02
Stratospheric ozone depletion	DALY	-2.69E-03	2.05E-01	3.81E-01	4.88E-01	5.96E-01
Terrestrial acidification	species. yr	3.03E-03	-1.65E+01	-1.65E+01	-8.23E+00	1.23E-02
Terrestrial ecotoxicity	species. yr	-4.00E-05	-5.91E-06	1.46E-03	1.60E-03	1.75E-03
Water consumption, Aquatic ecosystems	species. yr	-3.51E-06	-3.19E-05	-4.25E-05	-3.12E-05	-1.98E-05
Water consumption, Human health	DALY	-1.29E+01	-1.17E+02	-1.56E+02	-1.15E+02	-7.29E+01
Water consumption, Terrestrial ecosystem	species. yr	-7.85E-02	-7.12E-01	-9.50E-01	-6.97E-01	-4.43E-01

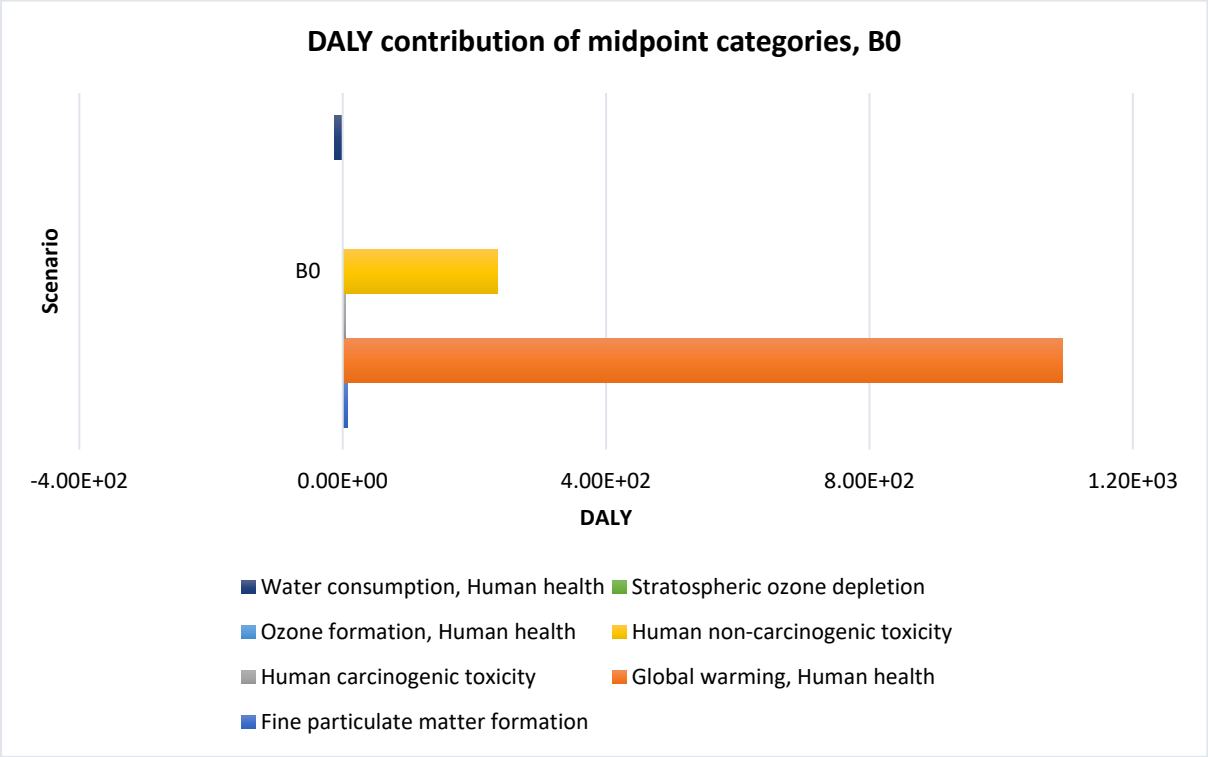


Figure 4.19: DALY contribution of midpoint categories, B0

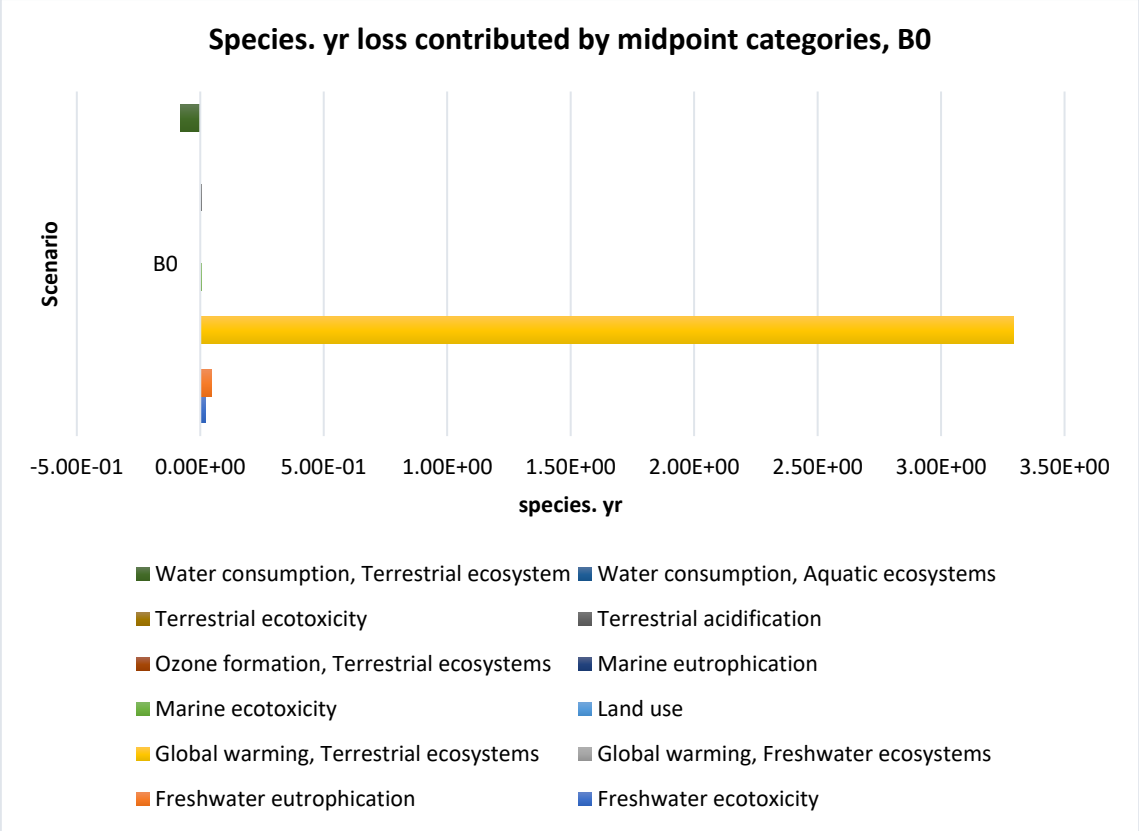


Figure 4.20: Species. yr loss contributed by midpoint categories, B0

In both, DALY and species. yr endpoint categories the contribution of midpoint global warming is the key contributing factor. Now if scenario A1 is presented graphically following Figure 4.21 and Figure 4.22 will be observed-

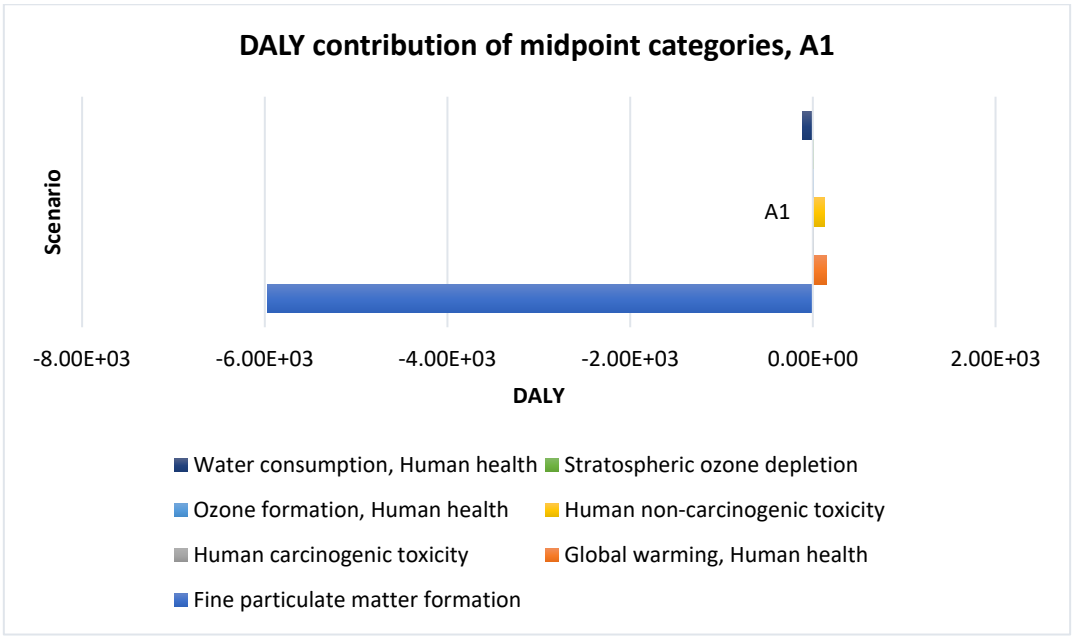


Figure 4.21: DALY contribution of midpoint categories, A1

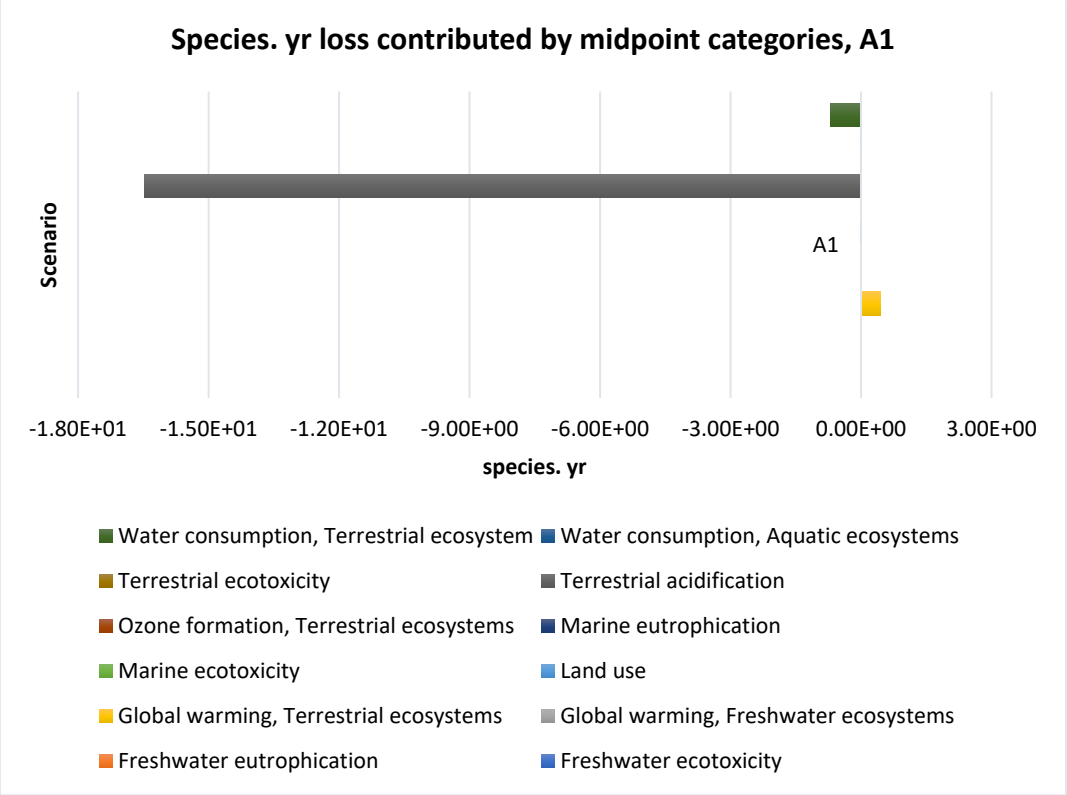


Figure 4.22: Species. yr loss contributed by midpoint categories, A1

Figure 4.21 shows that in scenario A1, midpoint fine particulate matter formation is the major contributing factor in DALY endpoint. However, terrestrial acidification is the main contributing factor for species loss per year in scenario A1 as shown in Figure 4.22. A similar graphical presentation of key contributing factors for scenario A2, A3 and A4 is provided in Appendix E. These results are indicative of the focus area for design and implementing these waste management scenarios.

4.3 Result Summary

Based on the analysis on the previous sections of this chapter, obtained results are summarized to understand which approach of MSWM is the most suitable that balances over all categories. Although, there is no specific weightage applied on impact categories i.e., global warming should have double priority over water consumption therefore putting a weightage of 2 on global warming if water consumption is considered as unit. As no such weightage is applied, it is considered that the approach which is most environment friendly in most categories or close to the highest savings or lowest emissions is more appropriate to apply for Dhaka city MSWM system. The summary for midpoint categories is shown in Table 4.7. It was found that the alternative A2 is the most environmentally friendly choice. In the global warming category

incineration-based options such as alternative A3 and A4 are the most preferable choice. If tropospheric ozone formation and stratospheric ozone depletion are considered baseline B0 is the most preferable method. Alternative A1 can be considered as the second most suitable choice from an overall perspective. Baseline B0 and total incineration A4 are the least environmentally friendly options.

Table 4.7: Summary of LCA result of combined scenarios in midpoint

Indicator	Baseline	Alt. 01	Alt. 02	Alt. 03	Alt. 04
Fine particulate matter formation	-	✓	✓	-	-
Freshwater ecotoxicity	-	✓	✓	✓	-
Freshwater eutrophication	-	✓	✓	-	-
Global warming	-	-	-	✓	✓
Human carcinogenic toxicity	-	✓	-	-	-
Human non-carcinogenic toxicity	-	-	✓	-	-
Land use	-	-	-	✓	✓
Marine ecotoxicity	-	✓	✓	✓	-
Marine eutrophication	-	-	✓	-	-
Ozone formation, Human health	✓	-	-	-	-
Ozone formation, Terrestrial ecosystems	✓	-	-	-	-
Stratospheric ozone depletion	✓	-	-	-	-
Terrestrial acidification	-	✓	✓	-	-
Terrestrial ecotoxicity	✓	✓	-	-	-
Water consumption	-	-	✓	-	-

Similar to midpoint, in endpoint scenario A2 is the friendliest from environmental perspective. Scenario A1 is the second most environmentally friendly strategy but the gap between A2 and A1 at endpoint is very insignificant in both DALY and per year species loss/save categories.

4.4 Comparison of Baseline Scenario: DNCC VS. DSCC

There are some major differences between DNCC and DSCC waste management practices in categories like fine particulate matter formation, global warming, freshwater eutrophication, marine eutrophication, ozone related categories, terrestrial pollution, and water consumption. In fine particulate matter formation, the net burden from DSCC is 2869 kg $PM_{2.5}$ equivalent and DNCC is 8183 kg $PM_{2.5}$ equivalent. This variation occurred due to the difference in quantity of biowaste landfilling, difference in diesel burn during landfill operation, difference in number of vehicles involved in waste transportation, different number of STSs and different quantity in plastic recycling. A similar explanation is applicable to ozone related categories, terrestrial pollution categories and water consumption. In marine and freshwater eutrophication categories the impact variation between city corporations is caused by the variation of

efficiency of the leachate treatment system. In the whole analysis, sanitary landfill data is used for Matuail while unsanitary landfill data is used for Aminbazar. In these categories DSCC baseline practice is found to be more environmentally friendly. Midpoint impact values and graphical presentation are provided in Table 4.8 and Figure 4.23. Endpoint results data is presented in column charts in Figure 4.24 and Figure 4.25. In both these graphs, impact from DNCC is greater than DSCC. Detail endpoint data and contribution of midpoint categories at endpoint are provided graphically in Appendix E.

Table 4.8: Midpoint categories burden for DNCC and DSCC

Indicator	Unit	DNCC	DSCC
Fine particulate matter formation	kg $PM_{2.5}$ eq	8.18E+03	2.87E+03
Freshwater ecotoxicity	kg 1,4-DCB	1.52E+07	1.62E+07
Freshwater eutrophication	kg P eq	3.68E+04	3.33E+04
Global warming	kg CO_2 eq	6.49E+08	5.27E+08
Human carcinogenic toxicity	kg 1,4-DCB	6.03E+05	6.10E+05
Human non-carcinogenic toxicity	kg 1,4-DCB	5.18E+08	5.15E+08
Land use	m^2a crop eq	2.00E+05	1.85E+05
Marine ecotoxicity	kg 1,4-DCB	2.06E+07	2.19E+07
Marine eutrophication	kg N eq	5.91E+06	3.87E+06
Ozone formation, Human health	kg NOx eq	6.91E+03	-2.08E+03
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.49E+03	-8.22E+03
Stratospheric ozone depletion	kg CFC11 eq	-2.41E+00	-2.67E+00
Terrestrial acidification	kg SO_2 eq	1.64E+04	-2.07E+03
Terrestrial ecotoxicity	kg 1,4-DCB	-1.15E+06	-2.36E+06
Water consumption	m^3	-2.45E+06	-3.37E+06

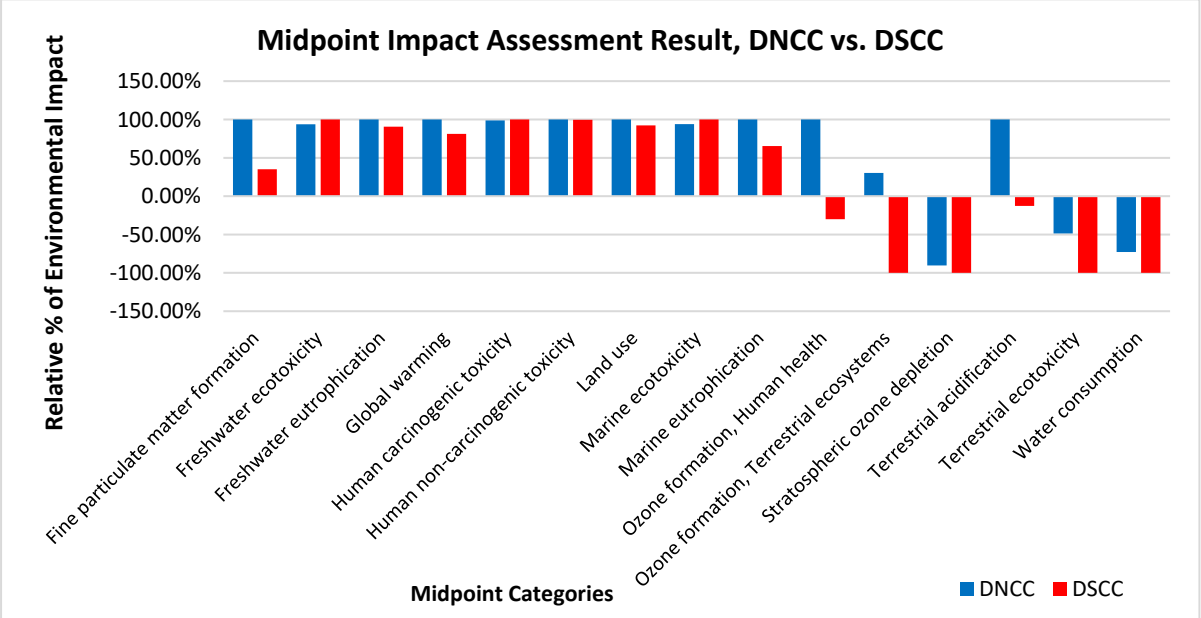


Figure 4.23: Midpoint LCIA results of DNCC vs DSCC MSWM

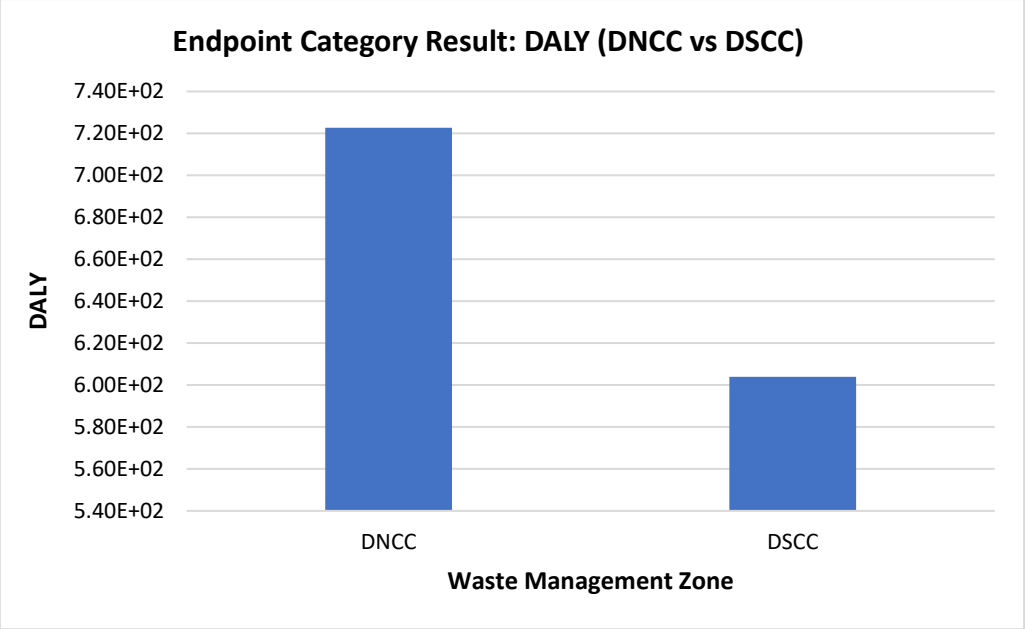


Figure 4.24: Endpoint LCA Result, Category: DALY, DNCC vs DSCC

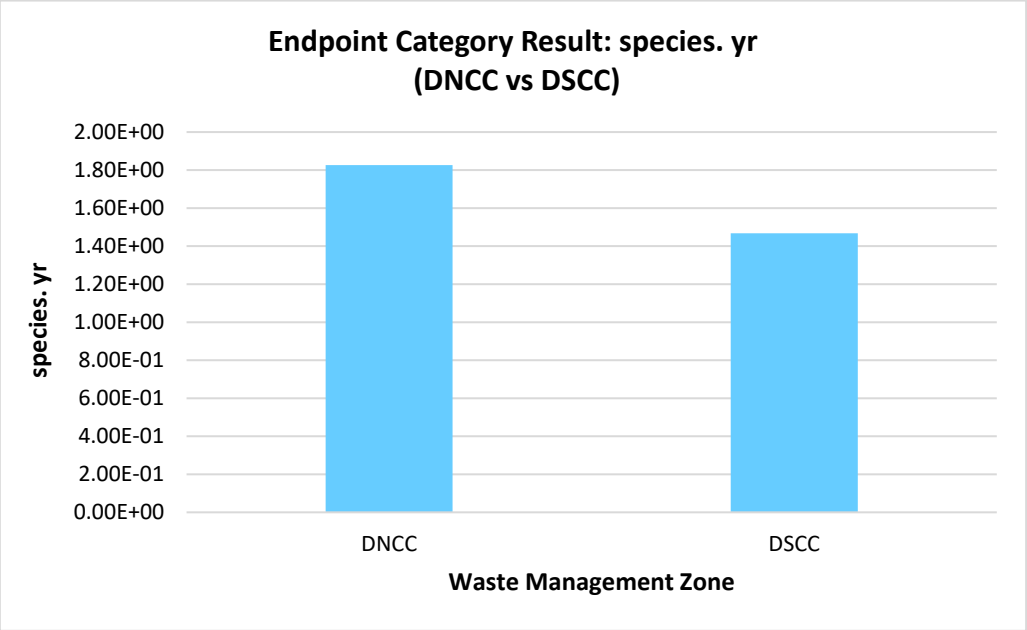


Figure 4.25: Endpoint LCA Result, Category: species. yr, DNCC vs DSCC

4.5 Discussion

The present study has analyzed different options/scenarios for managing solid waste of Dhaka City using LCA.

While the study investigates the baseline scenario in practice, the alternative waste management strategies and technologies are considered based on the waste types and the future of managing waste as per city corporations report.

From the analysis, it has been found that composting of organic wastes along with incineration of other wastes is the best strategy with respect to most impact categories e.g., fine particulate matter formation, freshwater eutrophication and ecotoxicity, human non-carcinogenic ecotoxicity, marine eutrophication and ecotoxicity, terrestrial acidification and ecotoxicity and water consumption. The second-best environmentally friendly approach is the composting of organic waste along with the remaining wastes landfilling. The reason behind this is that the impacts due to incineration can be avoided in this scenario.

Incineration of all types of wastes (organic and others) can be the third option while it tops in the savings in global warming. The reason for the reduction in global warming is that incineration eliminates the methane emission form organic wastes due to landfilling or composting process. But it emerges as the most polluting waste treatment method in all categories of ozone formation, human carcinogenic toxicity and terrestrial ecotoxicity. For instance, in midpoint stratospheric ozone depletion category, major waste incineration approach (scenario A4) has the highest emission of 1.12E+03 kg CFC11 equivalent whereas other alternatives A1, A2 and A3 emission values are 3.85E+02, 7.17E+02 and 9.19E+02 kg CFC11 equivalent. The baseline scenario B0 i.e., Business as Usual (BAU) has the lowest value of -5.07 kg CFC11 equivalent.

Land use is another important issue as Dhaka city has land scarcity and authorities are keen to find alternatives that have much less impact on land use. In this study, it is found that incineration proves to be the better solution than existing landfill practice (scenario B0) but not more effective than composting in the long term while treating organic waste. Because MSW of Dhaka city majorly contains biowaste which is high in moisture content and less in calorific value. As a result, the ash quantity produced is becomes higher than expected. Therefore, the landfill requirement generally becomes higher than expected. After a certain period of time, if the produced residue cannot be reused in other methods, the quantity of the residue will become significant, and more dumpsites will be required to store the ash. With the increase in waste quantity the land requirement will become higher. On the other hand, composting facility requires 78% less area compared to basic landfill practice and provides a more sustainable solution to this problem as organic waste composting produce tiny amount of by product that requires landfilling and same area can be used for repeated times. By efficient composting plant management, the scope of producing fertilizers will enhance and at the same time making space for the incoming waste. From a technological perspective, the process of maintaining compost plants is also easy to maintain and will prove economical compared to an incineration plant.

Another important criterion for incineration approach is the requirement of energy. As per the analysis of this study, the total electricity produced from alternative scenario A4 (wholly incineration) which has the most incineration quantity of waste is 5,73,330 MWh/year whereas the yearly consumption of Dhaka city is around 96,00,000 MWh as an average in year 2016 as per data of PGCB (Istiaque and Khan 2018). So, the produced quantity is 5.96% of the total electricity required.

A formal and administrative waste recycling structure is another area to improve. The informal plastic recycling sector greatly reduce environmental impacts in categories like fine particulate matter formation, ozone formation in both human health and terrestrial ecosystems category, stratospheric ozone depletion, terrestrial acidification and ecotoxicity and water consumption in baseline B0 scenario. By formalizing and enhancing recycling methods with other waste treatment options, the environmental impacts can be reduced significantly. A holistic approach is necessary for a sustainable MSWM in Dhaka.

Chapter 5
CONCLUSION

5.1 Introduction

In this study, the evaluation of MSW management of Dhaka city is performed using LCA approach. The environmental impacts have been assessed for the total waste produced in the year 2020 and using openLCA software. ReCiPe 2016 hierarchist method is used for environmental impact assessment in midpoint and endpoint categories. This chapter summarizes the key findings of the study and presents future recommendations.

5.2 Conclusions

The major conclusions of the present study are as follows:

i. Among all the scenarios, scenario named A2 which is a combination of composting of organic wastes (97% of the organic waste which is 60.37% of total generated waste) with incineration (95% of other waste such as paper, plastic, textile, glass which is 7.12% of total generated waste) of other wastes appears to be the most environment friendly approach in most impact categories.
ii. In marine eutrophication midpoint impact category, the scenario A2 has the highest environmental savings with negative value of 8.77E+06 kg N equivalent. In this category, baseline B0 (existing landfilling practice) has the highest emission with an adverse environmental impact of 9.78E+06 kg N equivalent. Remaining scenarios named A1 (60.38% composting, 12.33% landfilling), A3 (30.19% composting, 37.31% incineration, 5.20% landfilling) and A4 (67.5% incineration, 5.20% landfilling) scenarios, values for eutrophication are -5.56E+06, -4.12E+06 and 5.30E+05 kg N equivalent respectively. Similarly in endpoint marine eutrophication, the values of lost in species per year for B0, A1, A2, A3 and A4 scenarios are 1.85E-3, -1.52E-2, -1.55E-2, -7.71E-3 and 1.12E-4 species per year respectively.
iii. Only organic composting and other wastes into landfill named A1 (60.38% composting, 12.33% landfilling) evaluated as second-best option compared to other scenarios.
iv. Option with maximum incineration of wastes, scenario A4 (67.5% incineration, 5.20% landfilling), offers an appropriate option with respect to land use but the land has the possibility of getting exhausted after a certain period of time depending on the amount of produced ash and residues. It is found that the total land transformation for the 7.12E+05

ton of organic waste is 4185 m^2 and in incineration 7918 m^2 for initial one year of waste treatment but after 10 years if the same waste generation rate is applied and the incineration and composting process remains the same, the requirement for incineration will become 32238 m^2 and requirement for the composting will remain 7918 m^2. For the composting process, land is reusable, and the required land quantity after 10 years would not be changed. Therefore, in the long run, incineration may not be a sustainable solution from the land use perspective.

v. The approximate power generation from incineration scenario A2, A3 and A4 are 360630MWh, 466980MWh and 573330MWh respectively which cover 3.76%, 4.86% and 5.96% of the total electricity quantity of 9600000MWh required in Dhaka for the year 2016.
vi. The major midpoint factors are identified contributing to endpoint two categories: DALY and species. yr. For example, in scenario A2, midpoint fine particulate matter formation is mainly responsible for endpoint DALY impact. Also, in this scenario, midpoint terrestrial acidification is the prime contributing factor for species loss per year at endpoint.

5.3 Limitations of The Study

Following limitations are observed while conducting the study:

1. The main limitation to conducting the study is the lack of complete and precise waste data. Bangladesh has six seasons and numerous festivals. So, the waste composition fluctuates a lot in different seasons. Therefore, the quantification of year-round waste and forecast composition from total data would have been the most accurate approach to finding out the different types of waste percentage. But these approaches are lengthy, difficult for unsorted and mixed waste and complex to scrutinize at that level of details. Also, it requires enhanced organizational structure to perform such laborious analysis.
2. There is absence of organizational framework to perform such analysis in the administrative organizations also. Some recent studies are conducted based on the collection of waste sample from landfills as per ASTM D5231 “Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste” or other custom standard field analysis or from past literature (Dima, et al. 2022, JICA 2005, Yoshijima, et al. 2021). Also, some of these data are 10 to 20 years old.
3. The life of people changed rapidly with technology, industrial development, and economic growth. As a result, waste composition also changed with people’s lifestyle. The recent report on plastic waste of Bangladesh has the data of Dhaka city waste field survey. The

survey was conducted by The World Bank on both city corporations with a more complete pattern of waste flow and published in December 2021. Therefore, the difficulties in choosing the most updated waste composition data were possible to resolve. But there is still some lack of exact data regarding secondary transfer stations, waste transportation and landfill operations and maintenance. In waste reports the number of diesel driven vehicles and CNG driven vehicles were absent. Similarly, off road maintenance machineries fuel consumption was lacking. The only available data was the total fuel cost in the fiscal year from which it was difficult to differentiate the expenditure for specific fuel.

4. Several interviews were conducted with JICA and the city corporation waste management department to collect the data that is not available in waste reports. But some required data were not directly available and those are derived analytically from other secondary data and average assumption from different literatures, standards, and machine catalogues produced in developed countries.
5. There are also some limitations with ReCiPe 2016 LCIA method has no endpoint model for marine eutrophication. Therefore, BOD, COD or TOC impact on endpoint could not be addressed. The reason for this is described in Goedkoop, et al., (2013). By varying the concentration of Phosphorus in different Dutch surface waters showed that the concentration of macrofauna varied widely and is not dependent only on P concentration. There are many stressors that have impact on microfauna at varying levels.
6. The transportation process in informal recycling is kept out of the study due to data unavailability. Inclusion of this part could have enriched the scope of this study. There is also no data available on the health impact on the waste pickers who come in direct contact with waste while collecting and transferring waste.

5.4 Scopes for Further Study

Some scopes for further development of this study are discussed below.

1. The study is conducted on secondary data that can change in future depending on many factors like lifestyle, population, and environment of Dhaka city. Therefore, specific field data analysis should be conducted on every stage of waste management at certain interval. In addition, waste degradation in landfills should be monitored. The energy potential of methane gas generated from landfills can be a potential source of efficient energy and can be analyzed and compared with the current study.

2. The land requirement calculation for different waste treatment methods can be more comprehensive. In this analysis, land consumption is estimated with standard assumptions which are not present in Dhaka city landfills. Due to terrain and environmental consideration, practical measurements can be adopted for land use analysis.
3. The fuel consumption and emissions LCI are prepared with general assumptions based on different data and EEA/EMEP standards. But it is also possible to practically analyze the emissions from diesel and CNG driven vehicles and the fuel consumption data can be improved if year-round practical fuel consumption data can be recorded.
4. The carrying of waste for recycling is not considered in the scope of this analysis, which is another area of development. A comprehensive study can be carried out so that motorized and non-motorized emissions can be addressed.
5. The health impacts on waste pickers, scavengers and waste collectors need to be addressed in every step of waste management as their waste collection method is very crude and they barely have any safety precautions to prevent diseases and pathogen infection.
6. The waste percentage can be varied in recycling portion. Moreover, some other waste treatment methods like anaerobic digestion, mechanical biological treatment, landfill gas recovery etc. can be introduced and numerous scenarios can be formed.
7. The waste going to unserved areas is another scope of future development as the quantity is significant in terms of the total Dhaka city municipal solid waste.

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APPENDIX A

Table A.1: Value choices in the derivation of characterization factors, extracted from ReCiPe documentation report (Huijbregts, et al. 2017)

Impact Categories	Individualist	Hierarchist	Egalitarian
Climate change			
Time horizon	20 years	100 years	1,000 years
Climate-carbon feedbacks non-CO_2	No	Yes	No
Future socio-economic developments	Optimistic	Baseline	Pessimistic
Adaptation potential	Adaptive	Controlling	Comprehensive
Ozone depletion			
Time horizon	20 years	100 years	Infinite
Included effects	Skin cancer	Skin cancer	Skin cancer and cataract
Ionizing radiation			
Time horizon	20 years	100 years	100,000 years
Dose and dose rate effectiveness factor (DDREF)	10	6	2
Included effects	-Thyroid, bone marrow, lung, and breast cancer -Hereditary disease	-Thyroid, bone marrow, lung, breast, bladder, colon, ovary, skin, liver, oesophagus and stomach cancer -Hereditary disease	-Thyroid, bone marrow, lung, breast, bladder, colon, ovary, skin, liver, oesophagus, stomach, bone surface and remaining cancer -Hereditary disease
Fine particulate matter formation			
Included effects	Primary aerosols	Primary aerosols, secondary aerosols from SO_2	Primary aerosols, secondary aerosols from SO_2, NH_3 and Nox
Toxicity			
Time horizon	20 years	100 years	Infinite
Exposure routes for human toxicity	Organics: all exposure routes. Metals: drinking water and air only	All exposure routes for all chemicals	All exposure routes for all chemicals

Environmental compartments for marine ecotoxicity	Sea + ocean for organics and non-essential metals. For essential metals, the sea compartment is included only, excluding the oceanic compartments	Sea + ocean for all chemicals	Sea + ocean for all chemicals
Carcinogenity	Only chemicals with carcinogenicity classified as 1, 2A, 2B by IARC	All chemicals with reported carcinogenic effects	All chemicals with reported carcinogenic effects
Minimum number of tested species for ecotoxicity	4	1	1
Water use			
Regulation of stream flow	High	Standard	Standard
Water requirement for food production	1000 m^3/yr/capita	1350 m^3/yr/capita	1350 m^3/yr/capita
Impacts on terrestrial ecosystems considered	No	Yes	Yes
Mineral resource scarcity			
Future Production	Reserves	Ultimate recoverable resource	Ultimate recoverable resource

Table A.2: Impact indicators of midpoint categories, extracted from ReCiPe documentation report (Huijbregts, et al. 2017)

Impact category	Indicator	Unit	CFm	Abbr.	Unit
climate change	Infra-red radiative forcing increase	W × yr/m^2	global warming potential	GWP	kg CO_2 to air
ozone depletion	stratospheric ozone decrease	ppt×yr	ozone depletion potential	ODP	kg CFC-11 to air
ionizing radiation	absorbed dose increase	man×Sv	ionizing radiation potential	IRP	kBq Co-60 to air
fine particulate matter formation	$PM_{2.5}$ population intake increase	kg	particulate matter formation potential	PMFP	kg $PM_{2.5}$ to air
Photochemical oxidant formation: ecosystem quality	tropospheric ozone increase (AOT40)	ppb.yr	Photo-chemical oxidant formation potential: ecosystems	EOFP	kg NOx to air

Photochemical oxidant formation: human health	tropospheric ozone population intake increase (M6M)	kg	Photo-chemical oxidant formation potential: humans	HOFP	kg NOx to air
terrestrial acidification	proton increase in natural soils	yr×m^2×mol/l	terrestrial acidification potential	TAP	kg SO_2 to air
freshwater eutrophication	phosphorus increases in fresh water	yr×m^3	freshwater eutrophication potential	FEP	kg P to fresh water
human toxicity: cancer	risk increase of cancer disease incidence	-	human toxicity potential	HTPc	kg 1,4-DCB to urban air
human toxicity: non-cancer	risk increase of non-cancer disease incidence	-	human toxicity potential	HTPnc	kg 1,4-DCB to urban air
terrestrial ecotoxicity	hazard-weighted increase in natural soils	yr×m^2	terrestrial ecotoxicity potential	TETP	kg 1,4-DCB to industrial soil
freshwater ecotoxicity	hazard-weighted increase in fresh waters	yr×m^3	freshwater ecotoxicity potential	FETP	kg 1,4-DCB to fresh water
marine ecotoxicity	hazard-weighted increase in marine water	yr×m^3	marine ecotoxicity potential	METP	kg 1,4-DCB to marine water
land use	occupation and time-integrated transformation	yr×m^2	agricultural land occupation potential	LOP	m^2×yr annual crop land
water use	increase of water consumed	m^3	water consumption potential	WCP	m^3 water consumed
mineral resource scarcity	ore grade decrease	kg	surplus ore potential	SOP	kg Cu
fossil resource scarcity	upper heating value	MJ	fossil fuel potential	FFP	kg oil

Table A.3: Midpoint to endpoint factors for the Individualist (I), Hierarchist (H) and Egalitarian I perspectives, extracted from ReCiPe documentation report (Huijbregts, et al. 2017)

Impact category	Unit	I	H	E
Human health				
climate change	yr/kg CO_2 to air	8.1E-08	9.3E-07	1.3E-05
ozone depletion	yr/kg CFC11 to air	2.4E-04	5.3E-04	1.3E-03
ionizing radiation	yr//kBq Co-60 to air	6.8E-09	8.5E-09	1.4E-08
fine particulate matter formation	yr/kg $PM_{2.5}$ to air	6.3E-04	6.3E-04	6.3E-04
photochemical ozone formation	yr/kg NOx to air	9.1E-07	9.1E-07	9.1E-07
cancer toxicity	yr/kg 1,4-DCB to air	3.3E-06	3.3E-06	3.3E-06
non-cancer toxicity	yr/kg 1,4-DCB to air	6.7E-09	6.7E-09	6.7E-09
water use	yr/m3 water	3.1E-06	2.2E-06	2.2E-06
Ecosystem quality: terrestrial				
climate change	species. yr/kg CO_2 to air	5.3E-10	2.8E-09	2.5E-08
photochemical ozone formation	species. yr/kg No=Ox to air	1.3E-07	1.3E-07	1.3E-07
acidification	species. yr/kg SO_2 to air	2.1E-07	2.1E-07	2.1E-07
toxicity	species. yr/kg 1,4-DCB to industrial soil	5.4E-08	5.4E-08	5.4E-08
water use	species. yr/m^3 water consumed	0	1.4E-08	1.4E-08
land use	species/m^2 annual crop land	8.9E-09	8.9E-09	8.9E-09
Ecosystem quality: fresh water				
climate change	species. yr/kg CO_2	1.5E-14	7.7E-14	6.8E-13
eutrophication	species. yr/kg P to fresh water	6.1E-07	6.1E-07	6.1E-07
toxicity	species. yr/kg 1,4-DCB to fresh water	7.0E-10	7.0E-10	7.0E-10
water use	species. yr/m^3 water consumed	6.0E-13	6.0E-13	6.0E-13
Ecosystem quality: marine				
toxicity	species. yr/kg 1,4-DCB	1.1E-10	1.1E-10	1.1E-10

APPENDIX B

Table B.1: Pollutants from diesel burn

Item	Emission Factor, g/km	Yearly Emission, kg		
		DSCC	DNCC	Combined
CO	9.02E-01	2.67E+03	2.45E+03	5.12E+03
NOx	5.50E+00	1.63E+04	1.49E+04	3.12E+04
N_2O	8.00E-03	2.37E+01	2.17E+01	4.54E+01
NH_3	2.90E-03	8.57E+00	7.87E+00	1.64E+01
Pb	8.05E-06	2.38E-02	2.19E-02	4.57E-02
$PM_{2.5}$	1.04E-01	3.07E+02	2.82E+02	5.90E+02
CH_4	5.44E-02	1.61E+02	1.48E+02	3.08E+02
PCB	1.26E-11	3.73E-08	3.42E-08	7.15E-08
SO_2	2.77E-01	8.19E+02	7.52E+02	1.57E+03
CO_2	8.78E+02	2.60E+06	2.38E+06	4.98E+06
As	2.77E-08	8.19E-05	7.52E-05	1.57E-04
Cd	1.39E-08	4.09E-05	3.76E-05	7.85E-05
Cr	2.35E-06	6.96E-03	6.39E-03	1.34E-02
Cu	1.58E-06	4.67E-03	4.29E-03	8.95E-03
Hg	1.47E-06	4.34E-03	3.98E-03	8.33E-03
Ni	5.54E-08	1.64E-04	1.50E-04	3.14E-04
Se	2.77E-08	8.19E-05	7.52E-05	1.57E-04
Zn	4.99E-06	1.47E-02	1.35E-02	2.83E-02
PAH	4.92E-02	1.46E+02	1.34E+02	2.79E+02
NMVOC	1.58E-01	4.67E+02	4.29E+02	8.96E+02

Table B.2: Emission from yearly diesel burn for landfill operation in baseline condition

Input		**Aminbazar**	**Matuail**	**Combined**
Diesel (in kg/year)		614400	697600	1312000
Output	Emission factor (g/tonnes fuel)	Aminbazar, kg/year	Matuail, kg/year	Combined, kg/year
CH_4	8.30E+01	5.10E+01	5.79E+01	1.09E+02
CO	1.08E+04	6.62E+03	7.52E+03	1.41E+04
CO_2	3.16E+06	1.94E+06	2.20E+06	4.15E+06
N_2O	1.35E+02	8.29E+01	9.42E+01	1.77E+02
NH_3	8.00E+00	4.92E+00	5.58E+00	1.05E+01
NOx	3.28E+04	2.01E+04	2.29E+04	4.30E+04
SO_2	1.00E+03	6.14E+02	6.98E+02	1.31E+03
PM_{10}	2.10E+03	1.29E+03	1.47E+03	2.76E+03
$PM_{2.5}$	5.51E+03	3.39E+03	3.85E+03	7.23E+03
NMVOC	3.38E+03	2.07E+03	2.36E+03	4.43E+03
PAH	3.32E+00	2.04E+00	2.32E+00	4.36E+00
Cadmium	1.00E-02	6.14E-03	6.98E-03	1.31E-02
Copper	1.70E+00	1.04E+00	1.19E+00	2.23E+00
Chromium	5.00E-02	3.07E-02	3.49E-02	6.56E-02
Nickel	7.00E-02	4.30E-02	4.88E-02	9.18E-02
Selenium	1.00E-02	6.14E-03	6.98E-03	1.31E-02
Zinc	1.00E+00	6.14E-01	6.98E-01	1.31E+00

Table B.3: Emission from yearly electricity production in baseline condition

Ecoinvent Process: electricity production, natural gas, combined cycle power plant | electricity, high voltage | Cutoff, U – IN-DL (India-Delhi)			
Electricity Consumption	**Aminbazar**	**Matuail**	**Combined**
kWh/year	302597	259740	562338
Input	**Aminbazar**	**Matuail**	**Combined**
Water, cooling, unspecified origin, m^3/year	1.51E+04	1.30E+04	2.81E+04
Output	**Aminbazar**	**Matuail**	**Combined**
All substance is expressed in **kg/year** expect for water which is **m^3/year**			
Acenaphthene	2.03E-06	1.74E-06	3.77E-06
Acetaldehyde	2.05E-03	1.76E-03	3.80E-03
Acetic acid	3.10E-01	2.66E-01	5.75E-01
Arsenic	1.05E-04	9.03E-05	1.95E-04
Benzene	2.31E-03	1.98E-03	4.29E-03
Benzo(a)pyrene	1.35E-06	1.16E-06	2.52E-06
Beryllium	6.32E-06	5.43E-06	1.17E-05
Butane	2.37E+00	2.03E+00	4.40E+00
Cadmium	5.78E-04	4.96E-04	1.07E-03
Carbon dioxide, fossil	1.38E+05	1.19E+05	2.57E+05
Carbon monoxide, fossil	5.63E+00	4.83E+00	1.05E+01
Chromium	7.34E-04	6.30E-04	1.36E-03
Cobalt	4.40E-05	3.78E-05	8.18E-05
N_2O	2.50E+00	2.15E+00	4.65E+00
Ethane	3.51E+00	3.01E+00	6.52E+00
Formaldehyde	8.27E-02	7.09E-02	1.54E-01
Hexane	2.03E+00	1.74E+00	3.77E+00
Lead	2.64E-04	2.26E-04	4.90E-04
Manganese	2.00E-04	1.72E-04	3.71E-04
Mercury	1.76E-04	1.51E-04	3.27E-04
Methane, fossil	2.48E+00	2.13E+00	4.62E+00
Nickel	1.10E-03	9.47E-04	2.05E-03
NOx	6.53E+01	5.60E+01	1.21E+02
PAH	2.05E-02	1.76E-02	3.80E-02
$PM_{2.5}$	1.25E+00	1.07E+00	2.33E+00
Pentane	2.94E+00	2.53E+00	5.47E+00
Propane	1.80E+00	1.55E+00	3.35E+00
Propionic acid	4.09E-02	3.51E-02	7.61E-02
Selenium	1.26E-05	1.08E-05	2.34E-05
Sulfur dioxide	1.46E+00	1.26E+00	2.72E+00
Toluene	3.84E-03	3.29E-03	7.13E-03
Water (air emission)	2.51E+02	2.16E+02	4.67E+02
Water (water emission)	1.54E+04	1.32E+04	2.86E+04

Table B.4: Emission from diesel burn for landfill operation in alternative scenarios

Input		**Alternative A1**	**Alternative A2, A3, A4**
Output	Emission factor (g/tonnes fuel)	Kg/year	Kg/year
CH_4	8.30E+01	1.75E+01	7.57E+00
CO	1.08E+04	2.27E+03	9.83E+02
CO_2	3.16E+06	6.67E+05	2.88E+05
N_2O	1.35E+02	2.85E+01	1.23E+01
NH_3	8.00E+00	1.69E+00	7.30E-01
NOx	3.26E+04	6.92E+03	2.99E+03
SO_2	1.00E+03	2.11E+02	9.12E+01
PM_{10}	2.10E+03	4.44E+02	1.92E+02
$PM_{2.5}$	5.51E+03	1.16E+03	5.03E+02
NMVOC	3.38E+03	7.13E+02	3.08E+02
PAH	3.32E+00	7.01E-01	3.03E-01
Cadmium	1.00E-02	2.11E-03	9.12E-04
Copper	1.70E+00	3.59E-01	1.55E-01
Chromium	5.00E-02	1.06E-02	4.56E-03
Nickel	7.00E-02	1.48E-02	6.39E-03
Selenium	1.00E-02	2.11E-03	9.12E-04
Zinc	1.00E+00	2.11E-01	9.12E-02

Table B.5: Emission from the production of electricity used for landfill maintenance in alternative scenarios

Input	**Alternative A1**	**Alternative A2, A3, A4**
All the units are in kg except water in m^3		
Water, cooling, unspecified natural origin	4756.53	2002.61
Output	**Alternative A1**	**Alternative A2, A3, A4**
Acenaphthene	6.38E-07	2.69E-07
Acetaldehyde	6.44E-04	2.71E-04
Acetic acid	9.74E-02	4.10E-02
Arsenic	3.31E-05	1.39E-05
Benzene	7.26E-04	3.06E-04
Benzo(a)pyrene	4.26E-07	1.79E-07
Beryllium	1.99E-06	8.37E-07
Butane	7.45E-01	3.14E-01
Cadmium	1.82E-04	7.66E-05
Carbon dioxide, fossil	4.35E+04	1.83E+04
Carbon monoxide, fossil	1.77E+00	7.46E-01
Chromium	2.31E-04	9.73E-05
Cobalt	1.38E-05	5.83E-06
N_2O	7.87E-01	3.31E-01
Ethane	1.10E+00	4.64E-01
Formaldehyde	2.60E-02	1.09E-02
Hexane	6.38E-01	2.69E-01
Lead	8.29E-05	3.49E-05
Manganese	6.29E-05	2.65E-05
Mercury	5.54E-05	2.33E-05
Methane, fossil	7.82E-01	3.29E-01
Nickel	3.47E-04	1.46E-04
NOx	2.05E+01	8.64E+00
PAH	6.44E-03	2.71E-03
$PM_{2.5}$	3.94E-01	1.66E-01
Pentane	9.26E-01	3.90E-01
Propane	5.68E-01	2.39E-01
Propionic acid	1.29E-02	5.42E-03
Selenium	3.95E-06	1.66E-06
Sulfur dioxide	4.60E-01	1.94E-01
Toluene	1.21E-03	5.08E-04
Water (air emission)	7.90E+01	3.33E+01
Water (water emission)	4.84E+03	2.04E+03

Table B.6: LCI output data for biowaste landfilling for all alternative combined scenarios and DSCC, DNCC baseline scenario

Flow	Category and Description	Quantity for (quantities are provided in kg except for heat which is expressed in MJ)		
		Alt. A1, A2, A3, A4	DSCC	DNCC
Aluminium	Elementary flows/Emission to air/high population density burden from direct release or incineration of landfill biogas	1.48E+00	2.35E+01	2.59E+01
Arsenic		5.97E-02	9.50E-01	1.04E+00
Bromine		2.51E+00	3.99E+01	4.39E+01
Cadmium		1.92E-03	3.00E-02	3.00E-02
Calcium		8.42E+00	1.34E+02	1.47E+02
Carbon dioxide, biogenic		4.15E+06	6.59E+07	7.25E+07
Chromium		2.70E-04	0.00E+00	0.00E+00
Cobalt		4.76E-03	8.00E-02	8.00E-02
Copper		2.99E-04	0.00E+00	1.00E-02
Hydrogen chloride		1.72E+03	2.73E+04	3.01E+04
Hydrogen fluoride		9.45E+02	1.50E+04	1.65E+04
Iodine		2.30E-02	3.70E-01	4.00E-01
Iron		2.44E-02	3.90E-01	4.30E-01
Lead		4.32E-04	1.00E-02	1.00E-02
Magnesium		5.16E+00	8.19E+01	9.01E+01
Manganese		1.46E-02	2.30E-01	2.60E-01
Mercury		2.27E-02	3.60E-01	4.00E-01
Methane, biogenic		9.84E+05	1.56E+07	1.72E+07
Molybdenum		1.25E-04	0.00E+00	0.00E+00
Nickel		9.34E-04	1.00E-02	2.00E-02
Nitrogen oxides		6.51E+01	1.03E+03	1.14E+03
Potassium		7.59E+00	1.20E+02	1.33E+02
Selenium		1.56E-04	0.00E+00	0.00E+00
Silicon		5.92E+00	9.41E+01	1.03E+02
Sodium		1.65E+01	2.61E+02	2.88E+02
Sulfur dioxide		2.32E+03	3.68E+04	4.05E+04
Tin		1.40E-04	0.00E+00	0.00E+00
Vanadium		9.37E-04	1.00E-02	2.00E-02
Zinc		7.27E-03	1.20E-01	1.30E-01
Heat, waste	Elementary flows/Emission to soil/industrial burden from short-term decomposition of waste (0-100a).	6.72E+07	1.07E+09	1.17E+09

Table B.6: LCI output data for biowaste landfilling for all alternative combined scenarios and DSCC, DNCC baseline scenario, continued

Aluminium	Elementary flows/Emission to water/ground water burden from short-term leachate to groundwater in uncontrolled landfill in moist climate.	3.03E+03	1.88E+04	8.28E+04
Ammonium, ion		2.31E+04	1.43E+05	6.32E+05
Arsenic, ion		2.18E+00	1.35E+01	5.95E+01
BOD5, Biological Oxygen Demand		7.44E+03	4.61E+04	2.03E+05
Boron		2.30E+02	1.43E+03	6.28E+03
Bromine		9.17E+01	5.69E+02	2.50E+03
Cadmium, ion		1.47E-01	9.14E-01	4.02E+00
Calcium, ion		1.72E+04	1.07E+05	4.70E+05
Chloride		6.12E+04	3.79E+05	1.67E+06
Chromium VI		5.54E-01	3.43E+00	1.51E+01
Cobalt		9.76E+00	6.05E+01	2.66E+02
COD, Chemical Oxygen Demand		3.14E+04	1.95E+05	8.57E+05
Copper, ion		5.35E-01	3.32E+00	1.46E+01
DOC, Dissolved Organic Carbon		2.87E+04	1.78E+05	7.84E+05
Fluoride		8.92E+01	5.53E+02	2.43E+03
Hydrogen sulfide		2.47E+02	1.53E+03	6.74E+03
Iodide		8.41E-01	5.21E+00	2.29E+01
Iron, ion		5.00E+01	3.10E+02	1.37E+03
Lead		6.64E-01	4.12E+00	1.81E+01
Magnesium		1.06E+04	6.55E+04	2.88E+05
Manganese		2.99E+01	1.85E+02	8.16E+02
Mercury		2.91E-02	1.80E-01	7.94E-01
Molybdenum		2.56E-01	1.59E+00	6.99E+00
Nickel, ion		1.91E+00	1.19E+01	5.22E+01
Nitrate		2.43E+03	1.51E+04	6.64E+04
Nitrite		1.26E+03	7.81E+03	3.44E+04
Nitrogen, organic bound		3.78E+04	2.34E+05	1.03E+06
Phosphate		1.18E+03	7.29E+03	3.21E+04
Potassium, ion		1.55E+04	9.63E+04	4.24E+05
Selenium		3.20E-01	1.98E+00	8.73E+00
Silicon		1.21E+04	7.52E+04	3.31E+05
Sodium, ion		3.37E+04	2.09E+05	9.20E+05
Sulfate		9.47E+03	5.87E+04	2.59E+05
Tin, ion		2.86E-01	1.77E+00	7.81E+00
TOC, Total Organic Carbon		2.87E+04	1.78E+05	7.84E+05
Vanadium, ion		1.92E+00	1.19E+01	5.24E+01
Zinc, ion		1.67E+01	1.04E+02	4.57E+02

Table B.6: LCI output data for biowaste landfilling for all alternative combined scenarios and DSCC, DNCC baseline scenario, continued

Aluminium	Elementary flows/Emission to water/ground water, long-term Emissions from long-term leachate (>100a) directly from MSW landfill and indirectly via incineration of treatment sludge from leachate treatment.	2.22E+05	1.37E+06	6.05E+06
Ammonium, ion		1.19E+04	7.40E+04	3.26E+05
Arsenic, ion		4.28E+01	2.65E+02	1.17E+03
BOD5, Biological Oxygen Demand		6.90E+05	4.28E+06	1.88E+07
Boron		2.30E-07	1.43E-06	6.28E-06
Bromine		4.19E+01	2.60E+02	1.14E+03
Cadmium, ion		2.95E+00	1.83E+01	8.06E+01
Calcium, ion		4.73E+05	2.93E+06	1.29E+07
Chloride		2.79E+04	1.73E+05	7.62E+05
Chromium VI		2.75E-01	1.70E+00	7.49E+00
Cobalt		1.03E+02	6.36E+02	2.80E+03
COD, Chemical Oxygen Demand		2.92E+06	1.81E+07	7.96E+07
Copper, ion		4.04E+02	2.51E+03	1.10E+04
DOC, Dissolved Organic Carbon		2.67E+06	1.65E+07	7.28E+07
Fluoride		3.95E+03	2.45E+04	1.08E+05
Heat, waste		1.15E+08	7.10E+08	3.13E+09
Hydrogen sulfide		2.17E+03	1.34E+04	5.91E+04
Iodide		3.84E-01	2.38E+00	1.05E+01
Iron, ion		1.34E+04	8.33E+04	3.67E+05
Lead		4.17E+02	2.58E+03	1.14E+04
Magnesium		5.28E+04	3.28E+05	1.44E+06
Manganese		6.68E+01	4.14E+02	1.82E+03
Mercury		1.53E+00	9.50E+00	4.18E+01
Molybdenum		1.36E+00	8.46E+00	3.72E+01
Nickel, ion		1.20E+02	7.44E+02	3.27E+03
Nitrate		1.26E+03	7.79E+03	3.43E+04
Nitrite		6.50E+02	4.03E+03	1.77E+04
Nitrogen, organic bound		1.95E+04	1.21E+05	5.33E+05
Phosphate		5.16E+03	3.20E+04	1.41E+05
Potassium, ion		6.32E+04	3.92E+05	1.72E+06
Selenium		1.15E+00	7.16E+00	3.15E+01
Silicon		6.36E+03	3.94E+04	1.74E+05
Sodium, ion		3.37E-05	2.09E-04	9.20E-04
Sulfate		8.31E+04	5.15E+05	2.27E+06
Tin, ion		1.79E+02	1.11E+03	4.90E+03
TOC, Total Organic Carbon		2.67E+06	1.65E+07	7.28E+07
Vanadium, ion		7.19E+00	4.45E+01	1.96E+02
Zinc, ion		1.29E+03	8.01E+03	3.53E+04

Table B.7: Combined baseline, alternative scenarios, DNCC and DSCC glass landfill LCI

Flow	Category	Quantity expressed in kg/year for all substances except heat (MJ/year)				Description
		Combined Baseline B0, Alt. A1	Alt. A2, A3, A4	DSCC, Baseline	DNCC, Baseline	
Calcium, ion	Elementary flows/Emission to water/ground water, long-term	1.02E+06	5.12E+04	2.19E+05	8.05E+05	Emissions/ burdens from long-term leachate (>100a) directly from MSW landfill
Chloride		2.76E+03	1.38E+02	5.89E+02	2.17E+03	
Chromium VI		11.57E+00	5.78E-01	5.05E+00	6.52E+00	
Copper, ion		1.10E+02	5.51E+00	2.36E+01	8.67E+01	
Heat, waste		2.00E+06	1.00E+05	4.28E+05	1.57E+06	
Lead		5.44E+02	2.72E+01	1.16E+02	4.28E+02	
Silicon		6.41E+04	3.20E+03	2.80E+04	3.61E+04	
Sodium, ion		9.07E+05	4.53E+04	1.94E+05	7.13E+05	
Zinc, ion		5.51E+01	2.76E+00	1.18E+01	4.33E+01	

Table B.8: Graphical paper landfilling LCI for baseline, alternative, DNCC and DSCC

Flow	Category	Quantity expressed in kg/year for all substances except heat (MJ/year)			
		Baseline B0, Alt. A1	Alt. A1, A2, A3	DSCC	DNCC
Aluminium	Elementary flows/Emission to air/high population density burden from direct release or incineration of landfill biogas	2.07E+00	1.03E-01	1.21E+00	8.55E-01
Ammonia		1.11E+01	5.57E-01	1.11E+01	-
Antimony		1.08E-04	5.40E-06	4.90E-06	1.03E-04
Arsenic		2.86E-02	1.43E-03	1.38E-04	2.85E-02
Barium		3.44E-01	1.72E-02	1.64E-01	1.81E-01
Beryllium		1.15E-04	5.76E-06	3.71E-05	7.81E-05
Boron		5.03E+00	2.51E-01	5.03E+00	-
Cadmium		1.08E-02	5.39E-04	1.07E-05	1.08E-02
Calcium		7.15E-01	3.58E-02	9.76E-02	6.18E-01
Carbon dioxide, biogenic		3.54E+06	1.77E+05	4.50E+04	3.50E+06
Carbon monoxide, biogenic		3.07E+01	1.54E+00	3.07E+01	-
Chromium		2.27E-04	1.14E-05	7.99E-09	2.27E-04
Cobalt		3.26E-04	1.63E-05	-	3.26E-04
Copper		4.72E-04	2.36E-05	2.17E-06	4.70E-04
Cyanide		3.14E-01	1.57E-02	3.14E-01	-
Dinitrogen monoxide		3.07E+01	1.54E+00	3.07E+01	-
Hydrogen chloride		3.68E+02	1.84E+01	-	3.68E+02
Hydrogen fluoride		4.28E+01	2.14E+00	-	4.28E+01
Iron		2.40E-02	1.20E-03	1.47E-03	2.25E-02
Lead		8.92E-04	4.46E-05	2.09E-05	8.71E-04
Magnesium		4.14E+00	2.07E-01	4.77E-01	3.66E+00
Manganese		6.36E-02	3.18E-03	1.65E-07	6.36E-02
Mercury		2.10E-02	1.05E-03	2.15E-08	2.10E-02
Methane, biogenic		1.62E+06	8.08E+04	8.83E+01	1.62E+06
Molybdenum		1.22E-03	6.11E-05	5.97E-04	6.25E-04
Nickel		7.58E-04	3.79E-05	1.24E-08	7.58E-04
Nitrogen oxides		1.37E+02	6.87E+00	1.09E+02	2.84E+01
NMVOC, non-methane volatile organic compounds, unspecified origin		4.00E-01	2.00E-02	4.00E-01	-
Phosphorus		5.33E-03	2.66E-04	5.33E-03	-
Potassium		1.34E+00	6.70E-02	-	1.34E+00
Selenium		3.75E-04	1.88E-05	-	3.75E-04
Silicon		4.56E+00	2.28E-01	3.10E+00	1.47E+00
Silver		3.69E-07	1.84E-08	-	3.69E-07
Sodium		4.70E+00	2.35E-01	-	4.70E+00
Strontium		4.90E-03	2.45E-04	2.22E-04	4.68E-03
Sulfur dioxide		1.01E+03	5.07E+01	-	1.01E+03
Thallium		2.03E-04	1.02E-05	6.56E-05	1.38E-04
Titanium		1.75E-02	8.74E-04	5.62E-03	1.19E-02
Zinc		7.34E-03	3.67E-04	8.88E-05	7.25E-03

Table B.8: Graphical paper landfilling LCI for baseline, alternative, DNCC and DSCC, continued

Aluminium	Elementary flows/Emission to air/low population density burden from direct release or incineration of landfill biogas	2.06E-01	1.03E-02	2.06E-01	-
Antimony		2.49E-05	1.25E-06	2.49E-05	-
Arsenic		6.85E-03	3.43E-04	6.85E-03	-
Barium		4.35E-02	2.18E-03	4.35E-02	-
Beryllium		1.88E-05	9.42E-07	1.88E-05	-
Cadmium		2.60E-03	1.30E-04	2.60E-03	-
Calcium		1.49E-01	7.45E-03	1.49E-01	-
Carbon dioxide, biogenic		1.35E+06	6.73E+04	1.35E+06	-
Carbon monoxide, land transformation		7.64E+01	3.82E+00	7.64E+01	-
Chromium		5.47E-05	2.74E-06	5.47E-05	-
Cobalt		7.89E-05	3.94E-06	7.89E-05	-
Copper		1.13E-04	5.67E-06	1.13E-04	-
Hydrogen chloride		8.88E+01	4.44E+00	8.88E+01	-
Hydrogen fluoride		1.04E+01	5.18E-01	1.04E+01	-
Iron		5.42E-03	2.71E-04	5.42E-03	-
Lead		2.10E-04	1.05E-05	2.10E-04	-
Magnesium		8.83E-01	4.41E-02	8.83E-01	-
Manganese		1.53E-02	7.67E-04	1.53E-02	-
Mercury		5.08E-03	2.54E-04	5.08E-03	-
Methane, biogenic		2.07E+05	1.03E+04	2.07E+05	-
Molybdenum		1.51E-04	7.54E-06	1.51E-04	-
Nickel		1.83E-04	9.15E-06	1.83E-04	-
Nitrogen oxides		3.22E+00	1.61E-01	3.22E+00	-
NMVOC, non-methane volatile organic compounds, unspecified origin		1.44E+00	7.22E-02	1.44E+00	-
Particulates, < 2.5 um		2.56E+01	1.28E+00	2.56E+01	-
Potassium		3.23E-01	1.61E-02	3.23E-01	-
Selenium		9.07E-05	4.54E-06	9.07E-05	-
Silicon		3.54E-01	1.77E-02	3.54E-01	-
Silver		8.88E-08	4.44E-09	8.88E-08	-
Sodium		1.13E+00	5.67E-02	1.13E+00	-
Strontium		1.13E-03	5.65E-05	1.13E-03	-
Sulfur dioxide		2.45E+02	1.22E+01	2.45E+02	-
Thallium		3.33E-05	1.66E-06	3.33E-05	-
Titanium		2.86E-03	1.43E-04	2.86E-03	-
Zinc		1.75E-03	8.75E-05	1.75E-03	-
Heat, waste	Elementary flows/Emission to soil/industrial burden from short-term decomposition of waste (0-100a).	5.55E+07	2.78E+06	-	5.55E+07

Table B.8: Graphical paper landfilling LCI for baseline, alternative, DNCC and DSCC, continued

Aluminium	Elementary flows/Emission to water/ground water burden from short-term leachate to groundwater in uncontrolled landfill in moist climate.	3.42E+03	1.71E+02	-	3.42E+03
Ammonium, ion		1.98E+04	9.88E+02	-	1.98E+04
Antimony		4.13E-01	2.06E-02	-	4.13E-01
Arsenic, ion		2.03E+00	1.02E-01	-	2.03E+00
Barium		7.22E+02	3.61E+01	-	7.22E+02
Beryllium		3.13E-01	1.56E-02	-	3.13E-01
BOD5, Biological Oxygen Demand		1.68E+04	8.41E+02	-	1.68E+04
Boron		3.52E+02	1.76E+01	-	3.52E+02
Cadmium, ion		1.62E+00	8.08E-02	-	1.62E+00
Calcium, ion		2.47E+03	1.24E+02	-	2.47E+03
Chloride		2.55E+04	1.28E+03	-	2.55E+04
Chromium VI		9.10E-01	4.55E-02	-	9.10E-01
Cobalt		1.31E+00	6.53E-02	-	1.31E+00
COD, Chemical Oxygen Demand		7.10E+04	3.55E+03	-	7.10E+04
Copper, ion		1.65E+00	8.23E-02	-	1.65E+00
DOC, Dissolved Organic Carbon		6.49E+04	3.25E+03	-	6.49E+04
Fluoride		7.89E+00	3.95E-01	-	7.89E+00
Hydrogen sulfide		2.11E+02	1.05E+01	-	2.11E+02
Iron, ion		9.01E+01	4.50E+00	-	9.01E+01
Lead		2.61E+00	1.31E-01	-	2.61E+00
Magnesium		1.46E+04	7.32E+02	-	1.46E+04
Manganese		2.54E+02	1.27E+01	-	2.54E+02
Mercury		5.26E-02	2.63E-03	-	5.26E-02
Molybdenum		2.50E+00	1.25E-01	-	2.50E+00
Nickel, ion		3.03E+00	1.52E-01	-	3.03E+00
Nitrate		2.08E+03	1.04E+02	-	2.08E+03
Nitrite		1.08E+03	5.38E+01	-	1.08E+03
Nitrogen, organic bound		3.23E+04	1.61E+03	-	3.23E+04
Phosphate		1.07E+02	5.34E+00	-	1.07E+02
Potassium, ion		5.36E+03	2.68E+02	-	5.36E+03
Selenium		1.50E+00	7.50E-02	-	1.50E+00
Silicon		5.86E+03	2.93E+02	-	5.86E+03
Silver, ion		1.29E-03	6.45E-05	-	1.29E-03
Sodium, ion		1.88E+04	9.40E+02	-	1.88E+04
Strontium		1.87E+01	9.35E-01	-	1.87E+01
Sulfate		8.08E+03	4.04E+02	-	8.08E+03
Thallium		5.52E-01	2.76E-02	-	5.52E-01
Titanium, ion		4.74E+01	2.37E+00	-	4.74E+01
TOC, Total Organic Carbon		6.49E+04	3.25E+03	-	6.49E+04
Zinc, ion		3.26E+01	1.63E+00	-	3.26E+01

Table B.8: Graphical paper landfilling LCI for baseline, alternative, DNCC and DSCC, continued

Aluminium	Elementary flows/Emission to water/ground water, long-term Emissions from long-term leachate (>100a) directly from MSW landfill and indirectly via incineration of treatment sludge from leachate treatment.	3.11E+05	1.55E+04	6.07E+04	2.50E+05
Ammonium, ion		1.27E+04	6.35E+02	2.46E+03	1.02E+04
Antimony		9.96E-01	4.98E-02	3.72E-01	6.24E-01
Arsenic, ion		4.95E+01	2.48E+00	9.67E+00	3.99E+01
Barium		2.15E+03	1.07E+02	5.33E+02	1.62E+03
Beryllium		2.44E+01	1.22E+00	4.76E+00	1.96E+01
BOD5, Biological Oxygen Demand		1.66E+06	8.30E+04	9.67E+04	1.56E+06
Boron		2.75E+01	1.38E+00	2.75E+01	3.52E-07
Cadmium, ion		4.02E+01	2.01E+00	7.79E+00	3.24E+01
Calcium, ion		8.43E+04	4.22E+03	1.64E+04	6.79E+04
Chloride		1.45E+04	7.26E+02	2.82E+03	1.17E+04
Chromium VI		9.06E-01	4.53E-02	3.33E-01	5.73E-01
Cobalt		1.72E+01	8.60E-01	3.45E+00	1.38E+01
COD, Chemical Oxygen Demand		7.01E+06	3.51E+05	4.08E+05	6.60E+06
Copper, ion		1.54E+03	7.72E+01	3.00E+02	1.24E+03
DOC, Dissolved Organic Carbon		6.41E+06	3.21E+05	3.73E+05	6.04E+06
Fluoride		4.34E+02	2.17E+01	8.43E+01	3.50E+02
Heat, waste		2.48E+08	1.24E+07	-	2.48E+08
Hydrogen sulfide		2.30E+03	1.15E+02	4.46E+02	1.85E+03
Iron, ion		2.47E+04	1.23E+03	4.30E+02	2.42E+04
Lead		2.04E+03	1.02E+02	3.96E+02	1.64E+03
Magnesium		9.13E+04	4.57E+03	1.80E+04	7.33E+04
Manganese		7.29E+02	3.64E+01	1.60E+02	5.69E+02
Mercury		3.44E+00	1.72E-01	6.71E-01	2.77E+00
Molybdenum		2.49E+01	1.25E+00	8.38E+00	1.65E+01
Nickel, ion		2.36E+02	1.18E+01	4.61E+01	1.90E+02
Nitrate		1.35E+03	6.74E+01	2.71E+02	1.08E+03
Nitrite		6.91E+02	3.45E+01	1.34E+02	5.57E+02
Nitrogen, organic bound		2.07E+04	1.04E+03	4.02E+03	1.67E+04
Phosphate		4.81E+02	2.41E+01	1.20E+01	4.69E+02
Potassium, ion		2.71E+04	1.35E+03	5.28E+03	2.18E+04
Selenium		1.04E+01	5.19E-01	3.60E+00	6.78E+00
Silicon		6.00E+03	3.00E+02	2.10E+03	3.90E+03
Silver, ion		1.21E+00	6.05E-02	2.35E-01	9.76E-01
Sodium, ion		2.33E-05	1.17E-06	4.53E-06	1.88E-05
Strontium		1.46E+03	7.30E+01	2.85E+02	1.17E+03
Sulfate		8.81E+04	4.40E+03	1.71E+04	7.10E+04
Thallium		4.30E+01	2.15E+00	8.38E+00	3.46E+01
Titanium, ion		4.31E+03	2.15E+02	8.38E+02	3.47E+03
TOC, Total Organic Carbon		6.41E+06	3.21E+05	3.73E+05	6.04E+06
Zinc, ion		3.02E+03	1.51E+02	5.03E+02	2.52E+03

Table B.8: Graphical paper landfilling LCI for baseline, alternative, DNCC and DSCC, continued

Aluminium	Elementary flows/Emission to water/surface water	4.93E+01	2.47E+00	4.93E+01	-
Ammonium, ion		6.07E+03	3.03E+02	6.07E+03	-
Antimony		6.76E-02	3.38E-03	6.76E-02	-
Arsenic, ion		4.31E-01	2.16E-02	4.31E-01	-
Barium		1.05E+01	5.23E-01	1.05E+01	-
Beryllium		3.83E-02	1.91E-03	3.83E-02	-
BOD5, Biological Oxygen Demand	Emissions from short-term leachate treatment and incineration of resulting sludge.	3.11E+03	1.56E+02	3.11E+03	-
Boron		4.93E+01	2.47E+00	4.93E+01	-
Cadmium, ion		1.98E-01	9.89E-03	1.98E-01	-
Calcium, ion		5.37E+02	2.69E+01	5.37E+02	-
Chloride		6.21E+03	3.11E+02	6.21E+03	-
Chromium VI		1.15E-01	5.74E-03	1.15E-01	-
Chromium, ion		3.45E-04	1.72E-05	3.45E-04	-
Cobalt		1.60E-01	7.99E-03	1.60E-01	-
COD, Chemical Oxygen Demand		9.86E+03	4.93E+02	9.86E+03	-
Copper, ion		1.03E-01	5.15E-03	1.03E-01	-
DOC, Dissolved Organic Carbon		2.40E+03	1.20E+02	2.40E+03	-
Fluoride		1.90E+00	9.52E-02	1.90E+00	-
Iron, ion		1.10E+01	5.52E-01	1.10E+01	-
Lead		6.95E-02	3.48E-03	6.95E-02	-
Magnesium		3.19E+03	1.59E+02	3.19E+03	-
Manganese		3.11E+01	1.56E+00	3.11E+01	-
Mercury		4.01E-03	2.01E-04	4.01E-03	-
Molybdenum		3.57E-01	1.79E-02	3.57E-01	-
Nickel, ion		4.43E-01	2.22E-02	4.43E-01	-
Nitrate		2.20E+04	1.10E+03	2.20E+04	-
Nitrite		1.27E+02	6.36E+00	1.27E+02	-
Nitrogen		1.64E+02	8.21E+00	1.64E+02	-
Phosphate		9.07E+00	4.54E-01	9.07E+00	-
Potassium, ion		1.29E+03	6.46E+01	1.29E+03	-
Selenium		2.42E-01	1.21E-02	2.42E-01	-
Silicon		8.53E+01	4.27E+00	8.53E+01	-
Silver, ion		8.09E-05	4.04E-06	8.09E-05	-
Sodium, ion		4.53E+03	2.27E+02	4.53E+03	-
Strontium		2.29E+00	1.15E-01	2.29E+00	-
Sulfate		2.16E+03	1.08E+02	2.16E+03	-
Thallium		6.76E-02	3.38E-03	6.76E-02	-
Titanium, ion		5.82E+00	2.91E-01	5.82E+00	-
TOC, Total Organic Carbon		2.50E+03	1.25E+02	2.50E+03	-
Zinc, ion		2.44E+00	1.22E-01	2.44E+00	-

Table B.9: Packaging paper/ paperboard landfilling LCI in different scenarios

Flow	Category	Quantity expressed in kg/year for all substances except heat (MJ/year)			
		Baseline B0, Alt. A1	Alt. A1, A2, A3	DSCC	DNCC
Ammonia	Elementary flows/Emission to air/high population density burden from direct release or incineration of landfill biogas	1.02E+00	5.12E-02	1.02E+00	-
Antimony		9.37E-08	4.68E-09	4.25E-09	8.94E-08
Arsenic		2.18E-03	1.09E-04	1.05E-05	2.17E-03
Barium		2.30E-02	1.15E-03	1.10E-02	1.21E-02
Beryllium		1.79E-05	8.93E-07	5.75E-06	1.21E-05
Cadmium		8.07E-04	4.04E-05	8.00E-07	8.07E-04
Carbon dioxide, biogenic		5.07E+05	2.54E+04	6.47E+03	5.01E+05
Carbon monoxide, biogenic		4.15E+00	2.07E-01	4.15E+00	-
Chromium		1.94E-05	9.70E-07	6.79E-10	1.94E-05
Cobalt		5.44E-05	2.72E-06	8.22E-10	5.44E-05
Copper		3.64E-05	1.82E-06	1.67E-07	3.62E-05
Cyanide		2.88E-02	1.44E-03	2.88E-02	-
Dinitrogen monoxide		2.82E+00	1.41E-01	2.82E+00	-
Hydrogen chloride		1.92E+02	9.59E+00	-	1.92E+02
Lead		4.29E-05	2.15E-06	1.00E-06	4.19E-05
Manganese		2.01E-02	1.00E-03	5.19E-08	2.01E-02
Mercury		6.08E-03	3.04E-04	6.19E-09	6.08E-03
Methane, biogenic		2.31E+05	1.16E+04	1.26E+01	2.31E+05
Nickel		1.14E-04	5.70E-06	1.87E-09	1.14E-04
Nitrogen oxides		1.26E+01	6.32E-01	1.00E+01	2.61E+00
NMVOC, non-methane volatile organic compounds, unspecified origin		5.75E-02	2.88E-03	5.75E-02	-
Selenium		6.04E-05	3.02E-06	-	6.04E-05
Strontium		5.05E-04	2.52E-05	2.29E-05	4.82E-04
Sulfur dioxide		1.71E+02	8.54E+00	-	1.71E+02
Tin		1.28E-05	6.39E-07	5.46E-06	7.33E-06
Zinc		4.97E-04	2.49E-05	6.03E-06	4.91E-04
Antimony	Elementary flows/Emission to air/low population density burden from direct release or incineration of landfill biogas	2.16E-08	1.08E-09	2.16E-08	-
Arsenic		5.23E-04	2.61E-05	5.23E-04	-
Barium		2.91E-03	1.45E-04	2.91E-03	-
Beryllium		2.92E-06	1.46E-07	2.92E-06	-
Cadmium		1.95E-04	9.73E-06	1.95E-04	-
Carbon dioxide, biogenic		1.93E+05	9.64E+03	1.93E+05	-
Carbon monoxide, land transformation		1.09E+01	5.45E-01	1.09E+01	-
Chromium		4.68E-06	2.34E-07	4.68E-06	-
Cobalt		1.31E-05	6.55E-07	1.31E-05	-
Copper		8.71E-06	4.36E-07	8.71E-06	-
Hydrogen chloride		4.63E+01	2.31E+00	4.63E+01	-
Lead		1.01E-05	5.07E-07	1.01E-05	-
Manganese		4.84E-03	2.42E-04	4.84E-03	-
Mercury		1.47E-03	7.34E-05	1.47E-03	-
Methane, biogenic		2.96E+04	1.48E+03	2.96E+04	-
Nickel		2.75E-05	1.38E-06	2.75E-05	-

Table B.9: Packaging paper/ paperboard landfilling LCI in different scenarios, continued

Nitrogen oxides		2.96E-01	1.48E-02	2.96E-01	-
NMVOC, non-methane volatile organic compounds, unspecified origin		2.07E-01	1.03E-02	2.07E-01	-
Particulates, < 2.5 um		3.67E+00	1.84E-01	3.67E+00	-
Selenium		1.46E-05	7.29E-07	1.46E-05	-
Strontium		1.16E-04	5.81E-06	1.16E-04	-
Sulfur dioxide		4.12E+01	2.06E+00	4.12E+01	-
Tin		1.77E-06	8.85E-08	1.77E-06	-
Zinc		1.18E-04	5.92E-06	1.18E-04	-
Heat, waste	Elementary flows/Emission to soil/industrial burden from short-term decomposition of waste (0-100a).	8.02E+06	4.01E+05	-	8.02E+06
Ammonium, ion	Elementary flows/Emission to water/ground water burden from short-term leachate to groundwater in uncontrolled landfill in moist climate.	1.81E+03	9.07E+01	-	1.81E+03
Antimony		3.58E-04	1.79E-05	-	3.58E-04
Arsenic, ion		1.55E-01	7.73E-03	-	1.55E-01
Barium		4.83E+01	2.41E+00	-	4.83E+01
Beryllium		4.84E-02	2.42E-03	-	4.84E-02
BOD5, Biological Oxygen Demand		2.41E+03	1.20E+02	-	2.41E+03
Cadmium, ion		1.21E-01	6.05E-03	-	1.21E-01
Chloride		1.33E+04	6.66E+02	-	1.33E+04
Chromium VI		7.76E-02	3.88E-03	-	7.76E-02
Cobalt		2.17E-01	1.09E-02	-	2.17E-01
COD, Chemical Oxygen Demand		1.02E+04	5.09E+02	-	1.02E+04
Copper, ion		1.27E-01	6.33E-03	-	1.27E-01
DOC, Dissolved Organic Carbon		9.30E+03	4.65E+02	-	9.30E+03
Hydrogen sulfide		3.55E+01	1.78E+00	-	3.55E+01
Lead		1.26E-01	6.29E-03	-	1.26E-01
Manganese		8.03E+01	4.02E+00	-	8.03E+01
Mercury		1.52E-02	7.60E-04	-	1.52E-02
Nickel, ion		4.56E-01	2.28E-02	-	4.56E-01
Nitrate		1.91E+02	9.54E+00	-	1.91E+02
Nitrite		9.87E+01	4.94E+00	-	9.87E+01
Nitrogen, organic bound		2.96E+03	1.48E+02	-	2.96E+03
Selenium		2.41E-01	1.21E-02	-	2.41E-01
Strontium		1.93E+00	9.64E-02	-	1.93E+00
Sulfate		1.36E+03	6.81E+01	-	1.36E+03
Tin, ion		2.93E-02	1.47E-03	-	2.93E-02
TOC, Total Organic Carbon		9.30E+03	4.65E+02	-	9.30E+03
Zinc, ion		2.21E+00	1.11E-01	-	2.21E+00

Table B.9: Packaging paper/ paperboard landfilling LCI in different scenarios, continued

Ammonium, ion	Elementary flows/Emission to water/ground water, long-term Emissions from long-term leachate (>100a) directly from MSW landfill and indirectly via incineration of treatment sludge from leachate treatment.	5.66E+02	2.83E+01	1.10E+02	4.57E+02
Antimony		7.19E-04	3.59E-05	2.72E-04	4.47E-04
Arsenic, ion		3.11E+00	1.55E-01	6.08E-01	2.50E+00
Barium		1.11E+02	5.56E+00	2.94E+01	8.18E+01
Beryllium		3.13E+00	1.57E-01	6.14E-01	2.52E+00
BOD5, Biological Oxygen Demand		1.83E+05	9.15E+03	1.06E+04	1.72E+05
Cadmium, ion		2.48E+00	1.24E-01	4.82E-01	2.00E+00
Chloride		3.49E+03	1.74E+02	6.74E+02	2.82E+03
Chromium VI		6.45E-02	3.22E-03	2.38E-02	4.06E-02
Cobalt		2.34E+00	1.17E-01	4.73E-01	1.87E+00
COD, Chemical Oxygen Demand		7.73E+05	3.87E+04	4.50E+04	7.28E+05
Copper, ion		9.90E+01	4.95E+00	1.92E+01	7.97E+01
DOC, Dissolved Organic Carbon		7.07E+05	3.54E+04	4.11E+04	6.66E+05
Heat, waste		2.75E+07	1.38E+06	-	2.75E+07
Hydrogen sulfide		3.13E+02	1.57E+01	6.08E+01	2.53E+02
Lead		8.16E+01	4.08E+00	1.58E+01	6.57E+01
Manganese		1.76E+02	8.82E+00	4.03E+01	1.36E+02
Mercury		8.24E-01	4.12E-02	1.60E-01	6.64E-01
Nickel, ion		2.95E+01	1.47E+00	5.75E+00	2.37E+01
Nitrate		6.07E+01	3.04E+00	1.27E+01	4.80E+01
Nitrite		3.08E+01	1.54E+00	5.97E+00	2.49E+01
Nitrogen, organic bound		9.26E+02	4.63E+01	1.79E+02	7.47E+02
Selenium		1.38E+00	6.92E-02	4.83E-01	9.02E-01
Strontium		1.25E+02	6.24E+00	2.44E+01	1.00E+02
Sulfate		1.20E+04	6.01E+02	2.33E+03	9.69E+03
Tin, ion		1.90E+01	9.51E-01	3.69E+00	1.53E+01
TOC, Total Organic Carbon		7.07E+05	3.54E+04	4.11E+04	6.66E+05
Zinc, ion		1.70E+02	8.50E+00	2.82E+01	1.42E+02
Ammonium, ion	Elementary flows/Emission to water/surface water Emissions from short-term leachate treatment and incineration of resulting sludge.	5.53E+02	2.77E+01	5.53E+02	-
Antimony		5.86E-05	2.93E-06	5.86E-05	-
Arsenic, ion		3.29E-02	1.64E-03	3.29E-02	-
Barium		7.01E-01	3.51E-02	7.01E-01	-
Beryllium		5.92E-03	2.96E-04	5.92E-03	-
BOD5, Biological Oxygen Demand		4.45E+02	2.22E+01	4.45E+02	-
Cadmium, ion		1.48E-02	7.40E-04	1.48E-02	-
Chloride		3.21E+03	1.61E+02	3.21E+03	-
Chromium VI		9.81E-03	4.90E-04	9.81E-03	-
Chromium, ion		2.94E-05	1.47E-06	2.94E-05	-
Cobalt		2.66E-02	1.33E-03	2.66E-02	-
COD, Chemical Oxygen Demand		1.41E+03	7.07E+01	1.41E+03	-
Copper, ion		7.94E-03	3.97E-04	7.94E-03	-
DOC, Dissolved Organic Carbon		3.44E+02	1.72E+01	3.44E+02	-
Lead		3.34E-03	1.67E-04	3.34E-03	-
Manganese		9.86E+00	4.93E-01	9.86E+00	-
Mercury		1.16E-03	5.81E-05	1.16E-03	-
Nickel, ion		6.68E-02	3.34E-03	6.68E-02	-
Nitrate		2.03E+03	1.01E+02	2.03E+03	-

Table B.9: Packaging paper/ paperboard landfilling LCI in different scenarios, continued

Nitrite		1.17E+01	5.84E-01	1.17E+01	-
Nitrogen		1.51E+01	7.53E-01	1.51E+01	-
Selenium		3.89E-02	1.95E-03	3.89E-02	-
Strontium		2.36E-01	1.18E-02	2.36E-01	-
Sulfate		3.59E+02	1.80E+01	3.59E+02	-
Tin, ion		2.96E-03	1.48E-04	2.96E-03	-
TOC		3.58E+02	1.79E+01	3.58E+02	-
Zinc, ion		1.65E-01	8.25E-03	1.65E-01	-

Table B.10: Plastic (mixed) waste landfilling emission LCI for different scenarios

Flow	Category	Quantity expressed in kg/year for all substances except heat (MJ/year)			
		Combined Baseline, Alt. 01	Alt. 02,03,04	DSCC, Baseline	DNCC, Baseline
Aluminium	Elementary flows/Emission to air/high population density burden from direct release or incineration of landfill biogas	2.63E-03	1.31E-04	1.54E-03	1.09E-03
Antimony		1.19E-03	5.96E-05	6.98E-04	4.93E-04
Arsenic		5.03E-03	2.52E-04	2.95E-03	2.08E-03
Barium		5.62E-02	2.81E-03	3.29E-02	2.33E-02
Beryllium		7.65E-06	3.82E-07	4.48E-06	3.17E-06
Bromine		2.60E+00	1.30E-01	1.52E+00	1.08E+00
Cadmium		1.00E-01	5.01E-03	5.87E-02	4.15E-02
Carbon dioxide, fossil		1.12E+06	5.60E+04	6.56E+05	4.64E+05
Chromium		1.23E-04	6.13E-06	7.18E-05	5.07E-05
Cobalt		2.67E-03	1.34E-04	1.57E-03	1.11E-03
Copper		4.68E-04	2.34E-05	2.74E-04	1.94E-04
Hydrogen chloride		7.42E+02	3.71E+01	4.35E+02	3.07E+02
Hydrogen fluoride		6.16E+00	3.08E-01	3.61E+00	2.55E+00
Iron		1.35E-02	6.73E-04	7.89E-03	5.57E-03
Lead		9.65E-04	4.83E-05	5.66E-04	4.00E-04
Manganese		2.41E-02	1.20E-03	1.41E-02	9.97E-03
Mercury		2.45E-02	1.22E-03	1.43E-02	1.01E-02
Methane, fossil		5.17E+05	2.59E+04	3.03E+05	2.14E+05
Nickel		3.15E-04	1.57E-05	1.85E-04	1.30E-04
Nitrogen oxides		9.45E+00	4.73E-01	5.54E+00	3.91E+00
Selenium		5.82E-05	2.91E-06	3.41E-05	2.41E-05
Sodium		1.60E+00	7.98E-02	9.35E-01	6.60E-01
Strontium		1.35E-03	6.77E-05	7.93E-04	5.60E-04
Sulfur dioxide		2.07E+02	1.03E+01	1.21E+02	8.57E+01
Thallium		6.12E-06	3.06E-07	3.58E-06	2.53E-06
Tin		4.06E-05	2.03E-06	2.38E-05	1.68E-05
Titanium		1.31E-02	6.57E-04	7.70E-03	5.44E-03
Vanadium		7.99E-03	4.00E-04	4.68E-03	3.31E-03
Zinc		6.19E-03	3.10E-04	3.63E-03	2.56E-03
Heat, waste	Elementary flows/Emission to soil/industrial	2.68E+07	1.34E+06	1.57E+07	1.11E+07

Table B.10: Plastic (mixed) waste landfilling emission LCI for different scenarios, continued

Aluminium	Elementary flows/Emission to water/ground water burden from short-term leachate to groundwater in uncontrolled landfill in moist climate.	1.05E+01	5.26E-01	6.16E+00	4.35E+00
Ammonium, ion		6.57E+03	3.28E+02	3.85E+03	2.72E+03
Antimony		4.77E+00	2.38E-01	2.79E+00	1.97E+00
Arsenic, ion		3.59E-01	1.80E-02	2.10E-01	1.49E-01
Barium		2.25E+02	1.12E+01	1.32E+02	9.30E+01
Beryllium		3.06E-02	1.53E-03	1.79E-02	1.27E-02
BOD5, Biological Oxygen Demand		5.39E+03	2.69E+02	3.16E+03	2.23E+03
Bromine		1.85E+02	9.27E+00	1.09E+02	7.68E+01
Cadmium, ion		1.50E+01	7.52E-01	8.81E+00	6.22E+00
Chloride		5.15E+04	2.57E+03	3.02E+04	2.13E+04
Chromium VI		4.90E-01	2.45E-02	2.87E-01	2.03E-01
Cobalt		1.07E+01	5.34E-01	6.26E+00	4.42E+00
COD, Chemical Oxygen Demand		2.28E+04	1.14E+03	1.33E+04	9.42E+03
Copper, ion		1.64E+00	8.18E-02	9.59E-01	6.77E-01
DOC, Dissolved Organic Carbon		2.08E+04	1.04E+03	1.22E+04	8.61E+03
Fluoride		1.14E+00	5.68E-02	6.66E-01	4.70E-01
Hydrogen sulfide		4.30E+01	2.15E+00	2.52E+01	1.78E+01
Iron, ion		5.38E+01	2.69E+00	3.16E+01	2.23E+01
Lead		2.90E+00	1.45E-01	1.70E+00	1.20E+00
Manganese		9.63E+01	4.81E+00	5.64E+01	3.99E+01
Mercury		6.12E-02	3.06E-03	3.59E-02	2.53E-02
Nickel, ion		1.26E+00	6.30E-02	7.38E-01	5.22E-01
Nitrate		6.91E+02	3.45E+01	4.05E+02	2.86E+02
Nitrite		3.57E+02	1.79E+01	2.09E+02	1.48E+02
Nitrogen, organic bound		1.07E+04	5.37E+02	6.29E+03	4.44E+03
Selenium		2.33E-01	1.16E-02	1.37E-01	9.65E-02
Sodium, ion		6.38E+03	3.19E+02	3.74E+03	2.64E+03
Strontium		5.41E+00	2.71E-01	3.17E+00	2.24E+00
Sulfate		1.65E+03	8.25E+01	9.67E+02	6.83E+02
Thallium		2.45E-02	1.22E-03	1.43E-02	1.01E-02
Tin, ion		1.62E-01	8.12E-03	9.52E-02	6.73E-02
Titanium, ion		5.26E+01	2.63E+00	3.08E+01	2.18E+01
TOC, Total Organic Carbon		2.08E+04	1.04E+03	1.22E+04	8.61E+03
Vanadium, ion		3.20E+01	1.60E+00	1.87E+01	1.32E+01
Zinc, ion		2.79E+01	1.39E+00	1.63E+01	1.15E+01

Table B.10: Plastic (mixed) waste landfilling emission LCI for different scenarios, continued

Aluminium	Elementary flows/Emission to water/ground water, long-term Emissions from long-term leachate (>100a) directly from MSW landfill and indirectly via incineration of treatment sludge from leachate treatment.	2.11E+04	1.05E+03	1.23E+04	8.72E+03
Ammonium, ion		2.74E+05	1.37E+04	1.61E+05	1.14E+05
Antimony		2.00E+02	1.00E+01	1.17E+02	8.28E+01
Arsenic, ion		2.00E+02	9.99E+00	1.17E+02	8.27E+01
Barium		1.94E+04	9.71E+02	1.14E+04	8.04E+03
Beryllium		5.26E+01	2.63E+00	3.08E+01	2.18E+01
BOD5, Biological Oxygen Demand		1.83E+07	9.17E+05	1.07E+07	7.59E+06
Bromine		7.19E+03	3.59E+02	4.21E+03	2.97E+03
Cadmium, ion		8.54E+03	4.27E+02	5.00E+03	3.54E+03
Chloride		1.99E+06	9.97E+04	1.17E+06	8.26E+05
Chromium VI		8.35E+00	4.18E-01	4.90E+00	3.46E+00
Cobalt		3.32E+03	1.66E+02	1.94E+03	1.37E+03
COD, Chemical Oxygen Demand		7.74E+07	3.87E+06	4.54E+07	3.21E+07
Copper, ion		3.35E+04	1.67E+03	1.96E+04	1.39E+04
DOC, Dissolved Organic Carbon		7.08E+07	3.54E+06	4.15E+07	2.93E+07
Fluoride		1.54E+03	7.71E+01	9.03E+02	6.38E+02
Heat, waste		3.81E+09	1.90E+08	2.23E+09	1.58E+09
Hydrogen sulfide		1.15E+04	5.76E+02	6.75E+03	4.77E+03
Iron, ion		3.92E+05	1.96E+04	2.30E+05	1.62E+05
Lead		4.92E+04	2.46E+03	2.88E+04	2.04E+04
Manganese		8.32E+03	4.16E+02	4.88E+03	3.44E+03
Mercury		8.94E+01	4.47E+00	5.24E+01	3.70E+01
Nickel, ion		2.17E+03	1.08E+02	1.27E+03	8.98E+02
Nitrate		2.88E+04	1.44E+03	1.69E+04	1.19E+04
Nitrite		1.49E+04	7.46E+02	8.75E+03	6.18E+03
Nitrogen, organic bound		4.48E+05	2.24E+04	2.63E+05	1.86E+05
Selenium		2.92E+01	1.46E+00	1.71E+01	1.21E+01
Sodium, ion		1.48E+05	7.40E+03	8.67E+04	6.13E+04
Strontium		9.32E+03	4.66E+02	5.46E+03	3.86E+03
Sulfate		4.42E+05	2.21E+04	2.59E+05	1.83E+05
Thallium		4.21E+01	2.11E+00	2.47E+01	1.74E+01
Tin, ion		2.76E+03	1.38E+02	1.62E+03	1.14E+03
Titanium, ion		1.05E+05	5.26E+03	6.17E+04	4.36E+04
TOC, Total Organic Carbon		7.08E+07	3.54E+06	4.15E+07	2.93E+07
Vanadium, ion		4.15E+03	2.08E+02	2.43E+03	1.72E+03
Zinc, ion		5.89E+04	2.94E+03	3.45E+04	2.44E+04

Table B.11: Waste textile landfill burden LCI from different scenarios

Flow	Category and Description	Combined Baseline, Alt. 01, kg/year	Alt. 02,03,04, kg/year	DSCC, Baseline, kg/year	DNCC, Baseline, kg/year
Cadmium	Elementary flows/Emission to air/high population density burden from direct release or incineration of landfill biogas	1.43E-05	7.13E-07	6.44E-06	7.82E-06
Calcium		1.17E-05	5.85E-07	5.29E-06	6.42E-06
Carbon dioxide, biogenic		1.71E+06	8.56E+04	7.73E+05	9.39E+05
Copper		5.45E-04	2.73E-05	2.46E-04	2.99E-04
Iron		1.20E-03	6.00E-05	5.42E-04	6.58E-04
Manganese		1.71E-02	8.57E-04	7.74E-03	9.40E-03
Methane, biogenic		7.91E+05	3.96E+04	3.57E+05	4.34E+05
Zinc		7.12E-04	3.56E-05	3.22E-04	3.91E-04
BOD5, Biological Oxygen Demand	Elementary flows/Emission to water/ground water burden from short-term leachate to groundwater in uncontrolled landfill in moist climate	8.24E+03	4.12E+02	3.72E+03	4.52E+03
Cadmium, ion		2.14E-03	1.07E-04	9.66E-04	1.17E-03
Calcium, ion		4.68E-02	2.34E-03	2.11E-02	2.57E-02
COD, Chemical Oxygen Demand		3.48E+04	1.74E+03	1.57E+04	1.91E+04
Copper, ion		1.91E+00	9.54E-02	8.62E-01	1.05E+00
DOC, Dissolved Organic Carbon		3.18E+04	1.59E+03	1.44E+04	1.74E+04
Iron, ion		4.80E+00	2.40E-01	2.17E+00	2.63E+00
Manganese		6.85E+01	3.43E+00	3.09E+01	3.76E+01
TOC, Total Organic Carbon		3.18E+04	1.59E+03	1.44E+04	1.74E+04
Zinc, ion		3.21E+00	1.60E-01	1.45E+00	1.76E+00
BOD5, Biological Oxygen Demand	Elementary flows/Emission to water/ground water, long-term Emissions from long-term leachate (>100a) directly from MSW landfill	2.07E+06	1.04E+05	9.36E+05	1.14E+06
Cadmium, ion		9.91E-02	4.96E-03	4.48E-02	5.44E-02
Calcium, ion		2.95E+00	1.48E-01	1.33E+00	1.62E+00
COD, Chemical Oxygen Demand		8.76E+06	4.38E+05	3.96E+06	4.81E+06
Copper, ion		3.25E+03	1.62E+02	1.47E+03	1.78E+03
DOC, Dissolved Organic Carbon		8.01E+06	4.00E+05	3.62E+06	4.39E+06
Iron, ion		2.91E+03	1.45E+02	1.31E+03	1.60E+03
Manganese		4.30E+02	2.15E+01	1.94E+02	2.36E+02
TOC, Total Organic Carbon		8.01E+06	4.00E+05	3.62E+06	4.39E+06
Zinc, ion		5.61E+02	2.80E+01	2.53E+02	3.08E+02

Table B.12: LCI data for DNCC and DSCC writing paper recycling emissions and savings

Writing Paper Recycling		
Ecoinvent process: graphic paper production, 100% recycled | graphic paper, 100% recycled | Cutoff, U-RoW		
Output		
Flow	DSCC	DNCC
Elementary flows/Emission to water/unspecified all unit is in kg/year		
AOX, Adsorbable Organic Halogen as Cl	5.28E+00	3.85E+00
BOD5, Biological Oxygen Demand	5.50E+03	4.01E+03
COD, Chemical Oxygen Demand	6.87E+03	5.02E+03
DOC, Dissolved Organic Carbon	2.29E+03	1.67E+03
Nitrogen	3.22E+03	2.35E+03
Phosphorus	5.84E+01	4.26E+01
TOC, Total Organic Carbon	2.75E+03	2.01E+03
Virgin Writing Paper Production from Raw Materials		
Ecoinvent process: paper production, woodfree, uncoated, at non-integrated mill | paper, woodfree, uncoated | Cutoff, U – RoW		
Input		
Elementary flows/Resource/in water all unit is in m^3/year		
Water, cooling, unspecified natural origin	-1.06E+05	-7.75E+04
Water, unspecified natural origin	-3.04E+04	-2.22E+04
Output		
Elementary flows/Emission to water/surface water all unit is in kg/year except water which is in m^3/year		
BOD5, Biological Oxygen Demand	-9.44E+02	-6.89E+02
COD, Chemical Oxygen Demand	-6.81E+03	-4.97E+03
DOC, Dissolved Organic Carbon	-2.52E+03	-1.84E+03
Nitrogen	-1.18E+02	-8.61E+01
Phosphorus	-2.95E+01	-2.15E+01
Suspended solids, unspecified	-1.47E+02	-1.08E+02
TOC, Total Organic Carbon	-2.52E+03	-1.84E+03
Water	-4.57E+04	-3.34E+04
Water	-9.09E+04	-6.63E+04
"-ve" value indicates environmental savings		

Table B.13: LCI data for DNCC and DSCC printing paper recycling emissions and savings

Printing Paper Recycling			
Ecoinvent process: graphic paper production, 100% recycled | graphic paper, 100% recycled | Cutoff, U-RoW			
Output			
Category: Elementary flows/Emission to water/unspecified			
All unit is in kg/year			
Flow	**Combined Scenario, Baseline and All Alternatives**	**DSCC**	**DNCC**
AOX, Adsorbable Organic Halogen as Cl	2.13E+01	1.23E+01	8.99E+00
BOD5, Biological Oxygen Demand	2.22E+04	1.28E+04	9.37E+03
COD, Chemical Oxygen Demand	2.77E+04	1.60E+04	1.17E+04
DOC, Dissolved Organic Carbon	9.25E+03	5.35E+03	3.90E+03
Nitrogen	1.30E+04	7.50E+03	5.48E+03
Phosphorus	2.36E+02	1.36E+02	9.95E+01
TOC, Total Organic Carbon	1.11E+04	6.41E+03	4.68E+03
Virgin Printing Paper Production from Raw Materials			
Ecoinvent process: paper production, woodcontaining, lightweight coated | paper, woodcontaining, lightweight coated | Cutoff, U – RoW			
Input			
Category: Elementary flows/Resource/in water			
All unit is m^3/year			
Water, cooling, unspecified natural origin	-2.86E+05	-1.65E+05	-1.21E+05
Water, unspecified natural origin	-2.46E+05	-1.42E+05	-1.04E+05
Output			
Category: Elementary flows/Emission to water/unspecified			
All unit is in kg/year			
AOX, Adsorbable Organic Halogen as Cl	-1.91E+01	-1.10E+01	-8.04E+00
Category: Elementary flows/Emission to water/surface water			
All unit is in kg/year			
BOD5, Biological Oxygen Demand	-1.31E+03	-7.57E+02	-5.53E+02
COD, Chemical Oxygen Demand	-2.62E+04	-1.51E+04	-1.11E+04
DOC, Dissolved Organic Carbon	-9.70E+03	-5.61E+03	-4.09E+03
Nitrogen	-5.12E+02	-2.96E+02	-2.16E+02
Phosphorus	-9.05E+01	-5.23E+01	-3.82E+01
Suspended solids, unspecified	-4.05E+03	-2.34E+03	-1.71E+03
TOC, Total Organic Carbon	-9.70E+03	-5.61E+03	-4.09E+03
Category: Elementary flows/Emission to water/unspecified			
All unit is m^3/year			
Water	-1.48E+05	-8.54E+04	-6.23E+04
Water	-3.85E+05	-2.22E+05	-1.62E+05

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC

Flow	Category	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Newsprint Recycling				
Ecoinvent process: paper production, newsprint, recycled | paper, newsprint | Cutoff, U – RoW				
Input All unit is in m^3/year				
Water, cooling, unspecified natural origin	Elementary flows/Resource/ in water	9.61E+05	5.55E+05	4.05E+05
Water, unspecified natural origin		2.17E+05	1.25E+05	9.16E+04
Output All unit is in kg/year except all the radioactive materials which is in kBq/year and all water quantity which is in m^3/year				
Acetaldehyde	Elementary flows/Emission to air/high population density	3.73E+00	2.15E+00	1.57E+00
Acetic acid		9.66E+00	5.58E+00	4.07E+00
Acetone		1.06E+00	6.16E-01	4.49E-01
Aluminium		6.74E+01	3.90E+01	2.84E+01
Ammonia		7.45E+01	4.31E+01	3.15E+01
Antimony		1.14E-01	6.59E-02	4.81E-02
Arsenic		3.94E-01	2.28E-01	1.66E-01
Barium		1.29E+00	7.47E-01	5.45E-01
Benzene		7.64E+01	4.41E+01	3.22E+01
Benzene, ethyl-		1.29E+00	7.47E-01	5.45E-01
Benzene, hexachloro-		3.10E-07	1.79E-07	1.31E-07
Benzo(a)pyrene		1.10E-01	6.39E-02	4.66E-02
Beryllium		1.29E-02	7.47E-03	5.45E-03
Boron		5.10E+01	2.95E+01	2.15E+01
Bromine		2.67E+00	1.54E+00	1.13E+00
Butane		2.52E+01	1.46E+01	1.06E+01
Cadmium		3.01E-01	1.74E-01	1.27E-01
Calcium		4.77E+02	2.76E+02	2.01E+02
Carbon dioxide, biogenic		4.09E+06	2.36E+06	1.73E+06
Carbon dioxide, fossil		3.10E+06	1.79E+06	1.31E+06
Carbon monoxide, biogenic		2.07E+03	1.20E+03	8.74E+02
Carbon monoxide, fossil		1.79E+04	1.03E+04	7.55E+03
Chlorine		7.75E+00	4.48E+00	3.27E+00
Chromium		6.23E-01	3.60E-01	2.63E-01
Chromium VI		9.84E-03	5.69E-03	4.15E-03
Cobalt		4.06E-01	2.35E-01	1.71E-01
Copper		1.43E+00	8.29E-01	6.05E-01
Dinitrogen monoxide		1.26E+02	7.29E+01	5.33E+01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin		2.98E-05	1.72E-05	1.26E-05
Ethane		6.84E+01	3.95E+01	2.89E+01
Ethanol		2.14E+00	1.23E+00	9.02E-01
Ethene		1.37E+02	7.90E+01	5.77E+01
Ethyne		2.29E+01	1.32E+01	9.64E+00
Fluorine		2.15E+00	1.24E+00	9.09E-01
Formaldehyde		1.30E+01	7.49E+00	5.47E+00

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC, continued

Hydrocarbons, aliphatic, alkanes, unspecified		6.62E+01	3.83E+01	2.80E+01
Hydrocarbons, aliphatic, unsaturated		1.57E+02	9.05E+01	6.60E+01
Hydrocarbons, aromatic		1.06E+00	6.16E-01	4.49E-01
Hydrogen chloride		8.10E+01	4.68E+01	3.42E+01
Hydrogen fluoride		3.31E+00	1.91E+00	1.40E+00
Hydrogen sulfide		4.42E-01	2.56E-01	1.87E-01
Iodine		2.17E-01	1.25E-01	9.16E-02
Iron		6.74E+01	3.90E+01	2.84E+01
Lead		1.76E+00	1.01E+00	7.41E-01
Lead-210		3.38E+02	1.95E+02	1.43E+02
m-Xylene		5.17E+00	2.99E+00	2.18E+00
Magnesium		5.42E+01	3.13E+01	2.29E+01
Manganese		7.45E+00	4.31E+00	3.15E+00
Mercury		6.94E-02	4.01E-02	2.93E-02
Methane, biogenic		1.72E+01	9.96E+00	7.27E+00
Methane, fossil		1.43E+03	8.28E+02	6.05E+02
Methanol		3.63E+00	2.10E+00	1.53E+00
Molybdenum		3.15E-01	1.82E-01	1.33E-01
Nickel		5.15E+00	2.98E+00	2.17E+00
Nitrogen oxides		7.60E+03	4.39E+03	3.21E+03
NMVOC, non-methane volatile organic compounds, unspecified origin		1.05E+02	6.07E+01	4.43E+01
PAH, polycyclic aromatic hydrocarbons		8.41E-01	4.86E-01	3.55E-01
Particulates, < 2.5 um		6.46E+02	3.73E+02	2.73E+02
Particulates, > 10 um		2.15E+02	1.24E+02	9.09E+01
Particulates, > 2.5 um, and < 10um		2.98E+02	1.72E+02	1.26E+02
Pentane		4.32E+01	2.50E+01	1.82E+01
Phenol		2.20E+00	1.27E+00	9.30E-01
Phenol, pentachloro-		3.49E-04	2.02E-04	1.47E-04
Phosphorus		1.34E+01	7.77E+00	5.68E+00
Polonium-210		6.21E+02	3.59E+02	2.62E+02
Potassium		1.02E+03	5.87E+02	4.28E+02
Potassium-40		9.24E+01	5.34E+01	3.90E+01
Propane		5.30E+01	3.06E+01	2.24E+01
Propene		2.29E+01	1.32E+01	9.64E+00
Propionic acid		7.20E-01	4.16E-01	3.04E-01
Radium-226		8.73E+01	5.04E+01	3.68E+01
Radium-228		1.28E+02	7.39E+01	5.40E+01
Radon-220		1.90E+01	1.10E+01	8.04E+00
Radon-222		1.90E+01	1.10E+01	8.04E+00
Scandium		4.54E-03	2.62E-03	1.92E-03
Selenium		4.34E-01	2.51E-01	1.83E-01
Silicon		5.56E+02	3.22E+02	2.35E+02
Sodium		7.22E+01	4.17E+01	3.05E+01
Strontium		1.43E+00	8.29E-01	6.05E-01
Sulfur dioxide		1.03E+04	5.94E+03	4.33E+03

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC, continued

Thallium		2.75E-03	1.59E-03	1.16E-03
Thorium		1.60E-02	9.26E-03	6.76E-03
Thorium-228		4.02E+01	2.33E+01	1.70E+01
Thorium-232		2.52E+01	1.46E+01	1.06E+01
Tin		9.80E-03	5.67E-03	4.14E-03
Titanium		1.64E+00	9.49E-01	6.93E-01
Toluene		2.48E+01	1.44E+01	1.05E+01
Uranium		2.58E-02	1.49E-02	1.09E-02
Uranium-238		7.30E+01	4.22E+01	3.08E+01
Vanadium		1.90E+01	1.10E+01	8.04E+00
Xylene		1.47E+01	8.51E+00	6.21E+00
Zinc		1.32E+01	7.66E+00	5.59E+00
Water	Elementary flows/Emission to air/unspecified	4.05E+05	2.34E+05	1.71E+05
AOX, Adsorbable Organic Halogen as Cl	Elementary flows/Emission to water/surface water	4.97E+02	2.87E+02	2.10E+02
BOD5, Biological Oxygen Demand		5.47E+03	3.16E+03	2.31E+03
COD, Chemical Oxygen Demand		5.42E+04	3.13E+04	2.29E+04
DOC, Dissolved Organic Carbon		3.31E+03	1.91E+03	1.40E+03
Nitrogen		8.28E+02	4.79E+02	3.49E+02
Phosphorus		1.66E+02	9.57E+01	6.99E+01
Suspended solids, unspecified		7.95E+03	4.60E+03	3.35E+03
TOC, Total Organic Carbon		7.12E+03	4.12E+03	3.01E+03
Water	Elementary flows/Emission to water/unspecified	7.73E+05	4.47E+05	3.26E+05
Virgin Newsprint Production from Raw Materials				
Ecoinvent process: paper production, newsprint, virgin | paper, newsprint | Cutoff, U – RoW				
Input All unit is in m^3/year				
Water, cooling, unspecified natural origin	Elementary flows/Resource/ in water	-8.66E+05	-5.01E+05	-3.66E+05
Water, unspecified natural origin		-2.15E+05	-1.24E+05	-9.09E+04
Output All unit is in kg/year except all the radioactive materials which is in kBq/year and all water quantity which is in m^3/year				
Acetaldehyde	Elementary flows/Emission to air/high population density	-5.02E+00	-2.90E+00	-2.12E+00
Acetic acid		-5.48E-01	-3.17E-01	-2.31E-01
Acetone		-1.37E-01	-7.93E-02	-5.79E-02
Aluminium		-6.41E+01	-3.70E+01	-2.70E+01
Ammonia		-1.39E+02	-8.02E+01	-5.86E+01
Antimony		-9.47E-03	-5.48E-03	-4.00E-03
Arsenic		-2.43E-01	-1.41E-01	-1.03E-01
Barium		-7.55E-01	-4.37E-01	-3.19E-01
Benzene		-7.59E+01	-4.38E+01	-3.20E+01
Benzene, ethyl-		-2.40E+00	-1.39E+00	-1.01E+00

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC, continued

Benzene, hexachloro-		-5.76E-07	-3.33E-07	-2.43E-07
Benzo(a)pyrene		-4.01E-02	-2.32E-02	-1.69E-02
Beryllium		-7.55E-03	-4.37E-03	-3.19E-03
Boron		-2.85E+00	-1.65E+00	-1.20E+00
Bromine		-4.85E+00	-2.80E+00	-2.05E+00
Butane		-8.07E-01	-4.66E-01	-3.40E-01
Cadmium		-9.56E-02	-5.52E-02	-4.03E-02
Calcium		-4.75E+02	-2.75E+02	-2.01E+02
Carbon dioxide, biogenic		-7.59E+06	-4.38E+06	-3.20E+06
Carbon dioxide, fossil		-8.10E+05	-4.68E+05	-3.42E+05
Carbon monoxide, biogenic		-3.84E+03	-2.22E+03	-1.62E+03
Carbon monoxide, fossil		-6.16E+02	-3.56E+02	-2.60E+02
Chlorine		-1.44E+01	-8.32E+00	-6.07E+00
Chromium		-4.65E-01	-2.69E-01	-1.96E-01
Chromium VI		-2.00E-02	-1.16E-02	-8.46E-03
Cobalt		-4.92E-02	-2.84E-02	-2.08E-02
Copper		-3.69E+00	-2.13E+00	-1.56E+00
Dinitrogen monoxide		-2.09E+02	-1.21E+02	-8.81E+01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin		-1.22E-04	-7.07E-05	-5.16E-05
Ethane		-8.99E+00	-5.20E+00	-3.80E+00
Ethanol		-2.75E-01	-1.59E-01	-1.16E-01
Ethene		-1.81E+01	-1.04E+01	-7.62E+00
Ethyne		-3.00E+00	-1.73E+00	-1.27E+00
Fluorine		-3.99E+00	-2.31E+00	-1.68E+00
Formaldehyde		-1.36E+01	-7.86E+00	-5.74E+00
Hydrocarbons, aliphatic, alkanes, unspecified		-7.75E+01	-4.48E+01	-3.27E+01
Hydrocarbons, aliphatic, unsaturated		-2.50E+02	-1.45E+02	-1.06E+02
Hydrocarbons, aromatic		-2.14E-01	-1.23E-01	-9.02E-02
Hydrogen chloride		-2.45E+02	-1.42E+02	-1.03E+02
Hydrogen fluoride		-7.72E+00	-4.46E+00	-3.26E+00
Iodine		-6.84E-02	-3.95E-02	-2.89E-02
Iron		-2.67E+01	-1.54E+01	-1.13E+01
Lead		-2.50E+00	-1.45E+00	-1.06E+00
Lead-210		-2.78E+02	-1.61E+02	-1.17E+02
m-Xylene		-9.59E+00	-5.54E+00	-4.05E+00
Magnesium		-5.15E+01	-2.98E+01	-2.17E+01
Manganese		-1.37E+01	-7.94E+00	-5.79E+00
Mercury		-4.24E-02	-2.45E-02	-1.79E-02
Methane, biogenic		-3.20E+01	-1.85E+01	-1.35E+01
Methane, fossil		-6.53E+01	-3.77E+01	-2.75E+01
Methanol		-4.67E-01	-2.70E-01	-1.97E-01
Molybdenum		-4.31E-02	-2.49E-02	-1.82E-02
Nickel		-1.19E+00	-6.86E-01	-5.01E-01
Nitrogen oxides		-9.11E+03	-5.27E+03	-3.84E+03
NMVOC, non-methane volatile organic compounds, unspecified origin		-5.83E+01	-3.37E+01	-2.46E+01

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC, continued

PAH, polycyclic aromatic hydrocarbons		-8.89E-01	-5.14E-01	-3.75E-01
Particulates, < 2.5 um		-3.64E+02	-2.11E+02	-1.54E+02
Particulates, > 10 um		-3.48E+02	-2.01E+02	-1.47E+02
Particulates, > 2.5 um, and < 10um		-4.47E+02	-2.58E+02	-1.89E+02
Pentane		-5.38E-01	-3.11E-01	-2.27E-01
Phenol, pentachloro-		-6.48E-04	-3.74E-04	-2.73E-04
Phosphorus		-2.43E+01	-1.41E+01	-1.03E+01
Polonium-210		-5.10E+02	-2.95E+02	-2.15E+02
Potassium		-1.87E+03	-1.08E+03	-7.90E+02
Potassium-40		-8.10E+01	-4.68E+01	-3.42E+01
Propane		-6.08E+00	-3.51E+00	-2.56E+00
Propene		-3.00E+00	-1.73E+00	-1.27E+00
Radium-226		-7.20E+01	-4.16E+01	-3.04E+01
Radium-228		-3.89E+02	-2.25E+02	-1.64E+02
Radon-220		-6.00E+00	-3.47E+00	-2.53E+00
Radon-222		-6.00E+00	-3.47E+00	-2.53E+00
Scandium		-7.55E-03	-4.37E-03	-3.19E-03
Selenium		-6.79E-02	-3.92E-02	-2.87E-02
Silicon		-9.47E+01	-5.48E+01	-4.00E+01
Sodium		-1.08E+02	-6.27E+01	-4.58E+01
Strontium		-1.14E+00	-6.59E-01	-4.81E-01
Sulfur dioxide		-5.75E+03	-3.32E+03	-2.43E+03
Thallium		-9.47E-03	-5.48E-03	-4.00E-03
Thorium		-1.14E-02	-6.59E-03	-4.81E-03
Thorium-228		-3.30E+01	-1.91E+01	-1.39E+01
Thorium-232		-2.10E+01	-1.22E+01	-8.88E+00
Tin		-3.79E-03	-2.19E-03	-1.60E-03
Titanium		-2.27E+00	-1.31E+00	-9.58E-01
Toluene		-2.47E+01	-1.43E+01	-1.04E+01
Uranium		-1.52E-02	-8.77E-03	-6.40E-03
Uranium-238		-6.00E+01	-3.47E+01	-2.53E+01
Vanadium		-2.60E+00	-1.50E+00	-1.10E+00
Xylene		-6.00E-01	-3.47E-01	-2.53E-01
Zinc		-2.58E+01	-1.49E+01	-1.09E+01
Acetaldehyde		-7.49E-03	-4.33E-03	-3.16E-03
Acetic acid		-6.95E-03	-4.02E-03	-2.93E-03
Acetone		-1.47E-03	-8.50E-04	-6.20E-04
Ammonia		-1.71E-01	-9.86E-02	-7.20E-02
Arsenic		-2.26E-04	-1.31E-04	-9.53E-05
Benzene		-9.25E-02	-5.35E-02	-3.90E-02
Benzene, ethyl-		-2.96E-03	-1.71E-03	-1.25E-03
Benzo(a)pyrene		-4.96E-05	-2.87E-05	-2.09E-05
Bromine		-5.91E-03	-3.42E-03	-2.50E-03
Butane		-5.00E-03	-2.89E-03	-2.11E-03
Cadmium		-6.90E-05	-3.99E-05	-2.91E-05
Carbon dioxide, biogenic		-9.47E+03	-5.48E+03	-4.00E+03
Carbon dioxide, fossil		-1.12E+03	-6.48E+02	-4.73E+02
Carbon monoxide, fossil		-7.17E+01	-4.14E+01	-3.02E+01

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC, continued

Carbon monoxide, land transformation		-4.04E+00	-2.34E+00	-1.71E+00
Chlorine		-1.77E-02	-1.03E-02	-7.49E-03
Chromium		-4.39E-04	-2.54E-04	-1.85E-04
Chromium VI		-4.43E-06	-2.56E-06	-1.87E-06
Cobalt		-3.23E-04	-1.87E-04	-1.36E-04
Copper		-2.37E-03	-1.37E-03	-1.00E-03
Dinitrogen monoxide		-3.91E-01	-2.26E-01	-1.65E-01
Ethanol		-2.94E-03	-1.70E-03	-1.24E-03
Fluorine		-4.93E-03	-2.85E-03	-2.08E-03
Formaldehyde		-1.80E-02	-1.04E-02	-7.59E-03
Hydrocarbons, aliphatic, alkanes, unspecified		-9.56E-02	-5.53E-02	-4.03E-02
Hydrocarbons, aliphatic, unsaturated		-3.06E-01	-1.77E-01	-1.29E-01
Hydrocarbons, aromatic		-1.47E-03	-8.51E-04	-6.21E-04
Hydrogen chloride		-1.41E-02	-8.16E-03	-5.96E-03
Hydrogen fluoride		-4.71E-04	-2.72E-04	-1.99E-04
Iron		-8.04E-03	-4.64E-03	-3.39E-03
Lead		-3.88E-03	-2.25E-03	-1.64E-03
m-Xylene		-1.18E-02	-6.84E-03	-4.99E-03
Magnesium		-3.55E-02	-2.05E-02	-1.50E-02
Manganese		-1.68E-02	-9.68E-03	-7.07E-03
Mercury		-3.13E-05	-1.81E-05	-1.32E-05
Methane, biogenic		-3.94E-02	-2.28E-02	-1.66E-02
Methane, fossil		-2.80E+00	-1.62E+00	-1.18E+00
Methanol		-5.00E-03	-2.89E-03	-2.11E-03
Molybdenum		-7.84E-05	-4.53E-05	-3.31E-05
Nickel		-5.39E-03	-3.12E-03	-2.28E-03
Nitrogen oxides		-1.87E+01	-1.08E+01	-7.90E+00
NMVOC, non-methane volatile organic compounds, unspecified origin		-1.06E+01	-6.12E+00	-4.47E+00
PAH, polycyclic aromatic hydrocarbons		-1.17E-03	-6.77E-04	-4.94E-04
Particulates, < 2.5 um		-1.01E+00	-5.87E-01	-4.28E-01
Particulates, > 10 um		-1.79E-01	-1.03E-01	-7.54E-02
Particulates, > 2.5 um, and < 10um		-1.52E+00	-8.78E-01	-6.41E-01
Pentane		-8.55E-03	-4.94E-03	-3.61E-03
Phenol, pentachloro-		-7.98E-07	-4.61E-07	-3.37E-07
Phosphorus		-2.96E-02	-1.71E-02	-1.25E-02
Potassium		-2.31E+00	-1.33E+00	-9.73E-01
Propane		-1.72E-03	-9.93E-04	-7.25E-04
Propionic acid		-1.42E-04	-8.23E-05	-6.01E-05
Selenium		-1.18E-04	-6.80E-05	-4.96E-05
Sodium		-1.35E-01	-7.83E-02	-5.72E-02
Sulfur dioxide		-6.31E+00	-3.65E+00	-2.66E+00
Toluene		-3.13E-02	-1.81E-02	-1.32E-02
Vanadium		-9.80E-03	-5.66E-03	-4.14E-03
Zinc		-3.01E-02	-1.74E-02	-1.27E-02

Table B.14: LCI for newsprint recycling baseline, alternatives, DSCC and DNCC, continued

Water	Emission to air/unspecified	-2.07E+04	-1.20E+04	-8.74E+03
AOX, Adsorbable Organic Halogen as Cl	Elementary flows/Emission to water/surface water	-1.82E+00	-1.05E+00	-7.69E-01
BOD5, Biological Oxygen Demand		-4.31E+03	-2.49E+03	-1.82E+03
COD, Chemical Oxygen Demand		-7.45E+04	-4.31E+04	-3.15E+04
DOC, Dissolved Organic Carbon		-3.31E+03	-1.91E+03	-1.40E+03
Nitrogen		-1.49E+03	-8.62E+02	-6.29E+02
Phosphorus		-1.66E+02	-9.57E+01	-6.99E+01
Suspended solids, unspecified		-1.08E+04	-6.22E+03	-4.54E+03
TOC, Total Organic Carbon		-7.12E+03	-4.12E+03	-3.01E+03
Water	Emission to water/unspecified	-7.14E+05	-4.12E+05	-3.01E+05

Table B.15: LCI for packaging paper/paperboard recycling baseline, alternatives, DSCC and DNCC

Flow	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Packaging Paper/Paperboard Recycling			
All unit is in kg/year, except for water which is m^3/year and heavy metal radiation which is in kBq/year			
Ecoinvent process: - containerboard production, fluting medium, recycled | containerboard, fluting medium | Cutoff, U – RoW			
Input			
Elementary flows/Resource/in water			
Water, river	1.03E+04	5.94E+03	4.34E+03
Water, well	8.39E+03	4.85E+03	3.54E+03
Output			
Elementary flows/Emission to air/high population density			
Acetaldehyde	6.83E-02	3.95E-02	2.88E-02
Acetic acid	2.10E+00	1.21E+00	8.84E-01
Acetone	1.31E-03	7.56E-04	5.52E-04
Aluminium	1.21E+01	7.01E+00	5.12E+00
Ammonia	1.51E+00	8.75E-01	6.39E-01
Antimony	1.61E-02	9.30E-03	6.79E-03
Arsenic	4.32E-02	2.50E-02	1.82E-02
Barium	2.11E-01	1.22E-01	8.92E-02
Benzene	9.63E+00	5.57E+00	4.06E+00
Benzene, ethyl-	2.61E-02	1.51E-02	1.10E-02
Benzene, hexachloro-	6.26E-09	3.62E-09	2.64E-09
Benzo(a)pyrene	1.27E-02	7.35E-03	5.37E-03
Beryllium	2.11E-03	1.22E-03	8.92E-04
Boron	7.14E+00	4.13E+00	3.01E+00
Bromine	6.57E-02	3.80E-02	2.77E-02
Butane	9.77E+00	5.65E+00	4.12E+00
Cadmium	6.01E-03	3.48E-03	2.54E-03

Table B.15: LCI for packaging paper/paperboard recycling baseline, alternatives, DSCC and DNCC, continued

Calcium	3.63E+01	2.10E+01	1.53E+01
Carbon dioxide, biogenic	6.97E+04	4.03E+04	2.94E+04
Carbon dioxide, fossil	9.09E+05	5.25E+05	3.84E+05
Carbon monoxide, biogenic	1.16E+02	6.68E+01	4.88E+01
Carbon monoxide, fossil	1.58E+02	9.11E+01	6.65E+01
Chlorine	1.57E-01	9.05E-02	6.60E-02
Chromium	5.64E-02	3.26E-02	2.38E-02
Chromium VI	1.74E-03	1.00E-03	7.33E-04
Cobalt	2.47E-02	1.43E-02	1.04E-02
Copper	8.42E-02	4.86E-02	3.55E-02
Dinitrogen monoxide	4.37E+00	2.53E+00	1.84E+00
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	3.78E-08	2.18E-08	1.59E-08
Ethane	9.79E+00	5.66E+00	4.13E+00
Ethanol	2.62E-03	1.51E-03	1.10E-03
Ethene	1.96E+01	1.13E+01	8.27E+00
Ethyne	3.26E+00	1.89E+00	1.38E+00
Fluorine	4.35E-02	2.51E-02	1.83E-02
Formaldehyde	1.66E+00	9.60E-01	7.01E-01
Hydrocarbons, aliphatic, alkanes, unspecified	4.09E+00	2.36E+00	1.73E+00
Hydrocarbons, aliphatic, unsaturated	5.96E+00	3.45E+00	2.52E+00
Hydrocarbons, aromatic	3.07E-03	1.78E-03	1.30E-03
Hydrogen chloride	2.06E+01	1.19E+01	8.68E+00
Hydrogen fluoride	6.53E-01	3.78E-01	2.76E-01
Hydrogen sulfide	6.07E-02	3.51E-02	2.56E-02
Iodine	3.28E-02	1.90E-02	1.39E-02
Iron	1.03E+01	5.95E+00	4.34E+00
Lead	8.07E-02	4.67E-02	3.41E-02
Lead-210	5.89E+01	3.41E+01	2.49E+01
m-Xylene	1.04E-01	6.03E-02	4.40E-02
Magnesium	6.65E+00	3.84E+00	2.81E+00
Manganese	1.73E-01	1.00E-01	7.31E-02
Mercury	8.93E-03	5.16E-03	3.77E-03
Methane, biogenic	1.02E+00	5.88E-01	4.29E-01
Methane, fossil	2.15E+02	1.24E+02	9.06E+01
Methanol	4.45E-03	2.57E-03	1.88E-03
Molybdenum	2.91E-02	1.68E-02	1.23E-02
Nickel	5.27E-02	3.05E-02	2.23E-02
Nitrogen oxides	9.77E+02	5.65E+02	4.12E+02
NMVOC, non-methane volatile organic compounds, unspecified origin	1.35E+01	7.80E+00	5.69E+00
PAH, polycyclic aromatic hydrocarbons	1.49E-01	8.61E-02	6.29E-02
Particulates, < 2.5 um	7.14E+01	4.12E+01	3.01E+01
Particulates, > 10 um	8.96E+01	5.18E+01	3.78E+01
Particulates, > 2.5 um, and < 10um	3.43E+01	1.98E+01	1.45E+01
Pentane	1.67E+01	9.67E+00	7.06E+00
Phenol	3.04E-01	1.75E-01	1.28E-01
Phenol, pentachloro-	7.04E-06	4.07E-06	2.97E-06
Phosphorus	3.51E-01	2.03E-01	1.48E-01
Polonium-210	1.08E+02	6.25E+01	4.56E+01

Table B.15: LCI for packaging paper/paperboard recycling baseline, alternatives, DSCC and DNCC, continued

Potassium	2.18E+01	1.26E+01	9.22E+00
Potassium-40	1.63E+01	9.43E+00	6.89E+00
Propane	9.32E+00	5.39E+00	3.93E+00
Propene	3.26E+00	1.89E+00	1.38E+00
Propionic acid	2.79E-01	1.61E-01	1.18E-01
Radium-226	1.52E+01	8.79E+00	6.42E+00
Radium-228	3.50E+01	2.02E+01	1.48E+01
Radon-220	2.89E+00	1.67E+00	1.22E+00
Radon-222	2.89E+00	1.67E+00	1.22E+00
Scandium	9.61E-04	5.55E-04	4.05E-04
Selenium	5.05E-02	2.92E-02	2.13E-02
Silicon	8.07E+01	4.66E+01	3.41E+01
Sodium	2.80E+00	1.62E+00	1.18E+00
Strontium	2.48E-01	1.43E-01	1.05E-01
Sulfur oxides	1.16E+02	6.72E+01	4.91E+01
Thallium	0.00E+00	0.00E+00	0.00E+00
Thorium	0.00E+00	0.00E+00	0.00E+00
Thorium-228	7.01E+00	4.05E+00	2.96E+00
Thorium-232	4.40E+00	2.54E+00	1.85E+00
Tin	0.00E+00	0.00E+00	0.00E+00
Titanium	3.30E-01	1.90E-01	1.40E-01
Toluene	3.70E+00	2.14E+00	1.56E+00
Uranium	0.00E+00	0.00E+00	0.00E+00
Uranium-238	1.27E+01	7.35E+00	5.37E+00
Vanadium	1.10E-01	6.00E-02	5.00E-02
Water	3.88E+03	2.24E+03	1.64E+03
Xylene	2.05E+00	1.18E+00	8.60E-01
Zinc	3.10E-01	1.80E-01	1.30E-01
Elementary flows/Emission to water/surface water			
Water	15155.17	8759.82	6395.35
Elementary flows/Emission to water/unspecified			
Ammonium, ion	4.50E+01	2.60E+01	1.90E+01
AOX, Adsorbable Organic Halogen as Cl	2.32E+00	1.34E+00	9.79E-01
Arsenic, ion	1.41E-01	8.18E-02	5.97E-02
BOD5, Biological Oxygen Demand	1.73E+02	9.98E+01	7.29E+01
Chlorides, unspecified	2.14E+03	1.24E+03	9.02E+02
Chromium, ion	2.62E-01	1.51E-01	1.10E-01
COD, Chemical Oxygen Demand	2.32E+03	1.34E+03	9.77E+02
Copper, ion	2.27E-01	1.31E-01	9.60E-02
DOC, Dissolved Organic Carbon	9.17E+02	5.30E+02	3.87E+02
Lead	1.02E-01	5.91E-02	4.32E-02
Mercury	1.15E-02	6.67E-03	4.87E-03
Nickel, ion	5.99E-02	3.46E-02	2.53E-02
Nitrogen	1.56E+02	9.03E+01	6.59E+01
Phosphorus	2.03E+01	1.17E+01	8.57E+00
Suspended solids, unspecified	6.47E+02	3.74E+02	2.73E+02
TOC, Total Organic Carbon	9.17E+02	5.30E+02	3.87E+02
Zinc, ion	7.09E-01	4.10E-01	2.99E-01

Table B.15: LCI for packaging paper/paperboard recycling baseline, alternatives, DSCC and DNCC, continued

Virgin Paperboard Production from Raw Materials			
Ecoinvent process: containerboard production, fluting medium, semichemical | containerboard, fluting medium | Cutoff, U – RoW			
Input			
Elementary flows/Resource/in water			
Water, river	-9.52E+04	-5.50E+04	-4.02E+04
Water, well	-1.86E+00	-1.07E+00	-7.83E-01
Output			
Elementary flows/Emission to air/high population density			
Acetaldehyde	-9.11E-01	-5.26E-01	-3.84E-01
Acetic acid	-4.36E-01	-2.52E-01	-1.84E-01
Acetone	-1.09E-01	-6.30E-02	-4.60E-02
Aluminium	-8.05E+01	-4.65E+01	-3.40E+01
Ammonia	-2.28E+01	-1.32E+01	-9.60E+00
Antimony	-1.45E-01	-8.40E-02	-6.14E-02
Arsenic	-3.40E-01	-1.96E-01	-1.43E-01
Barium	-1.59E+00	-9.18E-01	-6.70E-01
Benzene	-4.09E+01	-2.37E+01	-1.73E+01
Benzene, ethyl-	-3.94E-01	-2.28E-01	-1.66E-01
Benzene, hexachloro-	-9.46E-08	-5.47E-08	-3.99E-08
Benzo(a)pyrene	-1.20E-01	-6.94E-02	-5.06E-02
Beryllium	-1.59E-02	-9.18E-03	-6.70E-03
Boron	-6.52E+01	-3.77E+01	-2.75E+01
Bromine	-8.86E-01	-5.12E-01	-3.74E-01
Butane	-2.64E-02	-1.52E-02	-1.11E-02
Cadmium	-5.48E-02	-3.17E-02	-2.31E-02
Calcium	-3.65E+02	-2.11E+02	-1.54E+02
Carbon dioxide, biogenic	-2.10E+06	-1.21E+06	-8.85E+05
Carbon dioxide, fossil	-9.25E+05	-5.35E+05	-3.90E+05
Carbon monoxide, biogenic	-6.57E+03	-3.80E+03	-2.77E+03
Carbon monoxide, fossil	-5.81E+03	-3.36E+03	-2.45E+03
Chlorine	-2.37E+00	-1.37E+00	-9.98E-01
Chromium	-4.80E-01	-2.78E-01	-2.03E-01
Chromium VI	-7.95E-03	-4.60E-03	-3.36E-03
Cobalt	-2.43E-01	-1.40E-01	-1.02E-01
Copper	-5.30E-01	-3.06E-01	-2.24E-01
Dinitrogen monoxide	-3.75E+01	-2.17E+01	-1.58E+01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-4.43E-07	-2.56E-07	-1.87E-07
Ethane	-8.69E+01	-5.02E+01	-3.67E+01
Ethanol	-2.18E-01	-1.26E-01	-9.20E-02
Ethene	-1.74E+02	-1.00E+02	-7.33E+01
Ethyne	-2.90E+01	-1.67E+01	-1.22E+01
Fluorine	-6.57E-01	-3.80E-01	-2.77E-01
Formaldehyde	-2.77E+00	-1.60E+00	-1.17E+00
Hydrocarbons, aliphatic, alkanes, unspecified	-4.14E+01	-2.39E+01	-1.75E+01
Hydrocarbons, aliphatic, unsaturated	-6.97E+01	-4.03E+01	-2.94E+01
Hydrocarbons, aromatic	-1.11E-01	-6.44E-02	-4.70E-02
Hydrogen chloride	-6.90E+01	-3.99E+01	-2.91E+01
Hydrogen fluoride	-2.27E+00	-1.31E+00	-9.57E-01

Table B.15: LCI for packaging paper/paperboard recycling baseline, alternatives, DSCC and DNCC, continued

Hydrogen sulfide	-5.67E-01	-3.28E-01	-2.39E-01
Hydrogen sulfide	-2.43E+02	-1.41E+02	-1.03E+02
Iodine	-2.72E-01	-1.57E-01	-1.15E-01
Iron	-8.31E+01	-4.80E+01	-3.51E+01
Lead	-7.41E-01	-4.28E-01	-3.13E-01
Lead-210	-4.08E+02	-2.36E+02	-1.72E+02
m-Xylene	-1.58E+00	-9.12E-01	-6.66E-01
Magnesium	-5.23E+01	-3.02E+01	-2.21E+01
Manganese	-2.40E+00	-1.39E+00	-1.01E+00
Mercury	-7.22E-02	-4.17E-02	-3.05E-02
Methane, biogenic	-5.91E+01	-3.42E+01	-2.50E+01
Methane, fossil	-1.72E+03	-9.92E+02	-7.24E+02
Methanol	-3.70E-01	-2.14E-01	-1.56E-01
Molybdenum	-2.62E-01	-1.52E-01	-1.11E-01
Nickel	-7.81E-01	-4.51E-01	-3.29E-01
Nitrogen oxides	-3.94E+03	-2.28E+03	-1.66E+03
NMVOC, non-methane volatile organic compounds, unspecified origin	-2.39E+02	-1.38E+02	-1.01E+02
PAH, polycyclic aromatic hydrocarbons	-1.46E-01	-8.46E-02	-6.18E-02
Particulates, < 2.5 um	-1.33E+03	-7.67E+02	-5.60E+02
Particulates, > 10 um	-3.15E+02	-1.82E+02	-1.33E+02
Particulates, > 2.5 um, and < 10um	-3.18E+02	-1.84E+02	-1.34E+02
Pentane	-1.76E-02	-1.02E-02	-7.41E-03
Phenol	-2.84E+00	-1.64E+00	-1.20E+00
Phenol, pentachloro-	-1.06E-04	-6.15E-05	-4.49E-05
Phosphorus	-4.59E+00	-2.65E+00	-1.94E+00
Polonium-210	-7.50E+02	-4.33E+02	-3.16E+02
Potassium	-3.18E+02	-1.84E+02	-1.34E+02
Potassium-40	-1.11E+02	-6.42E+01	-4.69E+01
Propane	-5.79E+01	-3.35E+01	-2.45E+01
Propene	-2.90E+01	-1.67E+01	-1.22E+01
Radium-226	-1.05E+02	-6.09E+01	-4.44E+01
Radium-228	-1.28E+02	-7.38E+01	-5.39E+01
Radon-220	-2.39E+01	-1.38E+01	-1.01E+01
Radon-222	-2.39E+01	-1.38E+01	-1.01E+01
Scandium	-5.11E-03	-2.96E-03	-2.16E-03
Selenium	-4.50E-01	-2.60E-01	-1.90E-01
Silicon	-7.05E+02	-4.08E+02	-2.98E+02
Sodium	-3.13E+01	-1.81E+01	-1.32E+01
Strontium	-1.73E+00	-1.00E+00	-7.32E-01
Sulfur oxides	-2.39E+03	-1.38E+03	-1.01E+03
Thallium	-2.63E-03	-1.52E-03	-1.11E-03
Thorium	-1.95E-02	-1.13E-02	-8.22E-03
Thorium-228	-4.86E+01	-2.81E+01	-2.05E+01
Thorium-232	-3.03E+01	-1.75E+01	-1.28E+01
Tin	-1.22E-02	-7.06E-03	-5.16E-03
Titanium	-1.89E+00	-1.10E+00	-8.00E-01
Toluene	-9.76E+00	-5.64E+00	-4.12E+00
Uranium	-3.17E-02	-1.83E-02	-1.34E-02
Uranium-238	-8.81E+01	-5.09E+01	-3.72E+01

Table B.15: LCI for packaging paper/paperboard recycling baseline, alternatives, DSCC and DNCC, continued

Vanadium	-1.53E+00	-8.82E-01	-6.44E-01
Water	-1.28E+04	-7.40E+03	-5.40E+03
Xylene	-1.88E+01	-1.09E+01	-7.95E+00
Zinc	-4.10E+00	-2.37E+00	-1.73E+00
Elementary flows/Emission to water/surface water			
Water	-8.46E+04	-4.89E+04	-3.57E+04
Elementary flows/Emission to water/unspecified			
BOD5, Biological Oxygen Demand	-1.81E+03	-1.04E+03	-7.63E+02
Chromium, ion	-1.52E-02	-8.77E-03	-6.40E-03
COD, Chemical Oxygen Demand	-2.01E+04	-1.16E+04	-8.47E+03
DOC, Dissolved Organic Carbon	-7.94E+03	-4.59E+03	-3.35E+03
Nickel, ion	-1.30E+00	-7.51E-01	-5.49E-01
Nitrogen	-9.67E+02	-5.59E+02	-4.08E+02
Phosphorus	-1.81E+01	-1.05E+01	-7.65E+00
Suspended solids, unspecified	-2.46E+03	-1.42E+03	-1.04E+03
TOC, Total Organic Carbon	-7.94E+03	-4.59E+03	-3.35E+03

Table B.16: Net electricity estimation for printing, newsprint and packaging paper recycling for combined baseline and alternative scenarios

Unit	Electricity required producing different paper from recycling	Electricity required for producing different virgin paper	Net Electricity
Printing paper			
kWh in unit process, 1kg paper production	1.0092	-0.4802	-0.529
kWh/year	12017580	-19045697	-7028117
Newsprint			
kWh in unit process, 1kg paper production	1.600	-2.824	-1.224
kWh/year	26499370	-46771388	-20272018
Packaging paper			
kWh in unit process, 1kg paper production	0.1628	-0.3172	-0.154
kWh/year	457894	-892395	-434501

Table B.17: Emissions/savings from net electricity production from natural gas fueled combined cycle power plant in combined baseline and alternative scenarios

Flow	Unit	Writing	Printing	Newsprint	Packaging
Acenaphthene	kg	1.81E-05	-4.71E-05	-1.36E-04	-2.91E-06
Acetaldehyde	kg	1.83E-02	-4.75E-02	-1.37E-01	-2.94E-03
Acetic acid	kg	2.76E+00	-7.19E+00	-2.07E+01	-4.45E-01
Arsenic	kg	9.38E-04	-2.44E-03	-7.05E-03	-1.51E-04
Benzene	kg	2.06E-02	-5.36E-02	-1.55E-01	-3.31E-03
Benzo(a)pyrene	kg	1.21E-05	-3.14E-05	-9.07E-05	-1.94E-06
Beryllium	kg	5.64E-05	-1.47E-04	-4.23E-04	-9.08E-06
Butane	kg	2.11E+01	-5.50E+01	-1.59E+02	-3.40E+00
Cadmium	kg	5.16E-03	-1.34E-02	-3.87E-02	-8.30E-04
Carbon dioxide, fossil	kg	1.23E+06	-3.21E+06	-9.27E+06	-1.99E+05
Carbon monoxide, fossil	kg	5.02E+01	-1.31E+02	-3.77E+02	-8.08E+00
Chromium	kg	6.55E-03	-1.71E-02	-4.92E-02	-1.05E-03
Cobalt	kg	3.93E-04	-1.02E-03	-2.95E-03	-6.32E-05
Dinitrogen monoxide	kg	2.23E+01	-5.81E+01	-1.67E+02	-3.59E+00
Ethane	kg	3.13E+01	-8.14E+01	-2.35E+02	-5.03E+00
Formaldehyde	kg	7.37E-01	-1.92E+00	-5.54E+00	-1.19E-01
Hexane	kg	1.81E+01	-4.71E+01	-1.36E+02	-2.91E+00
Lead	kg	2.35E-03	-6.12E-03	-1.77E-02	-3.78E-04
Manganese	kg	1.78E-03	-4.64E-03	-1.34E-02	-2.87E-04
Mercury	kg	1.57E-03	-4.09E-03	-1.18E-02	-2.53E-04
Methane, fossil	kg	2.22E+01	-5.77E+01	-1.66E+02	-3.57E+00
Nickel	kg	9.84E-03	-2.56E-02	-7.39E-02	-1.58E-03
Nitrogen oxides	kg	5.82E+02	-1.52E+03	-4.37E+03	-9.37E+01
PAH, polycyclic aromatic hydrocarbons	kg	1.83E-01	-4.75E-01	-1.37E+00	-2.94E-02
Particulates, < 2.5 um	kg	1.12E+01	-2.91E+01	-8.38E+01	-1.80E+00
Pentane	kg	2.63E+01	-6.84E+01	-1.97E+02	-4.23E+00
Propane	kg	1.61E+01	-4.19E+01	-1.21E+02	-2.59E+00
Propionic acid	kg	3.65E-01	-9.51E-01	-2.74E+00	-5.88E-02
Selenium	kg	1.12E-04	-2.92E-04	-8.42E-04	-1.80E-05
Sulfur dioxide	kg	1.31E+01	-3.40E+01	-9.81E+01	-2.10E+00
Toluene	kg	3.42E-02	-8.92E-02	-2.57E-01	-5.51E-03
Water/m^3	m^3	2.24E+03	-5.83E+03	-1.68E+04	-3.61E+02
Water/m^3	m^3	1.37E+05	-3.58E+05	-1.03E+06	-2.21E+04

Table B.18: Net electricity production/savings from different paper recycling in DSCC and DNCC

Paper Category	Writing	Printing	Newsprint	Packaging
DSCC, kWh/year	1560462.00	-4062314.24	-11717407.13	-251145.37
DNCC, kWh/year	1139257.60	-2965802.69	-8554610.86	-183355.49
"-ve" indicates savings in electricity production Calculation procedure is the same as combined scenario				

Table B.19: LCI for net electricity production/savings for DSCC paper recycling

Flow	Unit, /year	Writing	Printing	Newsprint	Packaging
Acenaphthene	kg	1.05E-05	-2.72E-05	-7.86E-05	-1.68E-06
Acetaldehyde	kg	1.06E-02	-2.75E-02	-7.93E-02	-1.70E-03
Acetic acid	kg	1.60E+00	-4.16E+00	-1.20E+01	-2.57E-01
Arsenic	kg	5.42E-04	-1.41E-03	-4.07E-03	-8.73E-05
Benzene	kg	1.19E-02	-3.10E-02	-8.94E-02	-1.92E-03
Benzo(a)pyrene	kg	6.98E-06	-1.82E-05	-5.24E-05	-1.12E-06
Beryllium	kg	3.26E-05	-8.49E-05	-2.45E-04	-5.25E-06
Butane	kg	1.22E+01	-3.18E+01	-9.18E+01	-1.97E+00
Cadmium	kg	2.98E-03	-7.76E-03	-2.24E-02	-4.80E-04
Carbon dioxide, fossil	kg	7.14E+05	-1.86E+06	-5.36E+06	-1.15E+05
Carbon monoxide, fossil	kg	2.90E+01	-7.56E+01	-2.18E+02	-4.67E+00
Chromium	kg	3.79E-03	-9.86E-03	-2.84E-02	-6.10E-04
Cobalt	kg	2.27E-04	-5.91E-04	-1.70E-03	-3.65E-05
Dinitrogen monoxide	kg	1.29E+01	-3.36E+01	-9.68E+01	-2.08E+00
Ethane	kg	1.81E+01	-4.71E+01	-1.36E+02	-2.91E+00
Formaldehyde	kg	4.26E-01	-1.11E+00	-3.20E+00	-6.86E-02
Hexane	kg	1.05E+01	-2.72E+01	-7.86E+01	-1.68E+00
Lead	kg	1.36E-03	-3.54E-03	-1.02E-02	-2.19E-04
Manganese	kg	1.03E-03	-2.68E-03	-7.74E-03	-1.66E-04
Mercury	kg	9.08E-04	-2.36E-03	-6.82E-03	-1.46E-04
Methane, fossil	kg	1.28E+01	-3.34E+01	-9.62E+01	-2.06E+00
Nickel	kg	5.69E-03	-1.48E-02	-4.27E-02	-9.15E-04
Nitrogen oxides	kg	3.37E+02	-8.76E+02	-2.53E+03	-5.42E+01
PAH, polycyclic aromatic hydrocarbons	kg	1.06E-01	-2.75E-01	-7.93E-01	-1.70E-02
Particulates, < 2.5 um	kg	6.45E+00	-1.68E+01	-4.84E+01	-1.04E+00
Pentane	kg	1.52E+01	-3.95E+01	-1.14E+02	-2.44E+00
Propane	kg	9.30E+00	-2.42E+01	-6.99E+01	-1.50E+00
Propionic acid	kg	2.11E-01	-5.50E-01	-1.59E+00	-3.40E-02
Selenium	kg	6.48E-05	-1.69E-04	-4.87E-04	-1.04E-05
Sulfur dioxide	kg	7.55E+00	-1.97E+01	-5.67E+01	-1.21E+00
Toluene	kg	1.98E-02	-5.15E-02	-1.49E-01	-3.19E-03
Water/m^3	m^3	1.29E+03	-3.37E+03	-9.72E+03	-2.08E+02
Water/m^3	m^3	7.94E+04	-2.07E+05	-5.96E+05	-1.28E+04

Table B.20: LCI for net electricity production/savings for DNCC paper recycling

Flow	Unit, /year	Writing	Printing	Newsprint	Packaging
Acenaphthene	kg	7.64E-06	-1.99E-05	-5.74E-05	-1.23E-06
Acetaldehyde	kg	7.71E-03	-2.01E-02	-5.79E-02	-1.24E-03
Acetic acid	kg	1.17E+00	-3.03E+00	-8.75E+00	-1.88E-01
Arsenic	kg	3.96E-04	-1.03E-03	-2.97E-03	-6.37E-05
Benzene	kg	8.69E-03	-2.26E-02	-6.53E-02	-1.40E-03
Benzo(a)pyrene	kg	5.10E-06	-1.33E-05	-3.83E-05	-8.20E-07
Beryllium	kg	2.38E-05	-6.20E-05	-1.79E-04	-3.83E-06
Butane	kg	8.92E+00	-2.32E+01	-6.70E+01	-1.44E+00
Cadmium	kg	2.18E-03	-5.67E-03	-1.63E-02	-3.50E-04
Carbon dioxide, fossil	kg	5.21E+05	-1.36E+06	-3.91E+06	-8.38E+04
Carbon monoxide, fossil	kg	2.12E+01	-5.52E+01	-1.59E+02	-3.41E+00
Chromium	kg	2.77E-03	-7.20E-03	-2.08E-02	-4.45E-04
Cobalt	kg	1.66E-04	-4.31E-04	-1.24E-03	-2.67E-05
Dinitrogen monoxide	kg	9.41E+00	-2.45E+01	-7.07E+01	-1.51E+00
Ethane	kg	1.32E+01	-3.44E+01	-9.91E+01	-2.12E+00
Formaldehyde	kg	3.11E-01	-8.10E-01	-2.34E+00	-5.01E-02
Hexane	kg	7.64E+00	-1.99E+01	-5.74E+01	-1.23E+00
Lead	kg	9.92E-04	-2.58E-03	-7.45E-03	-1.60E-04
Manganese	kg	7.52E-04	-1.96E-03	-5.65E-03	-1.21E-04
Mercury	kg	6.63E-04	-1.73E-03	-4.98E-03	-1.07E-04
Methane, fossil	kg	9.36E+00	-2.44E+01	-7.02E+01	-1.51E+00
Nickel	kg	4.15E-03	-1.08E-02	-3.12E-02	-6.68E-04
Nitrogen oxides	kg	2.46E+02	-6.40E+02	-1.84E+03	-3.95E+01
PAH, polycyclic aromatic hydrocarbons	kg	7.71E-02	-2.01E-01	-5.79E-01	-1.24E-02
Particulates, < 2.5 um	kg	4.71E+00	-1.23E+01	-3.54E+01	-7.58E-01
Pentane	kg	1.11E+01	-2.88E+01	-8.32E+01	-1.78E+00
Propane	kg	6.79E+00	-1.77E+01	-5.10E+01	-1.09E+00
Propionic acid	kg	1.54E-01	-4.01E-01	-1.16E+00	-2.48E-02
Selenium	kg	4.73E-05	-1.23E-04	-3.55E-04	-7.61E-06
Sulfur dioxide	kg	5.51E+00	-1.43E+01	-4.14E+01	-8.87E-01
Toluene	kg	1.45E-02	-3.76E-02	-1.09E-01	-2.33E-03
Water/m^3	m^3	9.45E+02	-2.46E+03	-7.10E+03	-1.52E+02
Water/m^3	m^3	5.80E+04	-1.51E+05	-4.35E+05	-9.33E+03

Table B.21: LCI for raw PET granulates production

Flow	Category	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Acetaldehyde	Elementary flows/Emission to air/high population density	kg	-2.86E+02	-1.65E+02	-1.21E+02
Benzene		kg	-1.44E+00	-8.31E-01	-6.07E-01
Carbon dioxide, fossil		kg	-2.53E+06	-1.46E+06	-1.07E+06
Carbon monoxide, fossil		kg	-5.71E+03	-3.30E+03	-2.41E+03
Dinitrogen monoxide		kg	-6.24E+00	-3.61E+00	-2.63E+00
Nitrogen oxides		kg	-2.01E+03	-1.16E+03	-8.46E+02
NMVOC, non-methane volatile organic compounds, unspecified origin		kg	-4.43E+02	-2.56E+02	-1.87E+02
Particulates, > 2.5 um, and < 10um		kg	-2.69E+02	-1.56E+02	-1.14E+02
Sulfur dioxide		kg	-4.23E+02	-2.44E+02	-1.78E+02
Water		m^3	-1.37E+04	-7.90E+03	-5.77E+03
Aluminium	Elementary flows/Emission to water/unspecified	kg	-5.15E-02	-2.98E-02	-2.17E-02
Antimony		kg	-1.62E+01	-9.38E+00	-6.85E+00
Cadmium, ion		kg	-2.77E-03	-1.60E-03	-1.17E-03
Chromium, ion		kg	-1.19E-02	-6.87E-03	-5.01E-03
Copper, ion		kg	-1.30E-02	-7.50E-03	-5.48E-03
Lead		kg	-2.50E-02	-1.45E-02	-1.06E-02
Mercury		kg	-1.35E-04	-7.82E-05	-5.71E-05
Nickel, ion		kg	-3.82E-02	-2.21E-02	-1.61E-02
Nitrogen, organic bound		kg	-7.46E+01	-4.31E+01	-3.15E+01
Phosphorus		kg	-2.67E+01	-1.54E+01	-1.13E+01
Suspended solids, unspecified		kg	-1.89E+04	-1.09E+04	-7.99E+03
Zinc, ion		kg	-6.24E-01	-3.61E-01	-2.64E-01

Table B.22: LCI for raw HDPE granulates production

Flow	Category	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Carbon dioxide, fossil	Elementary flows/Emission to air/high population density	kg	-3.33E+05	-1.93E+05	-1.41E+05
Carbon monoxide, fossil		kg	-6.42E+02	-3.71E+02	-2.71E+02
Chromium		kg	-1.45E-01	-8.38E-02	-6.12E-02
Dinitrogen monoxide		kg	-6.72E+01	-3.89E+01	-2.84E+01
Ethene		kg	-2.47E+03	-1.43E+03	-1.04E+03
Hydrogen		kg	-1.33E+00	-7.69E-01	-5.61E-01
Methane, fossil		kg	-1.23E+01	-7.09E+00	-5.17E+00
Nitrogen oxides		kg	-1.18E+02	-6.84E+01	-4.99E+01
NMVOC, non-methane volatile organic compounds, unspecified origin		kg	-2.34E+03	-1.35E+03	-9.87E+02
Particulates, > 10 um		kg	-5.63E+01	-3.25E+01	-2.38E+01
Particulates, > 2.5 um, and < 10um		kg	-1.36E+01	-7.84E+00	-5.73E+00
Sulfur dioxide		kg	-6.94E-01	-4.01E-01	-2.93E-01
Water		m^3	-4.39E+04	-2.54E+04	-1.85E+04
Aluminium	Elementary flows/Emission to water/unspecified	kg	-1.65E+01	-9.53E+00	-6.96E+00
Ammonium, ion		kg	-2.16E+00	-1.25E+00	-9.13E-01
AOX, Adsorbable Organic Halogen as Cl		kg	-2.61E-01	-1.51E-01	-1.10E-01
Chloride		kg	-7.60E+02	-4.39E+02	-3.21E+02
Chromium, ion		kg	-8.84E-02	-5.11E-02	-3.73E-02
Copper, ion		kg	-2.41E-02	-1.40E-02	-1.02E-02
Fluoride		kg	-1.91E+00	-1.10E+00	-8.05E-01
Nickel, ion		kg	-6.58E-04	-3.81E-04	-2.78E-04
Nitrate		kg	-3.15E+00	-1.82E+00	-1.33E+00
Nitrogen, organic bound		kg	-2.06E+01	-1.19E+01	-8.70E+00
Phosphorus		kg	-7.87E+00	-4.55E+00	-3.32E+00
Sulfate		kg	-9.42E+02	-5.44E+02	-3.97E+02
Suspended solids, unspecified		kg	-1.01E+03	-5.83E+02	-4.26E+02
Zinc, ion		kg	-2.76E+00	-1.59E+00	-1.16E+00

Table B.23: LCI for raw PVC granulates production

Flow	Category	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Ammonia	Elementary flows/Emission to air/high population density	kg	-2.24E+02	-1.30E+02	-9.45E+01
Carbon dioxide, fossil		kg	-1.21E+05	-7.01E+04	-5.12E+04
Carbon monoxide, fossil		kg	-1.91E+02	-1.11E+02	-8.08E+01
Ethene, chloro-		kg	-2.64E+02	-1.52E+02	-1.11E+02
Nitrogen oxides		kg	-5.94E+01	-3.43E+01	-2.51E+01
NMVOC, non-methane volatile organic compounds, unspecified origin		kg	-8.64E+01	-4.99E+01	-3.65E+01
Particulates, < 2.5 um		kg	-2.88E+01	-1.67E+01	-1.22E+01
Particulates, > 10 um		kg	-2.48E+02	-1.44E+02	-1.05E+02
Particulates, > 2.5 um, and < 10um		kg	-7.19E+01	-4.15E+01	-3.03E+01
Ammonium, ion	Elementary flows/Emission to water/unspecified	kg	-1.43E+02	-8.25E+01	-6.02E+01
AOX, Adsorbable Organic Halogen as Cl		kg	-1.61E+01	-9.28E+00	-6.78E+00
Chloride		kg	-3.06E+03	-1.77E+03	-1.29E+03
Ethane, 1,2-dichloro-		kg	-4.91E-03	-2.84E-03	-2.07E-03
Ethene, chloro-		kg	-3.64E+00	-2.11E+00	-1.54E+00
Nitrogen, organic bound		kg	-7.60E+01	-4.39E+01	-3.21E+01
Phosphorus		kg	-5.05E+00	-2.92E+00	-2.13E+00
Sodium, ion		kg	-2.03E+03	-1.18E+03	-8.59E+02
Sulfate		kg	-3.34E+01	-1.93E+01	-1.41E+01
Zinc, ion		kg	-1.22E-02	-7.03E-03	-5.13E-03

Table B.24: LCI for raw LDPE granulates production

Flow	Category	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Carbon dioxide, fossil	Elementary flows/Emission to air/high population density	kg	-3.78E+05	-2.18E+05	-1.59E+05
Carbon monoxide, fossil		kg	-3.20E+02	-1.85E+02	-1.35E+02
Dinitrogen monoxide		kg	-6.81E+00	-3.93E+00	-2.87E+00
Ethene		kg	-1.74E+04	-1.01E+04	-7.34E+03
Hydrogen		kg	-6.40E+01	-3.70E+01	-2.70E+01
Methane, fossil		kg	-2.88E+01	-1.67E+01	-1.22E+01
Nitrogen oxides		kg	-4.57E+02	-2.64E+02	-1.93E+02
NMVOC, non-methane volatile organic compounds, unspecified origin		kg	-1.92E+04	-1.11E+04	-8.12E+03
Particulates, > 10 um		kg	-6.15E+01	-3.56E+01	-2.60E+01
Particulates, > 2.5 um, and < 10um		kg	-1.74E+00	-1.00E+00	-7.32E-01
Propene		kg	-3.66E+02	-2.12E+02	-1.54E+02
Sulfur dioxide		kg	-1.22E+01	-7.07E+00	-5.16E+00
Sulfur hexafluoride		kg	-1.84E-02	-1.06E-02	-7.75E-03
Water		m^3	-1.93E+05	-1.12E+05	-8.14E+04
Zinc		kg	-1.07E-01	-6.20E-02	-4.52E-02
Ammonium, ion	Elementary flows/Emission to water/unspecified	kg	-2.27E+01	-1.31E+01	-9.56E+00
AOX, Adsorbable Organic Halogen as Cl		kg	-2.81E+00	-1.62E+00	-1.18E+00
Arsenic, ion		kg	-2.42E-02	-1.40E-02	-1.02E-02
Cadmium, ion		kg	-2.43E-03	-1.41E-03	-1.03E-03
Chloride		kg	-2.41E+03	-1.39E+03	-1.02E+03
Chromium, ion		kg	-3.53E-01	-2.04E-01	-1.49E-01
Copper, ion		kg	-2.61E-01	-1.51E-01	-1.10E-01
Fluoride		kg	-5.38E+00	-3.11E+00	-2.27E+00
Lead		kg	-2.42E-02	-1.40E-02	-1.02E-02
Mercury		kg	-4.69E-04	-2.71E-04	-1.98E-04
Nickel, ion		kg	-4.99E-02	-2.89E-02	-2.11E-02
Nitrate		kg	-9.22E+00	-5.33E+00	-3.89E+00
Nitrogen, organic bound		kg	-1.16E+02	-6.68E+01	-4.88E+01
Phosphorus		kg	-4.02E+01	-2.32E+01	-1.70E+01
Sulfate		kg	-5.84E+03	-3.38E+03	-2.47E+03
Suspended solids, unspecified		kg	-3.87E+02	-2.24E+02	-1.63E+02
Zinc, ion		kg	-7.52E+00	-4.34E+00	-3.17E+00

Table B.25: LCI for raw PP granulates production

Flow	Category	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Carbon dioxide, fossil	Elementary flows/Emission to air/high population density	kg	-5.32E+05	-3.08E+05	-2.25E+05
Carbon monoxide, fossil		kg	-2.03E+02	-1.17E+02	-8.58E+01
Dinitrogen monoxide		kg	-1.06E+01	-6.12E+00	-4.47E+00
Ethene		kg	-9.30E+00	-5.38E+00	-3.92E+00
Hydrogen		kg	-7.34E-01	-4.24E-01	-3.10E-01
Methane, fossil		kg	-4.11E+01	-2.37E+01	-1.73E+01
Nitrogen oxides		kg	-2.56E+02	-1.48E+02	-1.08E+02
NMVOC, non-methane volatile organic compounds, unspecified origin		kg	-3.45E+03	-1.99E+03	-1.45E+03
Particulates, > 10 um		kg	-8.48E+01	-4.90E+01	-3.58E+01
Particulates, > 2.5 um, and < 10um		kg	-3.55E+01	-2.05E+01	-1.50E+01
Propene		kg	-4.90E+02	-2.83E+02	-2.07E+02
Sulfur dioxide		kg	-8.13E-01	-4.70E-01	-3.43E-01
Sulfur hexafluoride		kg	-7.44E-03	-4.30E-03	-3.14E-03
Water		m^3	-3.70E+04	-2.14E+04	-1.56E+04
Aluminium	Elementary flows/Emission to water/unspecified	kg	-1.40E+00	-8.10E-01	-5.91E-01
Ammonium, ion		kg	-7.22E+00	-4.17E+00	-3.05E+00
AOX, Adsorbable Organic Halogen as Cl		kg	-8.64E-01	-5.00E-01	-3.65E-01
Arsenic, ion		kg	-1.94E-02	-1.12E-02	-8.21E-03
Cadmium, ion		kg	-1.90E-03	-1.10E-03	-8.04E-04
Chloride		kg	-1.86E+03	-1.08E+03	-7.87E+02
Chromium, ion		kg	-1.51E-01	-8.72E-02	-6.37E-02
Copper, ion		kg	-1.04E-01	-6.01E-02	-4.39E-02
Fluoride		kg	-1.58E+00	-9.16E-01	-6.68E-01
Lead		kg	-2.95E-02	-1.70E-02	-1.24E-02
Mercury		kg	-1.82E-04	-1.05E-04	-7.69E-05
Nickel, ion		kg	-2.21E-02	-1.28E-02	-9.31E-03
Nitrate		kg	-9.47E+00	-5.47E+00	-3.99E+00
Nitrogen, organic bound		kg	-4.01E+01	-2.32E+01	-1.69E+01
Phosphorus		kg	-1.46E+01	-8.43E+00	-6.16E+00
Sulfate		kg	-1.88E+03	-1.09E+03	-7.95E+02
Suspended solids, unspecified		kg	-1.34E+02	-7.73E+01	-5.64E+01
Zinc, ion		kg	-1.42E+00	-8.23E-01	-6.01E-01

Table B.26: LCI for raw PS granulates production

Flow	Category	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Aldehydes, unspecified	Elementary flows/Emission to air/high population density	kg	-1.37E-06	-7.93E-07	-5.79E-07
Ammonia		kg	-9.66E-02	-5.58E-02	-4.08E-02
Antimony		kg	-1.40E-03	-8.12E-04	-5.93E-04
Arsenic		kg	-1.03E-01	-5.95E-02	-4.35E-02
Benzene		kg	-2.46E+02	-1.42E+02	-1.04E+02
Benzene, ethyl-		kg	-4.37E+02	-2.52E+02	-1.84E+02
Cadmium		kg	-1.28E-02	-7.40E-03	-5.40E-03
Carbon dioxide, biogenic		kg	-3.93E+04	-2.27E+04	-1.66E+04
Carbon dioxide, fossil		kg	-2.94E+07	-1.70E+07	-1.24E+07
Carbon disulfide		kg	-4.27E-02	-2.47E-02	-1.80E-02
Carbon monoxide, biogenic		kg	-8.11E+01	-4.69E+01	-3.42E+01
Carbon monoxide, fossil		kg	-6.07E+04	-3.51E+04	-2.56E+04
Chlorine		kg	-9.81E+00	-5.67E+00	-4.14E+00
Chromium		kg	-1.71E+01	-9.91E+00	-7.23E+00
Copper		kg	-8.57E-01	-4.95E-01	-3.62E-01
Dinitrogen monoxide		kg	-2.09E-01	-1.21E-01	-8.82E-02
Ethane, 1,2-dichloro-		kg	-3.25E-02	-1.88E-02	-1.37E-02
Ethene		kg	-7.42E+01	-4.29E+01	-3.13E+01
Ethene, chloro-		kg	-1.10E-01	-6.38E-02	-4.66E-02
Fluorine		kg	-4.62E-01	-2.67E-01	-1.95E-01
Hydrocarbons, aliphatic, alkanes, cyclic		kg	-3.12E+01	-1.80E+01	-1.31E+01
Hydrocarbons, aromatic		kg	-3.39E+02	-1.96E+02	-1.43E+02
Hydrocarbons, chlorinated		kg	-5.28E+00	-3.05E+00	-2.23E+00
Hydrogen		kg	-5.64E+02	-3.26E+02	-2.38E+02
Hydrogen chloride		kg	-5.48E+02	-3.17E+02	-2.31E+02
Hydrogen fluoride		kg	-2.04E+01	-1.18E+01	-8.63E+00
Hydrogen sulfide		kg	-5.74E-01	-3.32E-01	-2.42E-01
Lead		kg	-2.80E+00	-1.62E+00	-1.18E+00
Mercury		kg	-1.99E-02	-1.15E-02	-8.39E-03
Methane, biogenic		kg	-4.40E+02	-2.54E+02	-1.86E+02
Methane, chlorodifluoro-, HCFC-22		kg	-1.62E-01	-9.34E-02	-6.82E-02
Methane, dichloro-, HCC-30		kg	-2.80E-02	-1.62E-02	-1.18E-02
Methane, fossil		kg	-3.29E+05	-1.90E+05	-1.39E+05
Nickel		kg	-3.12E+01	-1.80E+01	-1.31E+01
Nitrogen oxides		kg	-5.77E+04	-3.33E+04	-2.43E+04

Table B.26: LCI for raw PS granulates production, continued

NMVOC, non-methane volatile organic compounds, unspecified origin		kg	-3.25E+04	-1.88E+04	-1.37E+04
Particulates, < 2.5 um		kg	-2.44E+03	-1.41E+03	-1.03E+03
Particulates, > 10 um		kg	-3.13E+03	-1.81E+03	-1.32E+03
Particulates, > 2.5 um, and < 10um		kg	-4.20E+03	-2.43E+03	-1.77E+03
Propene		kg	-5.50E+01	-3.18E+01	-2.32E+01
Selenium		kg	-3.56E-04	-2.06E-04	-1.50E-04
Silver		kg	-1.03E-02	-5.95E-03	-4.34E-03
Styrene		kg	-8.08E+02	-4.67E+02	-3.41E+02
Sulfate		kg	-6.20E-08	-3.58E-08	-2.62E-08
Sulfur dioxide		kg	-7.93E+04	-4.59E+04	-3.35E+04
Toluene		kg	-4.61E+01	-2.67E+01	-1.95E+01
Water		m^3	-5.72E+05	-3.31E+05	-2.41E+05
Xylene		kg	-1.14E+01	-6.56E+00	-4.79E+00
Zinc		kg	-4.06E-01	-2.35E-01	-1.71E-01
Acidity, unspecified	Elementary flows/Emission to water/surface water	kg	-5.83E+01	-3.37E+01	-2.46E+01
Aluminium		kg	-1.14E+01	-6.59E+00	-4.81E+00
Ammonium, ion		kg	-1.39E+02	-8.02E+01	-5.85E+01
AOX, Adsorbable Organic Halogen as Cl		kg	-3.64E-04	-2.11E-04	-1.54E-04
Arsenic, ion		kg	-9.07E-03	-5.24E-03	-3.83E-03
Benzene		kg	-1.11E+01	-6.43E+00	-4.69E+00
BOD5, Biological Oxygen Demand		kg	-5.26E+02	-3.04E+02	-2.22E+02
Bromate		kg	-3.00E-02	-1.74E-02	-1.27E-02
Cadmium, ion		kg	-1.06E-03	-6.12E-04	-4.47E-04
Calcium, ion		kg	-1.37E+02	-7.91E+01	-5.77E+01
Carbonate		kg	-1.25E+03	-7.25E+02	-5.29E+02
Chlorate		kg	-5.22E+00	-3.02E+00	-2.20E+00
Chloride		kg	-3.73E+03	-2.15E+03	-1.57E+03
Chlorinated solvents, unspecified		kg	-2.62E-01	-1.51E-01	-1.10E-01
Chlorine		kg	-1.92E-01	-1.11E-01	-8.12E-02
Chromium, ion		kg	-1.76E-04	-1.02E-04	-7.43E-05
COD, Chemical Oxygen Demand		kg	-4.17E+03	-2.41E+03	-1.76E+03
Copper, ion		kg	-1.89E+01	-1.09E+01	-7.96E+00
Cyanide		kg	-1.62E-03	-9.38E-04	-6.85E-04
Dissolved solids		kg	-2.31E+03	-1.33E+03	-9.75E+02
DOC, Dissolved Organic Carbon		kg	-4.55E+02	-2.63E+02	-1.92E+02
Ethane, 1,2-dichloro-		kg	-5.07E-04	-2.93E-04	-2.14E-04
Ethene, chloro-		kg	-2.06E-03	-1.19E-03	-8.69E-04
Fluoride		kg	-3.65E+00	-2.11E+00	-1.54E+00
Hydrocarbons, unspecified		kg	-2.66E+02	-1.54E+02	-1.12E+02

Table B.26: LCI for raw PS granulates production, continued

Iron, ion		kg	-1.70E+00	-9.85E-01	-7.19E-01
Lead		kg	-3.42E-02	-1.98E-02	-1.44E-02
Magnesium		kg	-1.77E+00	-1.02E+00	-7.47E-01
Manganese		kg	-1.13E-02	-6.50E-03	-4.75E-03
Mercury		kg	-2.09E-03	-1.21E-03	-8.82E-04
Molybdenum		kg	-2.31E-01	-1.34E-01	-9.75E-02
Nickel, ion		kg	-1.68E+01	-9.71E+00	-7.09E+00
Nitrate		kg	-7.57E+01	-4.38E+01	-3.20E+01
Nitrogen		kg	-3.81E+01	-2.20E+01	-1.61E+01
Oils, unspecified		kg	-2.62E+02	-1.51E+02	-1.10E+02
Phenol		kg	-5.40E+00	-3.12E+00	-2.28E+00
Phosphorus		kg	-1.60E+01	-9.27E+00	-6.77E+00
Potassium, ion		kg	-3.53E+00	-2.04E+00	-1.49E+00
Sodium, ion		kg	-2.28E+03	-1.32E+03	-9.62E+02
Strontium		kg	-4.28E-04	-2.48E-04	-1.81E-04
Sulfate		kg	-4.38E+03	-2.53E+03	-1.85E+03
Sulfide		kg	-1.84E+00	-1.06E+00	-7.75E-01
Sulfite		kg	-1.32E+01	-7.65E+00	-5.59E+00
Suspended solids, unspecified		kg	-2.95E+03	-1.71E+03	-1.24E+03
Tin, ion		kg	-1.40E-05	-8.12E-06	-5.93E-06
TOC, Total Organic Carbon		kg	-4.55E+02	-2.63E+02	-1.92E+02
Zinc, ion		kg	-5.36E-01	-3.10E-01	-2.26E-01
Water		m^3	-9.51E+05	-5.50E+05	-4.01E+05

Table B.27: LCI of water savings from raw plastic granulate production process

Flow	Category	Combined	DSCC	DNCC
All unit is in m^3/year				
PET				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	-1.40E+04	-8.08E+03	-5.90E+03
Water, lake		-1.27E+03	-7.33E+02	-5.35E+02
Water, river		-1.11E+03	-6.42E+02	-4.69E+02
Water, well		-5.80E+03	-3.35E+03	-2.45E+03
HDPE				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	-2.19E+05	-1.27E+05	-9.25E+04
Water, unspecified natural origin		-7.37E+03	-4.26E+03	-3.11E+03
PVC				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	-1.73E+05	-1.00E+05	-7.31E+04
Water, lake		-7.18E+02	-4.15E+02	-3.03E+02
Water, river		-7.28E+03	-4.21E+03	-3.07E+03
Water, well		-1.99E+04	-1.15E+04	-8.41E+03
LDPE				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	-7.72E+05	-4.46E+05	-3.26E+05
Water, unspecified natural origin		-2.96E+04	-1.71E+04	-1.25E+04
PP				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	-2.47E+05	-1.43E+05	-1.04E+05
Water, unspecified natural origin		-7.51E+03	-4.34E+03	-3.17E+03
PS				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	-1.42E+06	-8.23E+05	-6.01E+05
Water, river		-6.54E+04	-3.78E+04	-2.76E+04
Water, salt, ocean		-5.68E+03	-3.28E+03	-2.40E+03
Water, unspecified natural origin		-2.84E+04	-1.64E+04	-1.20E+04
Water, well		-5.00E-02	-3.00E-02	-2.00E-02
Water consumption saving from various plastic granulate raw production indicated by "-ve" sign. These quantities are used as input for plastic recycling LCI				

Table B.28: Emissions LCI from plastic recycling process net reduction in electricity production

Flow	Unit, /year	DSCC	DNCC
Acenaphthene	kg	-6.32E-05	-4.61E-05
Acetaldehyde	kg	-6.37E-02	-4.65E-02
Acetic acid	kg	-9.64E+00	-7.04E+00
Arsenic	kg	-3.27E-03	-2.39E-03
Benzene	kg	-7.18E-02	-5.25E-02
Benzo(a)pyrene	kg	-4.21E-05	-3.08E-05
Beryllium	kg	-1.97E-04	-1.44E-04
Butane	kg	-7.38E+01	-5.38E+01
Cadmium	kg	-1.80E-02	-1.31E-02
Carbon dioxide, fossil	kg	-4.31E+06	-3.14E+06
Carbon monoxide, fossil	kg	-1.75E+02	-1.28E+02
Chromium	kg	-2.29E-02	-1.67E-02
Cobalt	kg	-1.37E-03	-1.00E-03
Dinitrogen monoxide	kg	-7.78E+01	-5.68E+01
Ethane	kg	-1.09E+02	-7.97E+01
Formaldehyde	kg	-2.57E+00	-1.88E+00
Hexane	kg	-6.32E+01	-4.61E+01
Lead	kg	-8.20E-03	-5.99E-03
Manganese	kg	-6.22E-03	-4.54E-03
Mercury	kg	-5.48E-03	-4.00E-03
Methane, fossil	kg	-7.73E+01	-5.65E+01
Nickel	kg	-3.43E-02	-2.51E-02
Nitrogen oxides	kg	-2.03E+03	-1.48E+03
PAH, polycyclic aromatic hydrocarbons	kg	-6.37E-01	-4.65E-01
Particulates, < 2.5 um	kg	-3.89E+01	-2.84E+01
Pentane	kg	-9.16E+01	-6.69E+01
Propane	kg	-5.62E+01	-4.10E+01
Propionic acid	kg	-1.27E+00	-9.30E-01
Selenium	kg	-3.91E-04	-2.86E-04
Sulfur dioxide	kg	-4.56E+01	-3.33E+01
Toluene	kg	-1.19E-01	-8.72E-02
Water/m^3	m^3	-7.82E+03	-5.71E+03
Water/m^3	m^3	-4.79E+05	-3.50E+05
All emission category belongs to: Elementary flows/Emission to air/high population density except water which belongs to: Elementary flows/Emission to air/unspecified and Elementary flows/Emission to water/unspecified "-ve" indicates saving in environmental burden			

Table B.29: Glass recycling LCI

Flow	Category	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
All unit is in kg/year except for water which is in m3/year				
Glass cullet production from waste recycled glass				
ecoinvent process used**: treatment of waste glass from unsorted public collection, sorting | glass cullet, sorted | Cutoff, U**				
Input				
Water, cooling, unspecified natural origin	Elementary flows/Resource/in water	3.41E+03	1.97E+03	1.44E+03
Water, unspecified natural origin		7.33E+00	4.24E+00	3.09E+00
Output				
Water/m3	Elementary flows/Emission to air/unspecified	1.32E+03	7.64E+02	5.57E+02
Water/m3		2.09E+03	1.21E+03	8.80E+02
Recycled glass production from recycled glass cullet				
ecoinvent process used: **packaging glass production, white | packaging glass, white | Cutoff, U**				
Input				
Water, unspecified natural origin	Elementary flows/Resource/in water	4.71E+04	2.72E+04	1.99E+04
Output				
Ammonia	Elementary flows/Emission to air/high population density	6.24E-01	3.61E-01	2.63E-01
Antimony		1.60E+00	9.28E-01	6.77E-01
Arsenic		1.60E+00	9.28E-01	6.77E-01
Benzene		3.57E+01	2.06E+01	1.51E+01
Benzo(a)pyrene		3.40E-03	1.96E-03	1.43E-03
Cadmium		1.60E+00	9.28E-01	6.77E-01
Carbon dioxide, fossil		1.33E+07	7.69E+06	5.61E+06
Carbon monoxide, fossil		7.82E+02	4.52E+02	3.30E+02
Chromium		1.60E+00	9.28E-01	6.77E-01
Cobalt		1.60E+00	9.28E-01	6.77E-01
Copper		1.60E+00	9.28E-01	6.77E-01
Dinitrogen monoxide		6.80E+01	3.93E+01	2.87E+01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin		4.25E-08	2.46E-08	1.79E-08
Formaldehyde		4.84E+01	2.80E+01	2.04E+01
Hydrocarbons, aliphatic, alkanes, unspecified		2.83E+02	1.64E+02	1.20E+02
Hydrogen chloride		1.18E+03	6.84E+02	4.99E+02
Hydrogen fluoride		4.29E+02	2.48E+02	1.81E+02
Lead		1.84E+01	1.06E+01	7.76E+00
Manganese		1.60E+00	9.28E-01	6.77E-01
Methane, fossil		3.91E+02	2.26E+02	1.65E+02
Nickel		1.60E+00	9.28E-01	6.77E-01
Nitrogen oxides		5.00E+04	2.89E+04	2.11E+04
NMVOC, non-methane volatile organic compounds, unspecified origin		1.05E+02	6.08E+01	4.44E+01
Particulates, < 2.5 um		6.00E+03	3.47E+03	2.53E+03
Particulates, > 10 um		3.81E+02	2.20E+02	1.61E+02

Table B.29: Glass recycling LCI, continued

Particulates, > 2.5 um, and < 10um		3.10E+02	1.79E+02	1.31E+02
Selenium		1.75E+02	1.01E+02	7.36E+01
Sulfur dioxide		8.19E+04	4.73E+04	3.46E+04
Water/m3	Elementary flows/Emission to air/unspecified	7.43E+03	4.29E+03	3.13E+03
AOX, Adsorbable Organic Halogen as Cl	Elementary flows/Emission to water/surface water	2.38E+00	1.38E+00	1.00E+00
BOD5, Biological Oxygen Demand		2.38E+02	1.38E+02	1.00E+02
COD, Chemical Oxygen Demand		2.38E+02	1.38E+02	1.00E+02
Copper, ion		2.38E-02	1.38E-02	1.00E-02
DOC, Dissolved Organic Carbon		2.38E+02	1.38E+02	1.00E+02
Nitrite		2.38E+00	1.38E+00	1.00E+00
Oils, unspecified		2.38E+01	1.38E+01	1.00E+01
Sulfate		2.38E+01	1.38E+01	1.00E+01
Suspended solids, unspecified		2.38E+01	1.38E+01	1.00E+01
TOC, Total Organic Carbon		2.38E+02	1.38E+02	1.00E+02
Zinc, ion		2.38E-01	1.38E-01	1.00E-01
Water/m^3	Elementary flows/Emission to water/unspecified	1.90E+02	1.10E+02	8.04E+01
Emissions reduction from virgin glass production reduction from raw materials				
ecoinvent process used: **packaging glass production, white, without cullet | packaging glass, white | Cutoff, U**				
"-ve" sign indicates savings in emission				
Input				
Water, unspecified natural origin	Elementary flows/Resource/in water	-4.71E+04	-2.72E+04	-1.99E+04
Output				
Ammonia	Elementary flows/Emission to air/high population density	-6.24E-01	-3.61E-01	-2.63E-01
Antimony		-1.60E+00	-9.28E-01	-6.77E-01
Arsenic		-1.60E+00	-9.28E-01	-6.77E-01
Benzene		-4.09E+01	-2.36E+01	-1.73E+01
Benzo(a)pyrene		-3.53E-03	-2.04E-03	-1.49E-03
Cadmium		-1.60E+00	-9.28E-01	-6.77E-01
Carbon dioxide, fossil		-1.64E+07	-9.48E+06	-6.92E+06
Carbon monoxide, fossil		-8.10E+02	-4.68E+02	-3.42E+02
Chromium		-1.60E+00	-9.28E-01	-6.77E-01
Cobalt		-1.60E+00	-9.28E-01	-6.77E-01
Copper		-1.60E+00	-9.28E-01	-6.77E-01
Dinitrogen monoxide		-6.93E+01	-4.00E+01	-2.92E+01
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin		-4.29E-08	-2.48E-08	-1.81E-08
Formaldehyde		-4.97E+01	-2.87E+01	-2.10E+01
Hydrocarbons, aliphatic, alkanes, unspecified		-2.83E+02	-1.64E+02	-1.20E+02
Hydrogen chloride		-1.18E+03	-6.84E+02	-4.99E+02
Hydrogen fluoride		-4.29E+02	-2.48E+02	-1.81E+02
Lead		-1.84E+01	-1.06E+01	-7.76E+00
Manganese		-1.60E+00	-9.28E-01	-6.77E-01
Methane, fossil		-4.17E+02	-2.41E+02	-1.76E+02
Nickel		-1.60E+00	-9.28E-01	-6.77E-01

Table B.29: Glass recycling LCI, continued

Nitrogen oxides		-5.00E+04	-2.89E+04	-2.11E+04
NMVOC, non-methane volatile organic compounds, unspecified origin		-1.05E+02	-6.08E+01	-4.44E+01
Particulates, < 2.5 um		-6.00E+03	-3.47E+03	-2.53E+03
Particulates, > 10 um		-3.81E+02	-2.20E+02	-1.61E+02
Particulates, > 2.5 um, and < 10um		-3.10E+02	-1.79E+02	-1.31E+02
Selenium		-1.75E+02	-1.01E+02	-7.36E+01
Sulfur dioxide		-8.19E+04	-4.73E+04	-3.46E+04
Water/m3	Elementary flows/Emission to air/unspecified	-7.43E+03	-4.29E+03	-3.13E+03
AOX, Adsorbable Organic Halogen as Cl	Elementary flows/Emission to water/surface water	-2.38E+00	-1.38E+00	-1.00E+00
BOD5, Biological Oxygen Demand		-2.38E+02	-1.38E+02	-1.00E+02
COD, Chemical Oxygen Demand		-2.38E+02	-1.38E+02	-1.00E+02
Copper, ion		-2.38E-02	-1.38E-02	-1.00E-02
DOC, Dissolved Organic Carbon		-2.38E+02	-1.38E+02	-1.00E+02
Nitrite		-2.38E+00	-1.38E+00	-1.00E+00
Oils, unspecified		-2.38E+01	-1.38E+01	-1.00E+01
Sulfate		-2.38E+01	-1.38E+01	-1.00E+01
Suspended solids, unspecified		-2.38E+01	-1.38E+01	-1.00E+01
TOC, Total Organic Carbon		-2.38E+02	-1.38E+02	-1.00E+02
Zinc, ion		-2.38E-01	-1.38E-01	-1.00E-01
Water/m3	Elementary flows/Emission to water/unspecified	-1.90E+02	-1.10E+02	-8.04E+01

Table B.30: LCI for emission reduction from net electricity production reduction due to glass recycling

Flow	Unit, /year	Combined Scenario, Baseline and All Alternatives	DSCC	DNCC
Acenaphthene	kg	-6.25E-06	-3.61E-06	-2.64E-06
Acetaldehyde	kg	-6.31E-03	-3.65E-03	-2.66E-03
Acetic acid	kg	-9.54E-01	-5.51E-01	-4.03E-01
Arsenic	kg	-3.24E-04	-1.87E-04	-1.37E-04
Benzene	kg	-7.11E-03	-4.11E-03	-3.00E-03
Benzo(a)pyrene	kg	-4.17E-06	-2.41E-06	-1.76E-06
Beryllium	kg	-1.95E-05	-1.13E-05	-8.22E-06
Butane	kg	-7.30E+00	-4.22E+00	-3.08E+00
Cadmium	kg	-1.78E-03	-1.03E-03	-7.52E-04
Carbon dioxide, fossil	kg	-4.26E+05	-2.46E+05	-1.80E+05
Carbon monoxide, fossil	kg	-1.73E+01	-1.00E+01	-7.32E+00
Chromium	kg	-2.26E-03	-1.31E-03	-9.55E-04
Cobalt	kg	-1.36E-04	-7.84E-05	-5.72E-05
Dinitrogen monoxide	kg	-7.70E+00	-4.45E+00	-3.25E+00
Ethane	kg	-1.08E+01	-6.24E+00	-4.56E+00
Formaldehyde	kg	-2.55E-01	-1.47E-01	-1.07E-01
Hexane	kg	-6.25E+00	-3.61E+00	-2.64E+00
Lead	kg	-8.12E-04	-4.69E-04	-3.43E-04
Manganese	kg	-6.16E-04	-3.56E-04	-2.60E-04
Mercury	kg	-5.42E-04	-3.14E-04	-2.29E-04
Methane, fossil	kg	-7.66E+00	-4.43E+00	-3.23E+00
Nickel	kg	-3.40E-03	-1.96E-03	-1.43E-03
Nitrogen oxides	kg	-2.01E+02	-1.16E+02	-8.48E+01
PAH, polycyclic aromatic hydrocarbons	kg	-6.31E-02	-3.65E-02	-2.66E-02
Particulates, < 2.5 um	kg	-3.85E+00	-2.23E+00	-1.63E+00
Pentane	kg	-9.07E+00	-5.24E+00	-3.83E+00
Propane	kg	-5.56E+00	-3.21E+00	-2.35E+00
Propionic acid	kg	-1.26E-01	-7.29E-02	-5.32E-02
Selenium	kg	-3.87E-05	-2.24E-05	-1.63E-05
Sulfur dioxide	kg	-4.51E+00	-2.61E+00	-1.90E+00
Toluene	kg	-1.18E-02	-6.84E-03	-4.99E-03
Water/m^3	m^3	-7.74E+02	-4.47E+02	-3.27E+02
Water/m^3	m^3	-4.74E+04	-2.74E+04	-2.00E+04
All emission category belongs to: Elementary flows/Emission to air/high population density except water which belongs to: Elementary flows/Emission to air/unspecified and Elementary flows/Emission to water/unspecified "-ve" indicates saving in environmental burden				

Table B.31: LCI for net emission savings from reduction in electricity production from composting process

Flow	Unit/year	Alt. A1, A2	Alt. A3
Input			
Category: Resource/in ground			
Water, cooling, unspecified natural origin	m^3	-1.49E+05	-7.43E+04
Output			
Category: Elementary flows/Emission to air/high population density			
Acenaphthene	kg	-2.00E-05	-9.98E-06
Acetaldehyde	kg	-2.01E-02	-1.01E-02
Acetic acid	kg	-3.05E+00	-1.52E+00
Arsenic	kg	-1.03E-03	-5.17E-04
Benzene	kg	-2.27E-02	-1.14E-02
Benzo(a)pyrene	kg	-1.33E-05	-6.66E-06
Beryllium	kg	-6.22E-05	-3.11E-05
Butane	kg	-2.33E+01	-1.17E+01
Cadmium	kg	-5.69E-03	-2.84E-03
Carbon dioxide, fossil	kg	-1.36E+06	-6.80E+05
Carbon monoxide, fossil	kg	-5.54E+01	-2.77E+01
Chromium	kg	-7.22E-03	-3.61E-03
Cobalt	kg	-4.33E-04	-2.16E-04
Dinitrogen monoxide	kg	-2.46E+01	-1.23E+01
Ethane	kg	-3.45E+01	-1.72E+01
Formaldehyde	kg	-8.13E-01	-4.06E-01
Hexane	kg	-2.00E+01	-9.98E+00
Lead	kg	-2.59E-03	-1.30E-03
Manganese	kg	-1.97E-03	-9.83E-04
Mercury	kg	-1.73E-03	-8.66E-04
Methane, fossil	kg	-2.44E+01	-1.22E+01
Nickel	kg	-1.08E-02	-5.42E-03
Nitrogen oxides	kg	-6.42E+02	-3.21E+02
PAH, polycyclic aromatic hydrocarbons	kg	-2.01E-01	-1.01E-01
Particulates, < 2.5 um	kg	-1.23E+01	-6.15E+00
Pentane	kg	-2.89E+01	-1.45E+01
Propane	kg	-1.77E+01	-8.87E+00
Propionic acid	kg	-4.03E-01	-2.01E-01
Selenium	kg	-1.24E-04	-6.18E-05
Sulfur dioxide	kg	-1.44E+01	-7.20E+00
Toluene	kg	-3.78E-02	-1.89E-02
Category: Elementary flows/Emission to air/unspecified			
Water/m^3	m^3	-2.47E+03	-1.23E+03
Category: Elementary flows/Emission to water/unspecified			
Water/m^3	m^3	-1.51E+05	-7.57E+04

Table B.32: LCI for diesel burning during composting

Flow	Unit, /year	Alt. A1, A2	Alt. A3
Output			
Category: Elementary flows/Emission to air/high population density			
Ammonia	kg	2.39E+01	1.20E+01
Cadmium	kg	2.99E-02	1.50E-02
Carbon dioxide, fossil	kg	9.45E+06	4.73E+06
Carbon monoxide, fossil	kg	3.22E+04	1.61E+04
Chromium	kg	1.50E-01	7.48E-02
Copper	kg	5.09E+00	2.54E+00
Methane, fossil	kg	2.48E+02	1.24E+02
Nickel	kg	2.09E-01	1.05E-01
Nitrogen oxides	kg	9.84E+04	4.92E+04
NMVOC	kg	1.01E+04	5.05E+03
PAH, polycyclic aromatic hydrocarbons	kg	9.93E+00	4.97E+00
Particulates, < 2.5 um	kg	1.65E+04	8.25E+03
Particulates, > 2.5 um, and < 10um	kg	6.29E+03	3.15E+03
Selenium	kg	2.99E-02	1.50E-02
Sulfur dioxide	kg	2.99E+03	1.50E+03
Zinc	kg	2.99E+00	1.50E+00

Table B.33: Diesel emission LCI from biowaste incineration

Flow	Unit/year	Alt. A3	Alt. A4
Category: Elementary flows/Emission to air/high population density			
Ammonia	kg	2.25E+00	4.49E+00
Cadmium	kg	2.81E-03	5.62E-03
Carbon dioxide, fossil	kg	8.88E+05	1.78E+06
Carbon monoxide, fossil	kg	3.03E+03	6.05E+03
Chromium	kg	1.40E-02	2.81E-02
Copper	kg	4.78E-01	9.55E-01
Methane, fossil	kg	2.33E+01	4.66E+01
Nickel	kg	1.97E-02	3.93E-02
Nitrogen oxides	kg	9.24E+03	1.85E+04
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	9.49E+02	1.90E+03
PAH, polycyclic aromatic hydrocarbons	kg	9.33E-01	1.87E+00
Particulates, < 2.5 um	kg	1.55E+03	3.10E+03
Particulates, > 2.5 um, and < 10um	kg	5.91E+02	1.18E+03
Selenium	kg	2.81E-03	5.62E-03
Sulfur dioxide	kg	2.81E+02	5.62E+02
Zinc	kg	2.81E-01	5.62E-01

Table B.34: Net electricity production from biowaste incineration

Item	Ecoinvent	Unit data for LCA	Alt. A3, /year	Alt. A4, /year
Biowaste, kg	1.00E+00	1.00E+00	7.12E+08	1.42E+09
LHV	4.29E+00	1.90E+00	-	-
Net Thermal Energy Production, MJ	1.00E+00	4.45E-01	3.17E+08	6.34E+08
Net Electric Energy from Thermal Energy, MJ, **80% efficiency**	-	3.56E-01	2.53E+08	5.07E+08
Net Electric Energy from Thermal Energy, kWh **1 MJ = 0.2778 kWh**	-	9.88E-02	**7.04E+07**	**1.41E+08**
Net Electric Energy Produced, MJ	4.10E-01	1.82E-01	1.29E+08	2.59E+08
Net Electric Energy Produced, kWh **1 MJ = 0.2778 kWh**	-	5.05E-02	**3.59E+07**	**7.19E+07**
Total Net Electricity, kWh	-	1.49E-01	**1.06E+08**	**2.13E+08**

Table B.35: Emissions savings LCI from reduced electricity production from natural gas combined cycle power plant due to added net electricity from incineration of biowaste

Flow	Unit, /year	Alt. A3	Alt. A4
Input			
Category: Elementary flows/Resource/in water			
Water, cooling, unspecified natural origin	m^3	-5.31E+06	-1.06E+07
Output			
Category: Elementary flows/Emission to air/low population density			
Acenaphthene	kg	-7.13E-04	-1.43E-03
Acetaldehyde	kg	-7.20E-01	-1.44E+00
Acetic acid	kg	-1.09E+02	-2.18E+02
Arsenic	kg	-3.70E-02	-7.39E-02
Benzene	kg	-8.11E-01	-1.62E+00
Benzo(a)pyrene	kg	-4.76E-04	-9.52E-04
Beryllium	kg	-2.22E-03	-4.44E-03
Butane	kg	-8.33E+02	-1.67E+03
Cadmium	kg	-2.03E-01	-4.07E-01
Carbon dioxide, fossil	kg	-4.86E+07	-9.73E+07
Carbon monoxide, fossil	kg	-1.98E+03	-3.96E+03
Chromium	kg	-2.58E-01	-5.16E-01
Cobalt	kg	-1.55E-02	-3.09E-02
Dinitrogen monoxide	kg	-8.79E+02	-1.76E+03
Ethane	kg	-1.23E+03	-2.46E+03
Formaldehyde	kg	-2.91E+01	-5.81E+01
Hexane	kg	-7.13E+02	-1.43E+03
Lead	kg	-9.26E-02	-1.85E-01
Manganese	kg	-7.02E-02	-1.40E-01
Mercury	kg	-6.19E-02	-1.24E-01
Methane, fossil	kg	-8.73E+02	-1.75E+03
Nickel	kg	-3.88E-01	-7.75E-01
Nitrogen oxides	kg	-2.29E+04	-4.59E+04
PAH, polycyclic aromatic hydrocarbons	kg	-7.20E+00	-1.44E+01
Particulates, < 2.5 um	kg	-4.40E+02	-8.79E+02
Pentane	kg	-1.03E+03	-2.07E+03
Propane	kg	-6.34E+02	-1.27E+03
Propionic acid	kg	-1.44E+01	-2.88E+01
Selenium	kg	-4.42E-03	-8.83E-03
Sulfur dioxide	kg	-5.14E+02	-1.03E+03
Toluene	kg	-1.35E+00	-2.70E+00
Elementary flows/Emission to air/unspecified			
Water/m^3	m^3	-8.83E+04	-1.77E+05
Elementary flows/Emission to water/unspecified			
Water/m^3	m^3	-5.41E+06	-1.08E+07

Table B.36: LCI of waste graphical paper incineration process

Flow	Unit, /year	Alt. A2, A3, A4
Graphical Paper Incineration		
Ecoinvent process: treatment of waste graphical paper, municipal incineration with fly ash extraction | waste graphical paper | Cutoff, U – CH		
Input		
Category: Elementary flows/Resource/in ground		
Water, unspecified natural origin	m^3	1.32E+04
Category: Elementary flows/Resource/in air		
Oxygen	kg	2.81E+07
Category: Elementary flows/Resource/land		
Municipal waste incineration facility		
Occupation, construction site	m^2*a	9.05E+01
Occupation, industrial area, built up	m^2*a	7.24E+02
Transformation, from wetland, inland (non-use)	m^2	1.81E+01
Transformation, to industrial area, built up	m^2	1.81E+01
Slag landfill		
Transformation, from wetland, inland (non-use)	m^2	1.67E+01
Residual material landfill		
Transformation, from wetland, inland (non-use)	m^2	1.61E+01
Output, due to incineration process		
Category: Elementary flows/Emission to air/high population density		
Aluminium	kg	2.44E-01
Ammonia	kg	2.24E+01
Antimony	kg	1.37E-05
Arsenic	kg	3.87E-01
Barium	kg	1.08E+01
Benzene	kg	7.96E-01
Benzene, hexachloro-	kg	1.66E-03
Benzene, pentachloro-	kg	4.20E-03
Benzo(a)pyrene	kg	1.77E-05
Cadmium	kg	2.05E-02
Calcium	kg	6.53E+02
Carbon dioxide, biogenic	kg	3.55E+07
Carbon monoxide, biogenic	kg	1.35E+03
Chromium	kg	3.05E-01
Cobalt	kg	3.23E-02
Copper	kg	1.35E-01

Table B.36: LCI of waste graphical paper incineration process, continued

Cyanide	kg	2.90E+02
Dinitrogen monoxide	kg	1.35E+03
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.59E-06
Heat, waste	MJ	2.97E+08
Hydrogen chloride	kg	2.53E+01
Hydrogen fluoride	kg	3.17E+00
Iron	kg	5.14E-02
Lead	kg	1.60E-01
Magnesium	kg	1.09E+02
Manganese	kg	1.85E-01
Mercury	kg	9.51E-02
Methane, biogenic	kg	1.19E+01
Molybdenum	kg	1.36E-01
Nickel	kg	2.86E-01
Nitrogen oxides	kg	7.08E+03
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	3.62E+01
Particulates, < 2.5 um	kg	9.50E+01
Particulates, > 2.5 um, and < 10um	kg	4.77E-01
Phenol, pentachloro-	kg	3.47E-04
Phosphorus	kg	2.77E+00
Potassium	kg	1.58E+02
Selenium	kg	7.42E-01
Silicon	kg	7.99E-01
Sodium	kg	1.82E+02
Strontium	kg	1.41E-01
Sulfur dioxide	kg	3.61E+02
Thallium	kg	4.15E-02
Titanium	kg	3.44E+00
Toluene	kg	1.59E+00
Water/m3	m^3	2.16E+04
Zinc	kg	2.02E+00
Category: Elementary flows/Emission to water/ground water, long-term		
Aluminium	kg	2.30E+05
Antimony	kg	6.96E+00
Arsenic, ion	kg	3.01E+01
Barium	kg	2.01E+03

Table B.36: LCI of waste graphical paper incineration process, continued

Beryllium	kg	2.21E+01
BOD5, Biological Oxygen Demand	kg	2.36E+04
Boron	kg	3.43E+02
Cadmium, ion	kg	6.43E+00
Calcium, ion	kg	7.31E+04
Chloride	kg	5.58E+03
Chromium VI	kg	1.88E+01
Cobalt	kg	1.56E+01
COD, Chemical Oxygen Demand	kg	7.22E+04
Copper, ion	kg	1.38E+03
DOC, Dissolved Organic Carbon	kg	2.86E+04
Fluoride	kg	3.13E+02
Iron, ion	kg	1.47E+04
Lead	kg	1.37E+03
Magnesium	kg	9.66E+04
Manganese	kg	7.69E+02
Mercury	kg	7.05E-01
Molybdenum	kg	7.99E+01
Nickel, ion	kg	2.23E+02
Nitrate	kg	3.25E+03
Phosphate	kg	2.45E+02
Potassium, ion	kg	2.30E+04
Selenium	kg	4.77E+01
Silicon	kg	3.88E+04
Silver, ion	kg	9.34E-01
Sodium, ion	kg	1.45E+04
Strontium	kg	1.40E+03
Sulfate	kg	8.11E+04
Thallium	kg	3.17E+01
Tin, ion	kg	5.83E-03
Titanium, ion	kg	1.24E+03
TOC, Total Organic Carbon	kg	2.86E+04
Vanadium, ion	kg	4.12E+00
Zinc, ion	kg	1.35E+03
Category: Elementary flows/Emission to water/surface water		
Aluminium	kg	2.07E+01
Antimony	kg	3.37E+00

Table B.36: LCI of waste graphical paper incineration process, continued

Arsenic, ion	kg	1.93E+01
Barium	kg	1.17E+00
Beryllium	kg	1.46E-02
BOD5, Biological Oxygen Demand	kg	7.25E+03
Boron	kg	4.30E+00
Cadmium, ion	kg	7.13E-03
Calcium, ion	kg	1.50E+03
Chloride	kg	3.77E+04
Chromium VI	kg	5.42E+00
Chromium, ion	kg	4.53E-02
Cobalt	kg	3.04E-03
COD, Chemical Oxygen Demand	kg	7.41E+03
Copper, ion	kg	1.27E-01
DOC, Dissolved Organic Carbon	kg	3.23E+03
Fluoride	kg	1.37E+02
Heat, waste	MJ	7.34E+07
Iron, ion	kg	5.65E-01
Lead	kg	1.32E-01
Magnesium	kg	7.85E+02
Manganese	kg	1.19E-01
Mercury	kg	1.78E-02
Molybdenum	kg	1.73E+01
Nickel, ion	kg	1.52E-01
Nitrate	kg	1.16E+03
Phosphate	kg	4.06E+00
Potassium, ion	kg	8.69E+03
Selenium	kg	1.24E+01
Silicon	kg	1.24E+02
Silver, ion	kg	2.32E-03
Sodium, ion	kg	7.30E+03
Strontium	kg	9.19E-01
Sulfate	kg	1.39E+04
Thallium	kg	2.94E-02
Tin, ion	kg	9.73E-06
Titanium, ion	kg	8.44E-01
TOC, Total Organic Carbon	kg	3.23E+03
Vanadium, ion	kg	1.31E-02

Table B.36: LCI of waste graphical paper incineration process, continued

Water	m^3	4.46E+03
Zinc, ion	kg	1.84E-01
Output, due to diesel burning emissions		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	2.39E-02
Cadmium	kg	2.99E-05
Carbon dioxide, fossil	kg	9.43E+03
Carbon monoxide, fossil	kg	3.22E+01
Chromium	kg	1.49E-04
Copper	kg	5.08E-03
Methane, fossil	kg	2.48E-01
Nickel	kg	2.09E-04
Nitrogen oxides	kg	9.82E+01
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.01E+01
PAH, polycyclic aromatic hydrocarbons	kg	9.91E-03
Particulates, < 2.5 um	kg	1.65E+01
Particulates, > 2.5 um, and < 10um	kg	6.28E+00
Selenium	kg	2.99E-05
Sulfur dioxide	kg	2.99E+00
Zinc	kg	2.99E-03
Savings from reduced electricity production that is added by incineration process		
Input		
Category: Elementary flows/Resource/in water		
Water, cooling, unspecified natural origin	m^3	-1.93E+05
Output		
Category: Elementary flows/Emission to air/high population density		
Acenaphthene	kg	-2.04E-04
Acetaldehyde	kg	-2.06E-01
Acetic acid	kg	-3.11E+01
Arsenic	kg	-1.06E-02
Benzene	kg	-2.32E-01
Benzo(a)pyrene	kg	-1.36E-04
Beryllium	kg	-6.36E-04
Butane	kg	-2.38E+02
Cadmium	kg	-5.82E-02
Carbon dioxide, fossil	kg	-1.39E+07
Carbon monoxide, fossil	kg	-5.66E+02

Table B.36: LCI of waste graphical paper incineration process, continued

Chromium	kg	-7.39E-02
Cobalt	kg	-4.43E-03
Dinitrogen monoxide	kg	-2.51E+02
Ethane	kg	-3.53E+02
Formaldehyde	kg	-8.31E+00
Hexane	kg	-2.04E+02
Lead	kg	-2.65E-02
Manganese	kg	-2.01E-02
Mercury	kg	-1.77E-02
Methane, fossil	kg	-2.50E+02
Nickel	kg	-1.11E-01
Nitrogen oxides	kg	-6.56E+03
PAH, polycyclic aromatic hydrocarbons	kg	-2.06E+00
Particulates, < 2.5 um	kg	-1.26E+02
Pentane	kg	-2.96E+02
Propane	kg	-1.81E+02
Propionic acid	kg	-4.12E+00
Selenium	kg	-1.26E-03
Sulfur dioxide	kg	-1.47E+02
Toluene	kg	-3.86E-01
Category: Elementary flows/Emission to air/unspecified		
Water/m^3	m^3	-2.53E+04
Category: Elementary flows/Emission to water/unspecified		
Water/m^3	m^3	-1.55E+06

Table B.37: LCI of waste packaging paper incineration process

Flow	Unit, /year	Alt. A2, A3, A4
Packaging Paper Incineration		
Ecoinvent process: treatment of waste paperboard, municipal incineration with fly ash extraction | waste paperboard | Cutoff, U – CH		
Input		
Category: Elementary flows/Resource/in ground		
Water, unspecified natural origin	m^3	4.14E+03
Category: Elementary flows/Resource/in air		
Oxygen	kg	3.26E+06
Category: Elementary flows/Resource/land		
Municipal waste incineration facility		
Occupation, construction site	m^2*a	1.01E+01
Occupation, industrial area, built up	m^2*a	8.04E+01
Transformation, from wetland, inland (non-use)	m^2	2.01E+00
Transformation, to industrial area, built up	m^2	2.01E+00
Slag landfill		
Transformation, from wetland, inland (non-use)	m^2	2.51E-01
Residual material landfill		
Transformation, from wetland, inland (non-use)	m^2	7.68E-01
Output, due to incineration process		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	2.13E+00
Antimony	kg	9.89E-09
Arsenic	kg	2.45E-02
Barium	kg	6.02E-01
Benzene	kg	8.62E-02
Benzene, hexachloro-	kg	1.80E-04
Benzene, pentachloro-	kg	4.56E-04
Benzo(a)pyrene	kg	1.92E-06
Cadmium	kg	1.28E-03
Carbon dioxide, biogenic	kg	4.23E+06
Carbon monoxide, biogenic	kg	1.47E+02
Chromium	kg	2.16E-02
Cobalt	kg	4.48E-03
Copper	kg	8.62E-03
Cyanide	kg	2.22E+01
Dinitrogen monoxide	kg	1.03E+02

Table B.37: LCI of waste packaging paper incineration process, continued

Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.72E-07
Heat, waste	MJ	3.54E+07
Hydrogen chloride	kg	1.10E+01
Lead	kg	6.40E-03
Manganese	kg	4.87E-02
Mercury	kg	2.29E-02
Methane, biogenic	kg	1.29E+00
Nickel	kg	3.58E-02
Nitrogen oxides	kg	6.76E+02
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	3.92E+00
Particulates, < 2.5 um	kg	1.03E+01
Particulates, > 2.5 um, and < 10um	kg	5.17E-02
Phenol, pentachloro-	kg	3.75E-05
Selenium	kg	9.94E-02
Strontium	kg	1.21E-02
Sulfur dioxide	kg	5.07E+01
Tin	kg	1.18E-05
Toluene	kg	1.72E-01
Water/m3	m^3	4.24E+03
Zinc	kg	1.14E-01
Category: Elementary flows/Emission to water/ground water, long-term		
Aluminium	kg	3.78E+01
Antimony	kg	5.64E-03
Arsenic, ion	kg	1.91E+00
Barium	kg	1.12E+02
Beryllium	kg	2.84E+00
BOD5, Biological Oxygen Demand	kg	2.82E+03
Cadmium, ion	kg	4.01E-01
Calcium, ion	kg	1.75E+02
Chloride	kg	2.42E+03
Chromium VI	kg	1.32E+00
Cobalt	kg	2.16E+00
COD, Chemical Oxygen Demand	kg	8.61E+03
Copper, ion	kg	8.87E+01
DOC, Dissolved Organic Carbon	kg	3.41E+03

Table B.37: LCI of waste packaging paper incineration process, continued

Iron, ion	kg	4.73E-01
Lead	kg	5.47E+01
Manganese	kg	2.02E+02
Mercury	kg	1.70E-01
Nickel, ion	kg	2.79E+01
Nitrate	kg	2.48E+02
Selenium	kg	6.39E+00
Silicon	kg	4.22E+02
Strontium	kg	1.21E+02
Sulfate	kg	1.14E+04
Thallium	kg	7.67E-04
Tin, ion	kg	1.20E+01
TOC, Total Organic Carbon	kg	3.41E+03
Vanadium, ion	kg	1.96E-01
Zinc, ion	kg	7.62E+01
Category: Elementary flows/Emission to water/surface water		
Aluminium	kg	6.31E-02
Antimony	kg	2.77E-03
Arsenic, ion	kg	1.21E+00
Barium	kg	6.51E-02
Beryllium	kg	1.89E-03
BOD5, Biological Oxygen Demand	kg	8.64E+02
Cadmium, ion	kg	4.45E-04
Calcium, ion	kg	2.92E-01
Chloride	kg	1.63E+04
Chromium VI	kg	3.81E-01
Chromium, ion	kg	3.22E-03
Cobalt	kg	4.11E-04
COD, Chemical Oxygen Demand	kg	8.83E+02
Copper, ion	kg	8.15E-03
DOC, Dissolved Organic Carbon	kg	3.85E+02
Heat, waste	MJ	8.69E+06
Iron, ion	kg	7.90E-04
Lead	kg	5.29E-03
Manganese	kg	3.12E-02
Mercury	kg	4.30E-03
Nickel, ion	kg	1.89E-02

Table B.37: LCI of waste packaging paper incineration process, continued

Nitrate	kg	8.90E+01
Selenium	kg	1.66E+00
Silicon	kg	9.51E-01
Strontium	kg	7.89E-02
Sulfate	kg	1.95E+03
Thallium	kg	1.28E-06
Tin, ion	kg	1.64E-02
TOC, Total Organic Carbon	kg	3.85E+02
Vanadium, ion	kg	6.25E-04
Water	m^3	1.42E+03
Zinc, ion	kg	1.04E-02
Output, due to diesel burning emissions		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	4.27E-04
Cadmium	kg	5.34E-07
Carbon dioxide, fossil	kg	1.69E+02
Carbon monoxide, fossil	kg	5.76E-01
Chromium	kg	2.67E-06
Copper	kg	9.08E-05
Methane, fossil	kg	4.43E-03
Nickel	kg	3.74E-06
Nitrogen oxides	kg	1.76E+00
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.80E-01
PAH, polycyclic aromatic hydrocarbons	kg	1.77E-04
Particulates, < 2.5 um	kg	2.95E-01
Particulates, > 2.5 um, and < 10um	kg	1.12E-01
Selenium	kg	5.34E-07
Sulfur dioxide	kg	5.34E-02
Zinc	kg	5.34E-05
Savings from reduced electricity production that is added by incineration process		
Input		
Category: Elementary flows/Resource/in water		
Water, cooling, unspecified natural origin	m^3	-1.52E+06
Output		
Category: Elementary flows/Emission to air/high population density		
Acetaldehyde	kg	-2.62E-02
Acetic acid	kg	-3.96E+00

Table B.37: LCI of waste packaging paper incineration process, continued

Arsenic	kg	-1.34E-03
Benzene	kg	-2.95E-02
Benzo(a)pyrene	kg	-1.73E-05
Beryllium	kg	-8.08E-05
Butane	kg	-3.03E+01
Cadmium	kg	-7.39E-03
Carbon dioxide, fossil	kg	-1.77E+06
Carbon monoxide, fossil	kg	-7.19E+01
Chromium	kg	-9.38E-03
Cobalt	kg	-5.62E-04
Dinitrogen monoxide	kg	-3.19E+01
Ethane	kg	-4.48E+01
Formaldehyde	kg	-1.06E+00
Hexane	kg	-2.59E+01
Lead	kg	-3.37E-03
Manganese	kg	-2.55E-03
Mercury	kg	-2.25E-03
Methane, fossil	kg	-3.17E+01
Nickel	kg	-1.41E-02
Nitrogen oxides	kg	-8.34E+02
PAH, polycyclic aromatic hydrocarbons	kg	-2.62E-01
Particulates, < 2.5 um	kg	-1.60E+01
Pentane	kg	-3.76E+01
Propane	kg	-2.31E+01
Propionic acid	kg	-5.23E-01
Selenium	kg	-1.61E-04
Sulfur dioxide	kg	-1.87E+01
Toluene	kg	-4.90E-02
Category: Elementary flows/Emission to air/unspecified		
Water/m^3	m^3	-3.21E+03
Category: Elementary flows/Emission to water/unspecified		
Water/m^3	m^3	-1.97E+05

Table B.38: LCI of waste textile incineration process

Flow	Category	Alt. A2, A3, A4
Textile Incineration		
Ecoinvent process: treatment of waste textile, soiled, municipal incineration with fly ash extraction | waste textile, soiled | Cutoff, U – CH		
Input		
Category: Elementary flows/Resource/in ground		
Water, unspecified natural origin	m^3	2.12E+04
Category: Elementary flows/Resource/in air		
Oxygen	kg	2.49E+07
Category: Elementary flows/Resource/land		
Municipal waste incineration facility		
Occupation, construction site	m^2*a	7.76E+01
Occupation, industrial area, built up	m^2*a	6.21E+02
Transformation, from wetland, inland (non-use)	m^2	1.55E+01
Transformation, to industrial area, built up	m^2	1.55E+01
Slag landfill		
Transformation, from wetland, inland (non-use)	m^2	5.75E+00
Residual material landfill		
Transformation, from wetland, inland (non-use)	m^2	1.32E+01
Output, due to incineration process		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	1.97E+02
Arsenic	kg	9.73E-03
Benzene	kg	6.69E-01
Benzene, hexachloro-	kg	1.40E-03
Benzene, pentachloro-	kg	3.54E-03
Benzo(a)pyrene	kg	1.49E-05
Cadmium	kg	4.22E-04
Carbon dioxide, biogenic	kg	1.88E+07
Carbon dioxide, fossil	kg	7.27E+06
Carbon monoxide, biogenic	kg	8.20E+02
Carbon monoxide, fossil	kg	3.18E+02
Chromium	kg	1.01E-02
Copper	kg	8.46E-02
Cyanide	kg	4.70E+03
Dinitrogen monoxide	kg	2.19E+04
Dioxins, as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.34E-06
Heat, waste	MJ	3.02E+08
Hydrogen chloride	kg	2.12E+01
Lead	kg	4.37E-02
Mercury	kg	3.52E-05

Table B.38: LCI of waste textile incineration process, continued

Methane, biogenic	kg	7.23E+00
Methane, fossil	kg	2.80E+00
Nickel	kg	4.16E-03
Nitrogen oxides	kg	6.25E+04
NMVOC, unspecified origin	kg	3.05E+01
Particulates, < 2.5 um	kg	7.99E+01
Particulates, > 2.5 um, and < 10um	kg	4.01E-01
Phenol, pentachloro-	kg	2.91E-04
Phosphorus	kg	7.89E-01
Sulfur dioxide	kg	3.20E+03
Thallium	kg	6.21E-04
Toluene	kg	1.34E+00
Water/m3	m^3	2.69E+04
Zinc	kg	1.46E+00
Category: Elementary flows/Emission to water/ground water, long-term		
Aluminium	kg	6.50E+02
Antimony	kg	1.08E-02
Arsenic, ion	kg	7.57E-01
BOD5, Biological Oxygen Demand	kg	1.73E+04
Cadmium, ion	kg	1.33E-01
Calcium, ion	kg	3.01E+03
Chloride	kg	4.67E+03
Chromium VI	kg	1.04E+00
Cobalt	kg	5.68E-02
COD, Chemical Oxygen Demand	kg	5.29E+04
Copper, ion	kg	8.70E+02
DOC, Dissolved Organic Carbon	kg	2.09E+04
Iron, ion	kg	8.14E+00
Lead	kg	3.73E+02
Manganese	kg	9.50E-02
Mercury	kg	3.46E-04
Nickel, ion	kg	3.88E+00
Nitrate	kg	5.26E+04
Phosphate	kg	6.98E+01
Silicon	kg	7.26E+03
Sulfate	kg	7.19E+05
Thallium	kg	4.88E-01
Tin, ion	kg	4.77E-03
TOC, Total Organic Carbon	kg	2.09E+04
Vanadium, ion	kg	3.37E+00
Zinc, ion	kg	9.77E+02

Table B.38: LCI of waste textile incineration process, continued

Category: Elementary flows/Emission to water/surface water		
Aluminium	kg	1.09E+00
Antimony	kg	5.88E-03
Arsenic, ion	kg	1.13E+00
BOD5, Biological Oxygen Demand	kg	5.31E+03
Cadmium, ion	kg	1.47E-04
Calcium, ion	kg	5.03E+00
Chloride	kg	3.15E+04
Chromium VI	kg	3.12E-01
Chromium, ion	kg	1.50E-03
Cobalt	kg	9.49E-05
COD, Chemical Oxygen Demand	kg	5.43E+03
Copper, ion	kg	8.00E-02
DOC, Dissolved Organic Carbon	kg	2.37E+03
Heat, waste	MJ	8.06E+07
Iron, ion	kg	1.36E-02
Lead	kg	3.61E-02
Manganese	kg	1.59E-04
Mercury	kg	6.75E-06
Nickel, ion	kg	3.27E-03
Nitrate	kg	1.88E+04
Phosphate	kg	1.16E+00
Silicon	kg	1.64E+01
Sulfate	kg	1.23E+05
Thallium	kg	4.61E-04
Tin, ion	kg	7.96E-06
TOC, Total Organic Carbon	kg	2.37E+03
Vanadium, ion	kg	1.07E-02
Water	m^3	7.23E+03
Zinc, ion	kg	1.33E-01
Output, due to diesel burning emissions		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	9.12E-03
Cadmium	kg	1.14E-05
Carbon dioxide, fossil	kg	3.60E+03
Carbon monoxide, fossil	kg	1.23E+01
Chromium	kg	5.70E-05
Copper	kg	1.94E-03
Methane, fossil	kg	9.47E-02
Nickel	kg	7.98E-05
Nitrogen oxides	kg	3.75E+01
NMVOC, unspecified origin	kg	3.85E+00
PAH, polycyclic aromatic hydrocarbons	kg	3.79E-03

Table B.38: LCI of waste textile incineration process, continued

Particulates, < 2.5 um	kg	6.29E+00
Particulates, > 2.5 um, and < 10um	kg	2.40E+00
Selenium	kg	1.14E-05
Sulfur dioxide	kg	1.14E+00
Zinc	kg	1.14E-03
Savings from reduced electricity production that is added by incineration process		
Input		
Category: Elementary flows/Resource/in water		
Water, cooling, unspecified natural origin	m^3	-1.33E+06
Output		
Category: Elementary flows/Emission to air/high population density		
Acenaphthene	kg	-1.79E-04
Acetaldehyde	kg	-1.81E-01
Acetic acid	kg	-2.73E+01
Arsenic	kg	-9.28E-03
Benzene	kg	-2.04E-01
Benzo(a)pyrene	kg	-1.19E-04
Beryllium	kg	-5.58E-04
Butane	kg	-2.09E+02
Cadmium	kg	-5.10E-02
Carbon dioxide, fossil	kg	-1.22E+07
Carbon monoxide, fossil	kg	-4.97E+02
Chromium	kg	-6.48E-02
Cobalt	kg	-3.88E-03
Dinitrogen monoxide	kg	-2.21E+02
Ethane	kg	-3.09E+02
Formaldehyde	kg	-7.29E+00
Hexane	kg	-1.79E+02
Lead	kg	-2.33E-02
Manganese	kg	-1.76E-02
Mercury	kg	-1.55E-02
Methane, fossil	kg	-2.19E+02
Nickel	kg	-9.73E-02
Nitrogen oxides	kg	-5.76E+03
PAH, polycyclic aromatic hydrocarbons	kg	-1.81E+00
Particulates, < 2.5 um	kg	-1.10E+02
Pentane	kg	-2.60E+02
Propane	kg	-1.59E+02
Propionic acid	kg	-3.61E+00
Selenium	kg	-1.11E-03
Sulfur dioxide	kg	-1.29E+02
Toluene	kg	-3.39E-01

Table B.38: LCI of waste textile incineration process, continued

Category: Elementary flows/Emission to air/unspecified		
Water/m^3	m^3	-2.22E+04
Category: Elementary flows/Emission to water/unspecified		
Water/m^3	m^3	-1.36E+06

Table B.39: LCI for waste glass incineration

Flow	Category	Alt. A2, A3, A4
Glass Incineration		
Ecoinvent process: treatment of waste glass, municipal incineration with fly ash extraction | waste glass | Cutoff, U – CH		
Input		
Category: Elementary flows/Resource/land		
Municipal waste incineration facility		
Occupation, construction site	m^2*a	5.01E+01
Occupation, industrial area, built up	m^2*a	4.01E+02
Transformation, from wetland, inland (non-use)	m^2	1.00E+01
Transformation, to industrial area, built up	m^2	1.00E+01
Slag landfill		
Transformation, from wetland, inland (non-use)	m^2	1.03E+02
Output, due to incineration process		
Category: Elementary flows/Emission to air/high population density		
Benzene	kg	6.68E-01
Benzene, hexachloro-	kg	1.40E-03
Benzene, pentachloro-	kg	3.53E-03
Benzo(a)pyrene	kg	1.49E-05
Carbon monoxide, biogenic	kg	6.86E+02
Carbon monoxide, fossil	kg	4.50E+02
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.34E-06
Heat, waste	MJ	2.52E+06
Methane, biogenic	kg	6.05E+00
Methane, fossil	kg	3.97E+00
NMVOC, unspecified origin	kg	3.04E+01
Particulates, < 2.5 um	kg	7.98E+01
Particulates, > 2.5 um, and < 10um	kg	4.01E-01
Phenol, pentachloro-	kg	2.91E-04
Toluene	kg	1.34E+00
Category: Elementary flows/Emission to water/ground water, long-term		
Calcium, ion	kg	9.69E+05
Chloride	kg	3.57E+02

Table B.39: LCI for waste glass incineration, continued

Chromium VI	kg	2.66E+01
Copper, ion	kg	1.05E+02
Lead	kg	5.17E+02
Silicon	kg	4.11E+04
Sodium, ion	kg	7.56E+05
Zinc, ion	kg	5.24E+01
Category: Elementary flows/Emission to water/surface water		
Calcium, ion	kg	4.25E+03
Chloride	kg	2.26E+03
Chromium VI	kg	1.16E-01
Copper, ion	kg	3.64E-03
Heat, waste	MJ	5.85E+05
Lead	kg	9.44E-03
Silicon	kg	1.77E+02
Sodium, ion	kg	1.05E+05
Zinc, ion	kg	1.56E-03
Output, due to diesel burning emissions		
Category: Elementary flows/Emission to air/high population density		
Ammonia	kg	1.27E-01
Cadmium	kg	1.59E-04
Carbon dioxide, fossil	kg	5.01E+04
Carbon monoxide, fossil	kg	1.71E+02
Chromium	kg	7.93E-04
Copper	kg	2.70E-02
Methane, fossil	kg	1.32E+00
Nickel	kg	1.11E-03
Nitrogen oxides	kg	5.22E+02
NMVOC, unspecified origin	kg	5.36E+01
PAH	kg	5.27E-02
Particulates, < 2.5 um	kg	8.75E+01
Particulates, > 2.5 um, and < 10um	kg	3.34E+01
Selenium	kg	1.59E-04
Sulfur dioxide	kg	1.59E+01
Zinc	kg	1.59E-02
Savings from reduced electricity production that is added by incineration process		
Input		
Category: Elementary flows/Resource/in water		
Water, cooling, unspecified natural origin	m^3	-1.48E+03
Output		
Category: Elementary flows/Emission to air/high population density		
Acenaphthene	kg	-1.99E-07

Table B.39: LCI for waste glass incineration, continued

Acetaldehyde	kg	-2.01E-04
Acetic acid	kg	-3.04E-02
Arsenic	kg	-1.03E-05
Benzene	kg	-2.27E-04
Benzo(a)pyrene	kg	-1.33E-07
Beryllium	kg	-6.20E-07
Butane	kg	-2.33E-01
Cadmium	kg	-5.68E-05
Carbon dioxide, fossil	kg	-1.36E+04
Carbon monoxide, fossil	kg	-5.53E-01
Chromium	kg	-7.21E-05
Cobalt	kg	-4.32E-06
Dinitrogen monoxide	kg	-2.45E-01
Ethane	kg	-3.44E-01
Formaldehyde	kg	-8.11E-03
Hexane	kg	-1.99E-01
Lead	kg	-2.59E-05
Manganese	kg	-1.96E-05
Mercury	kg	-1.73E-05
Methane, fossil	kg	-2.44E-01
Nickel	kg	-1.08E-04
Nitrogen oxides	kg	-6.40E+00
PAH, polycyclic aromatic hydrocarbons	kg	-2.01E-03
Particulates, < 2.5 um	kg	-1.23E-01
Pentane	kg	-2.89E-01
Propane	kg	-1.77E-01
Propionic acid	kg	-4.02E-03
Selenium	kg	-1.23E-06
Sulfur dioxide	kg	-1.44E-01
Toluene	kg	-3.77E-04
Category: Elementary flows/Emission to air/unspecified		
Water/m^3	m^3	-2.46E+01
Category: Elementary flows/Emission to water/unspecified		
Water/m^3	m^3	-1.51E+03

APPENDIX C

DNCC and DSCC waste composition

Recyclable waste quantification: The total recyclable quantity as per world bank report is 517.12ton. However, the division of this quantity between the city corporations are not provided on the report. Therefore, it is necessary to divide the total recyclable waste quantity between city corporations and then subdividing the recyclable quantity of each city corporation into different recyclable waste items.

On DSCC waste report the recycled materials quantity is provided as 389ton/day. But on DNCC waste report this quantity is not mentioned. Therefore, the ratio of recycled materials can be derived from the following:

1) From DNCC waste report 2018-2019, the material flow is provided as follows:

Total generation = 4220 ton/day
Disposed on Landfill = 3075 ton/day
Recycled = 349 ton/day
Uncollected = 796 ton/day

Recycled fraction with respect to generated waste = 349/4220 = 0.083

2) Therefore, applying this fraction to DNCC 2019-2020 waste report total generated waste will provide the recycled waste value:

Total generation = 3433 ton/day
Recycled waste = 0.083*3433 = 283.91 ton/day ~ 284 ton/day

3) Now the ratio of the recycled materials quantity of two city corporation remains:
DNCC: DSCC = 284:389 = 1:1.37

Finally, dividing the recyclable quantity of 517.12 ton from World Bank report into DNCC and DSCC will provide the recyclable waste amount of 218.2 ton and 298.9 ton respectively. These recycled quantities can be now divided into different types of recyclable materials like plastic, paper, glass etc. in the same method. For example, the combined recyclable paper quantity is calculated in research methodology section 3.2 is 84.17 ton/day. The ratio of DNCC:DSCC is found 1:1.37 in the previous section. Therefore,

$$DNCC\ recyclable\ waste\ plastic = 84.17 * \frac{1}{1+1.37} = 35.52\frac{ton}{day}$$

Following the above way, the rest of the recyclable items are calculated as:

Table C.1: Recyclable items in DNCC and DSCC

Item	Paper, ton/day	Plastic, ton/day	Glass, ton/day	Other, ton/day
Combined	84.17	240.50	40.16	152.29
DNCC	35.52	101.49	16.95	64.27
DSCC	48.65	139.01	23.21	88.03

Now the paper and plastic are subdivided into more specific categories following the procedure described at step 2, section 3.2 of research methodology chapter of this study. Doing so produced the following results

Table C.2: Categorization of recyclable waste of DNCC and DSCC

Item	Category	DNCC, ton/day	DSCC, ton/day
Recyclable paper	Writing	5.33	7.30
	Printing	12.43	17.03
	Newsprint	14.21	19.46
	Packaging and others	3.55	4.87
Recyclable plastic	PET	26.58	36.41
	HDPE	11.34	15.53
	PVC	13.29	18.20
	LDPE	22.22	30.43
	PP	15.20	20.82
	PS	12.87	17.62

Other recyclable waste contains metals and alloy mostly which is not considered for this study like the combined baseline scenario.

Remaining waste quantity except landfill and recycling include waste to drain, khals, river and unserved areas are similarly kept out of DNCC vs DSCC LCA as in combined LCA.

Final Waste Composition: The final percentage of different wastes for each city corporation with respect to the generated waste quantity in individual city corporation are shown on Table C.3 and C.4.

Table C.3: DNCC waste composition

Treatment Method	Waste Item	Waste Quantity, ton/day	Waste Quantity, ton/year	Waste Fraction, %
Landfill Items	Organic/biowaste	2108.31	769534.71	63.69
	Graphical paper	56.07	20466.82	1.69
	Paperboard	6.23	2274.09	0.19
	Plastic	128.03	46730.35	3.87
	Textile	32.74	11950.13	0.99
	Glass	30.30	11058.33	0.92
	Metal/Other Inorganics/Inert	81.61	29786.14	2.47
Recyclable Papers	Writing	5.33	1944.71	0.16
	Printing	12.43	4537.65	0.38
	Newsprint	14.21	5185.88	0.43
	Packaging and others	3.55	1296.47	0.11
Recyclable Plastics	PET	26.58	9701.78	0.80
	HDPE	11.34	4137.98	0.34
	PVC	13.29	4850.89	0.40
	LDPE	22.22	8108.58	0.67
	PP	15.20	5548.30	0.46
	PS	12.87	4695.91	0.39
Recyclable Glass	Recycled Glass	16.95	6184.99	0.51
Recyclable Metals	Recycled Others	64.27	23457.18	1.94
Khal and Rivers	Mixed	171.50	62596.81	5.18
Drains and unserved areas	Mixed	477.05	174125.01	14.41
Total		**3310.06**	**1208172.70**	**100.00**

Table C.4: DSCC waste composition

Treatment Method	Waste Item	Waste Quantity, ton/day	Waste Quantity, ton/year	Waste Fraction, %
Landfill Items	Organic/biowaste	1915.59	699190.62	60.72
	Graphical paper	13.51	4931.15	0.43
	Paperboard	1.50	547.91	0.05
	Plastic	181.23	66149.55	5.74
	Textile	26.95	9836.72	0.85
	Glass	8.24	3008.77	0.26
	Metal/Other Inorganics/Inert	109.68	40034.71	3.48
Recyclable Papers	Writing	7.30	2663.70	0.23
	Printing	17.03	6215.30	0.54
	Newsprint	19.46	7103.20	0.62
	Packaging and others	4.87	1775.80	0.15
Recyclable Plastics	PET	36.41	13288.70	1.15
	HDPE	15.53	5667.87	0.49
	PVC	18.20	6644.35	0.58
	LDPE	30.43	11106.47	0.96
	PP	20.82	7599.61	0.66
	PS	17.62	6432.07	0.56
Recyclable Glass	Recycled Glass	23.21	8471.70	0.74
Recyclable Metals	Recycled Others	88.03	32129.73	2.79
Khal and Rivers	Mixed	158.40	57816.69	5.02
Drains and unserved areas	Mixed	440.63	160828.19	13.97
Total		**3154.64**	**1151442.80**	**100.00**

With these compositions the LCA of DNCC vs DSCC in baseline condition is conducted.

APPENDIX D

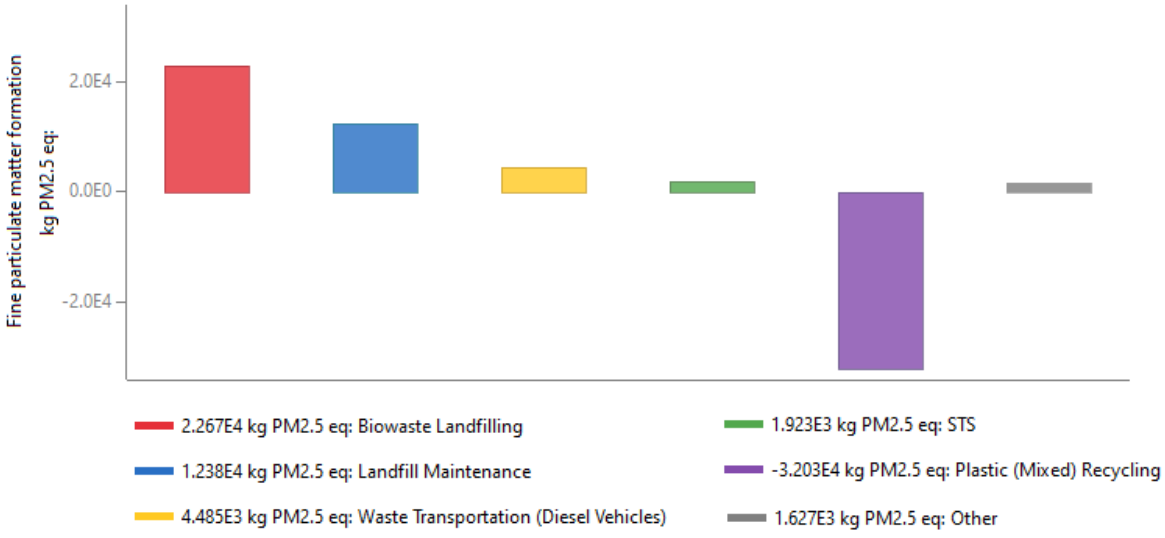

Figure D.1: Major contributors for fine particulate matter formation in baseline B0

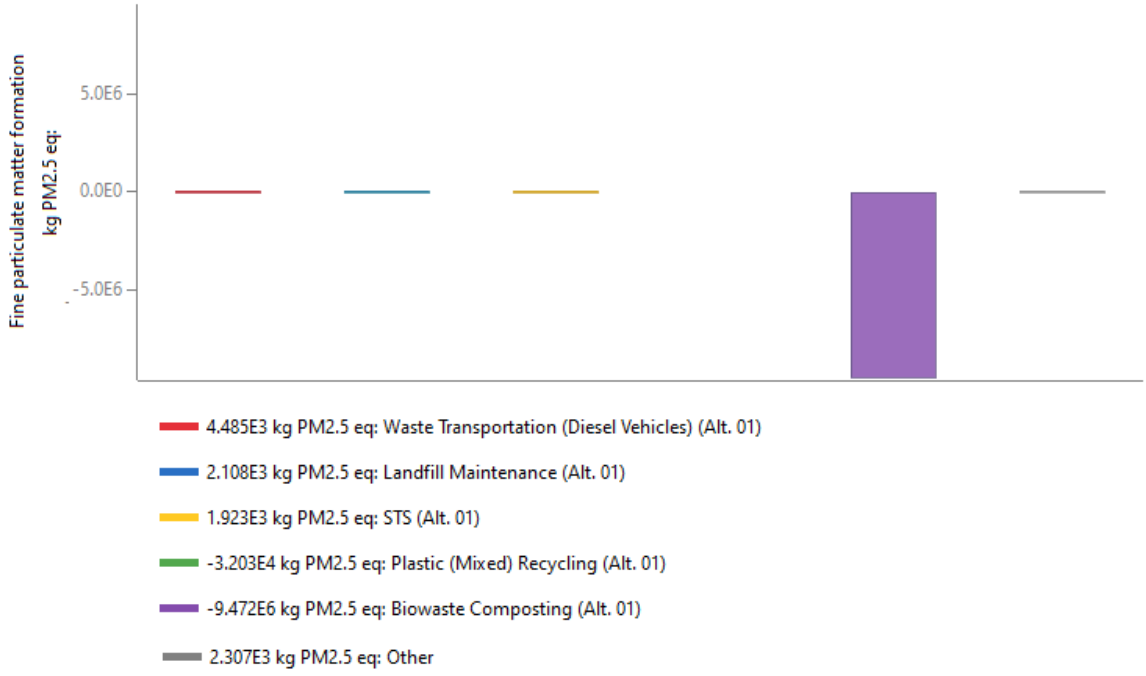

Figure D.2: Major contributors for fine particulate matter formation in alternative A1

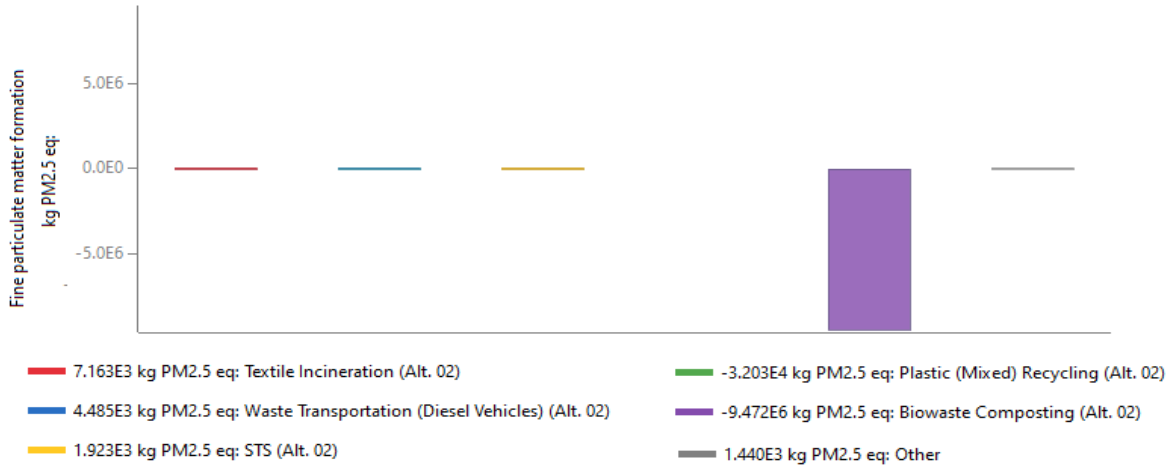

Figure D.3: Major contributors for fine particulate matter formation in alternative A2

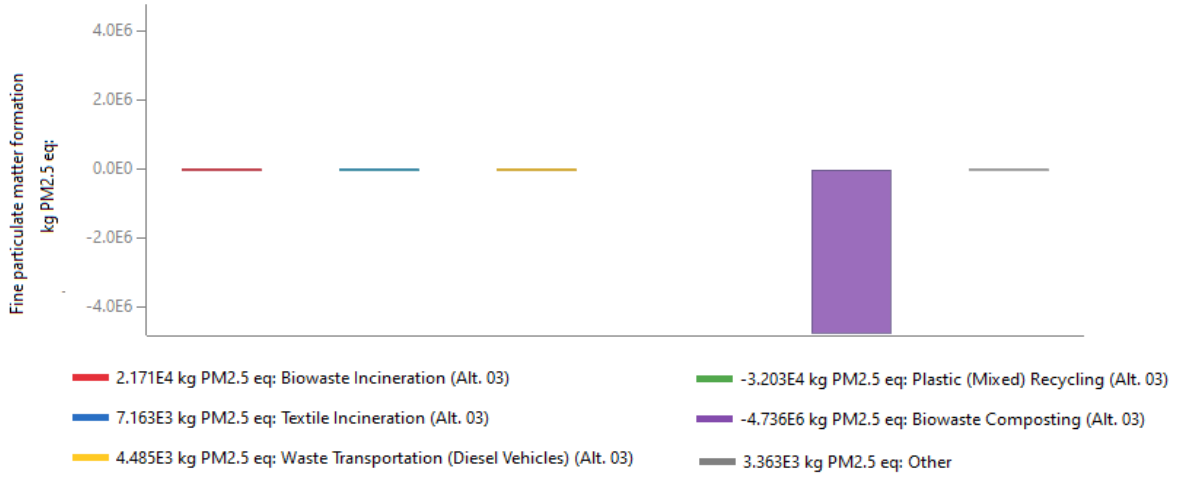

Figure D.4: Major contributors for fine particulate matter formation in alternative A3

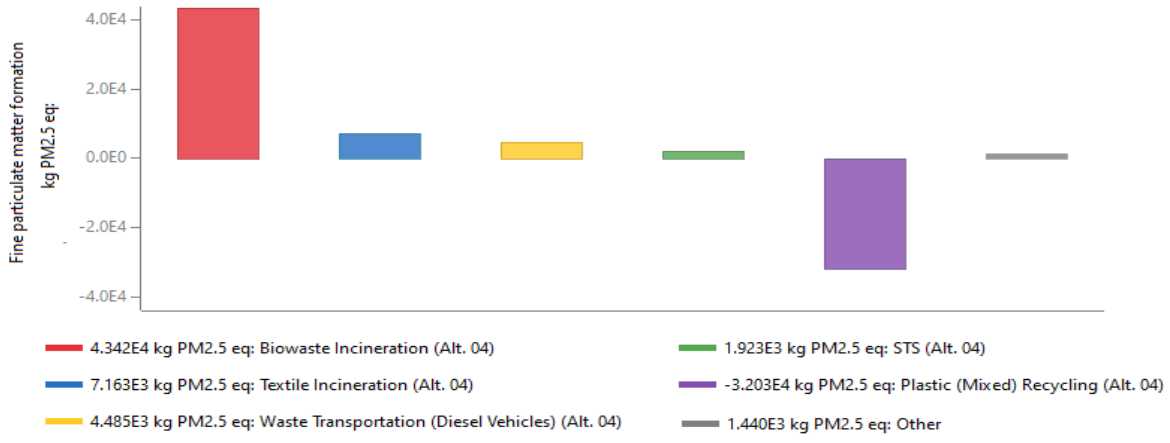

Figure D.5: Major contributors for fine particulate matter formation in alternative A4

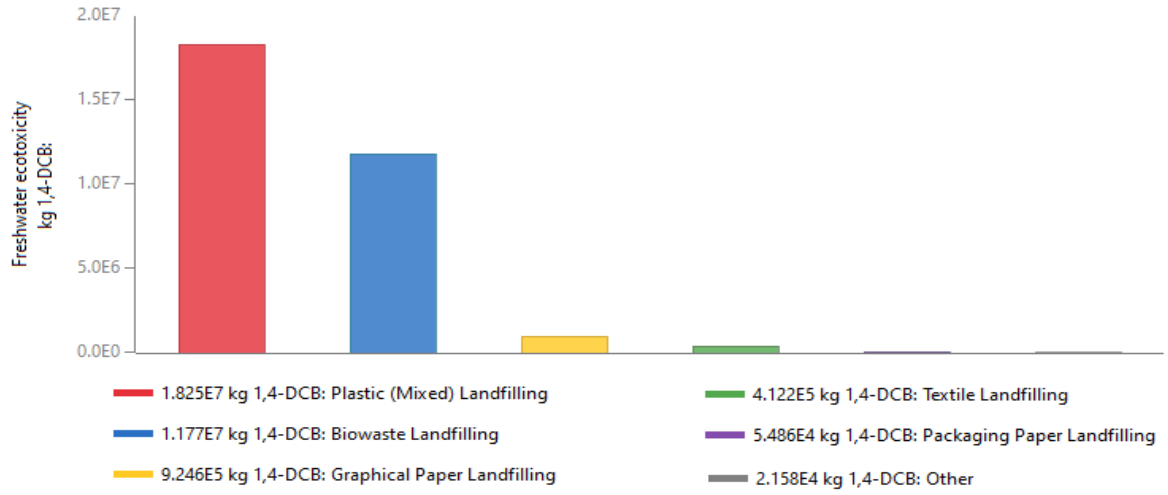

Figure D.6: Major contributors for freshwater ecotoxicity in baseline scenario B0

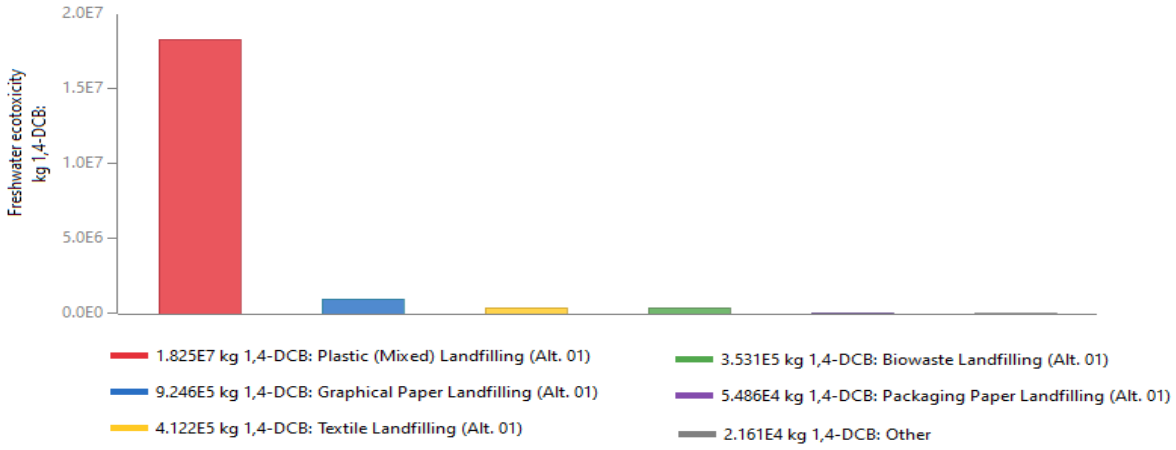

Figure D.7: Major contributors for freshwater ecotoxicity in alternative A1

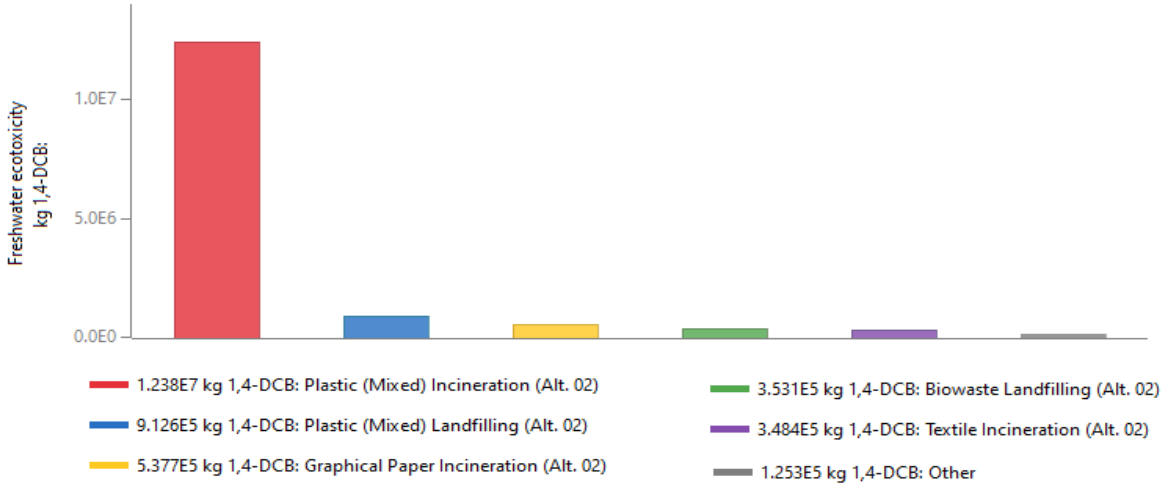

Figure D.8: Major contributors for freshwater ecotoxicity in alternative A2

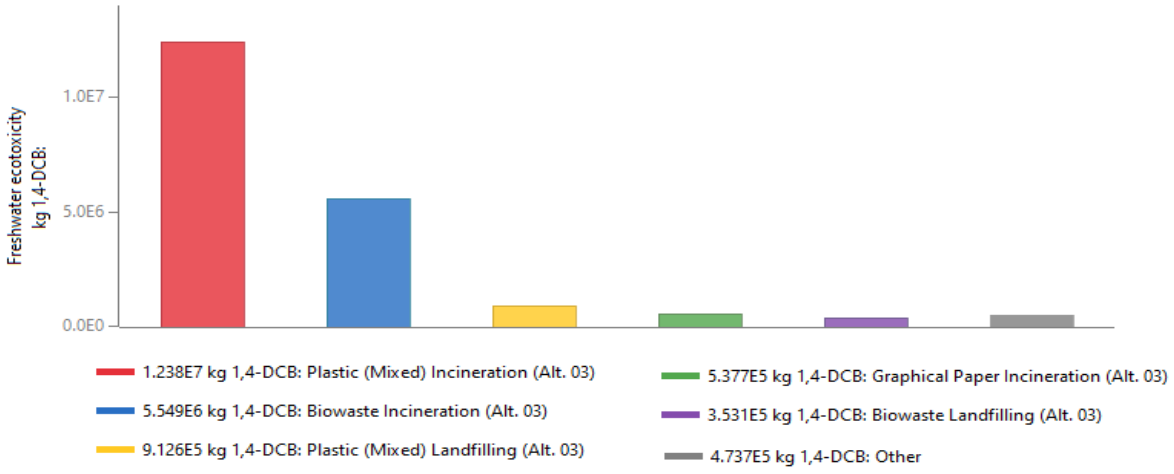

Figure D.9: Major contributors for freshwater ecotoxicity in alternative A3

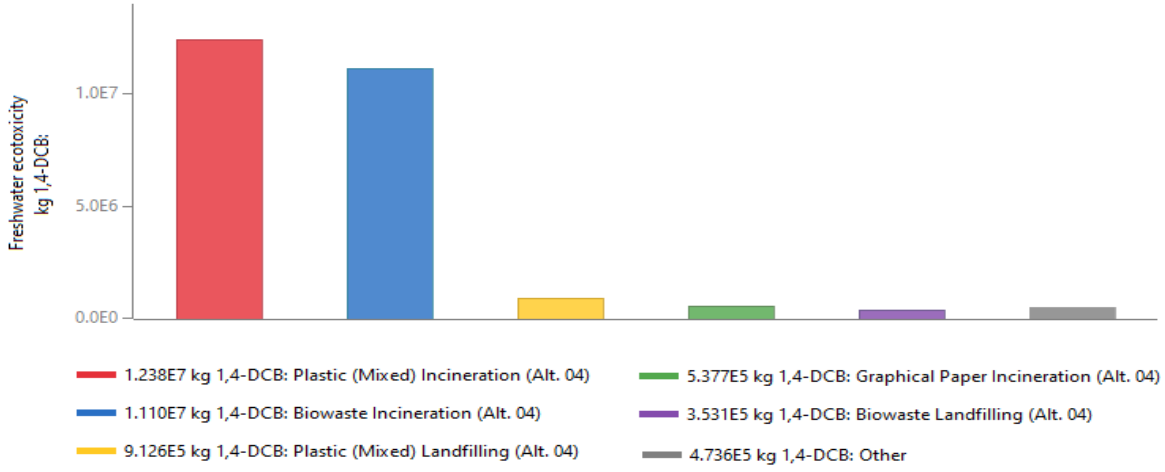

Figure D.10: Major contributors for freshwater ecotoxicity in alternative A4

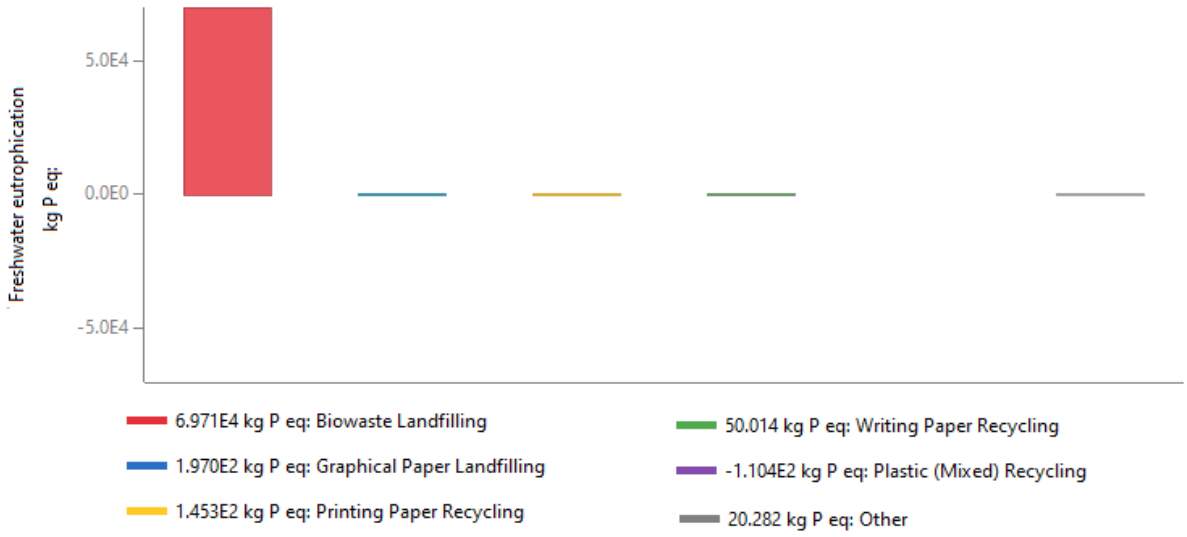

Figure D.11: Major contributors for freshwater eutrophication in baseline scenario B0

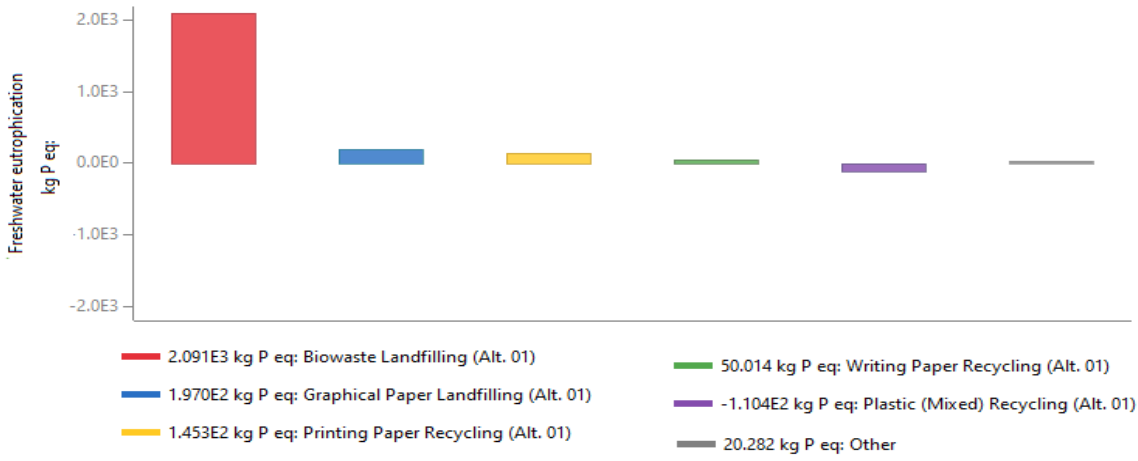

Figure D.12: Major contributors for freshwater eutrophication in alternative A1

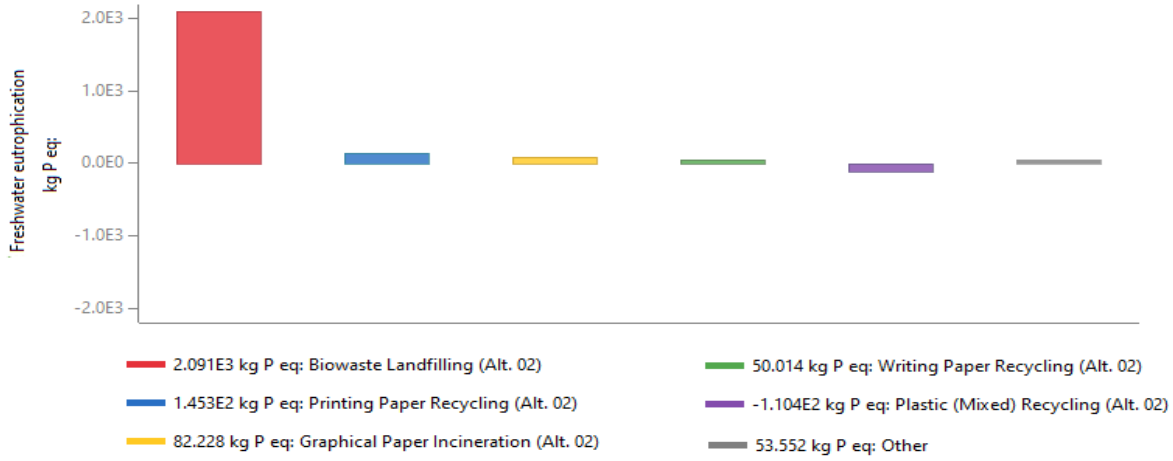

Figure D.13: Major contributors for freshwater eutrophication in alternative A2

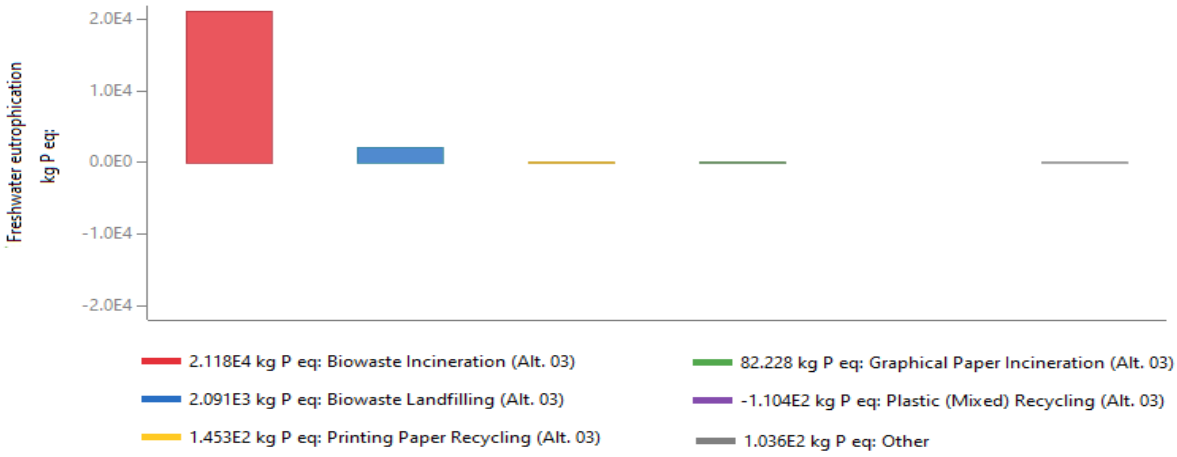

Figure D.14: Major contributors for freshwater eutrophication in alternative A3

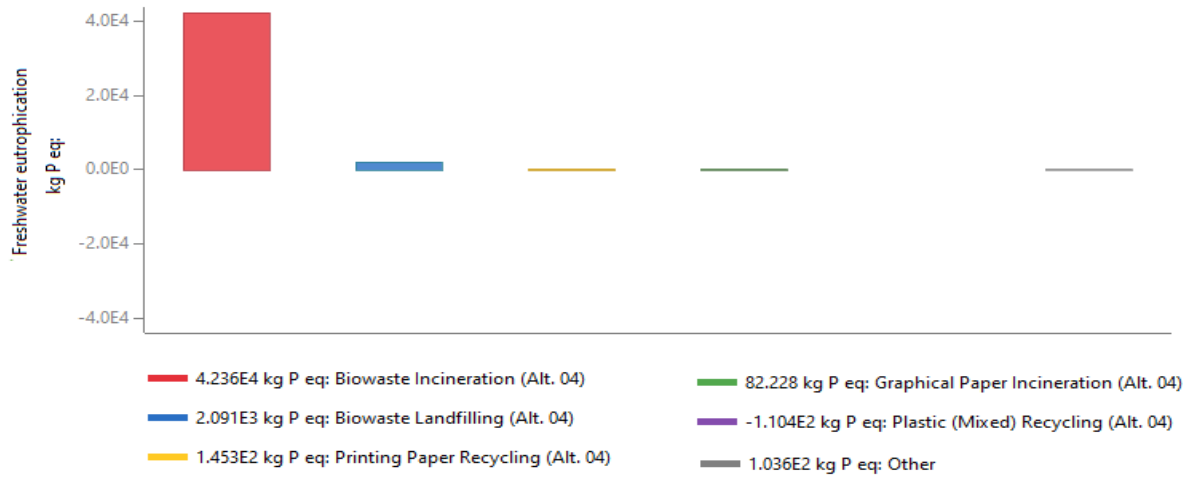

Figure D.15: Major contributors for freshwater eutrophication in alternative A4

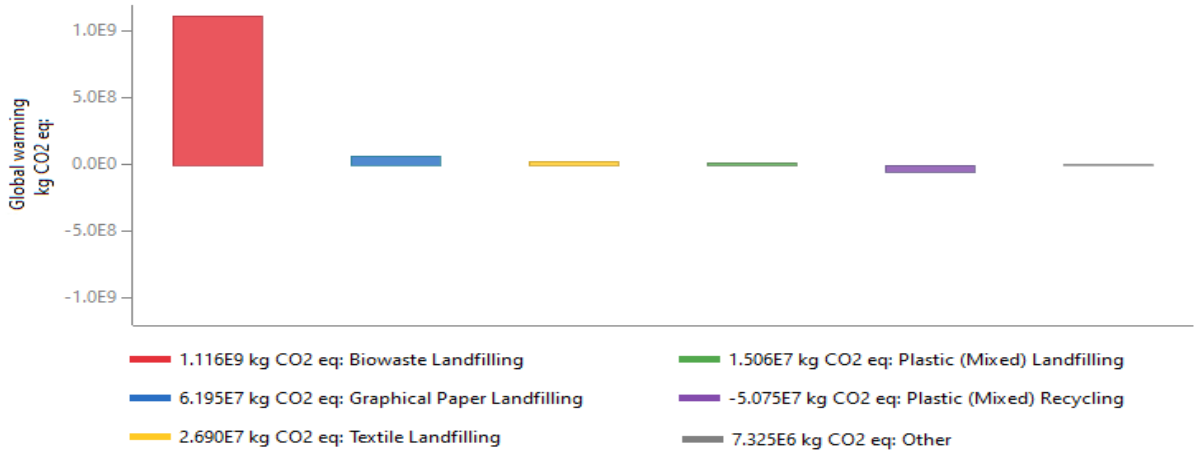

Figure D.16: Major contributors for global warming in baseline scenario B0

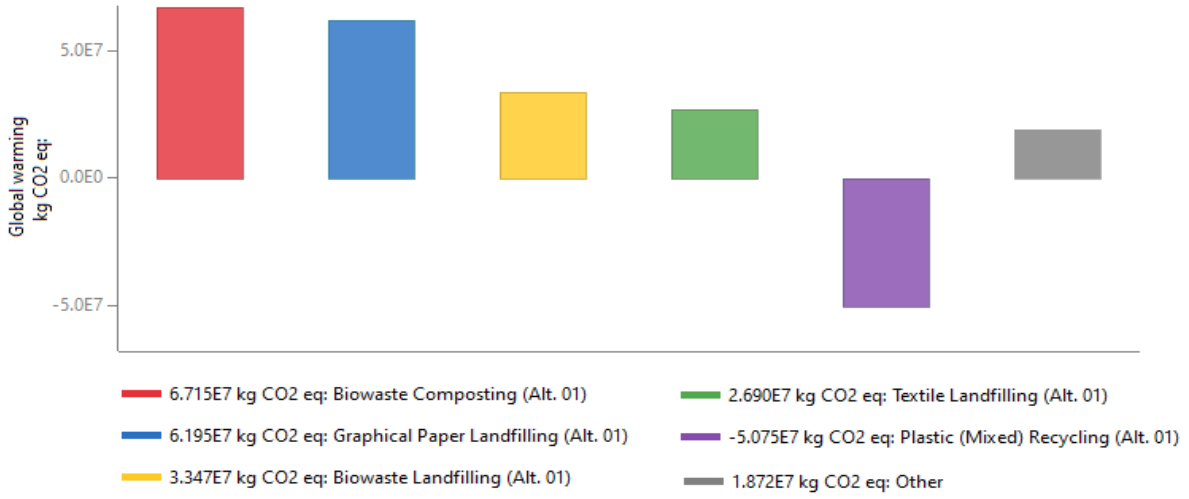

Figure D.17: Major contributors for global warming in alternative A1

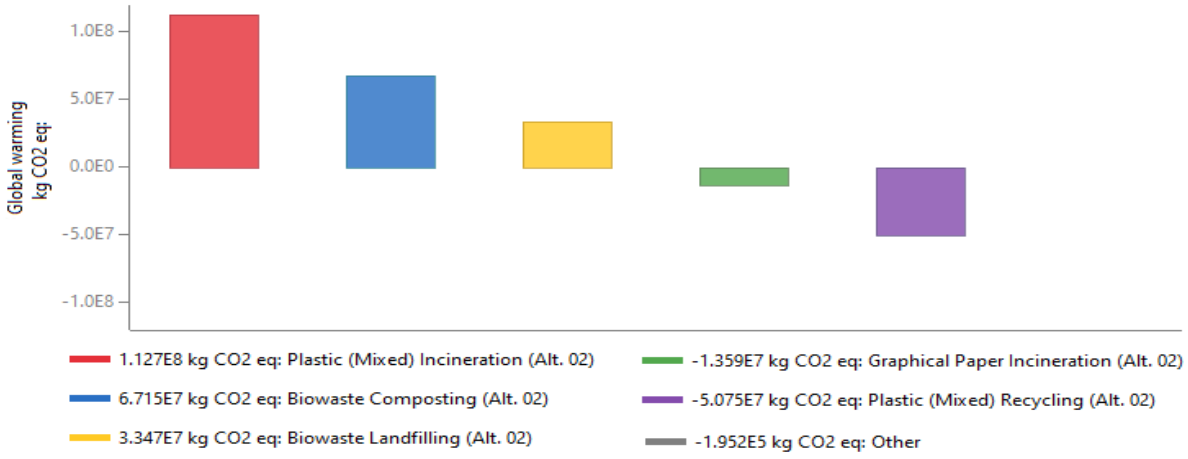

Figure D.18: Major contributors for global warming in alternative A2

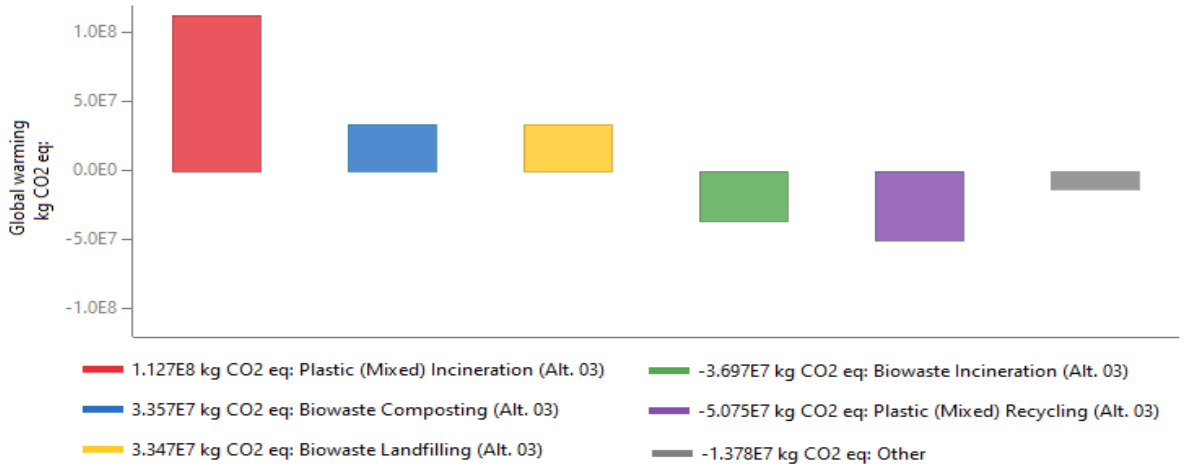

Figure D.19: Major contributors for global warming in alternative A3

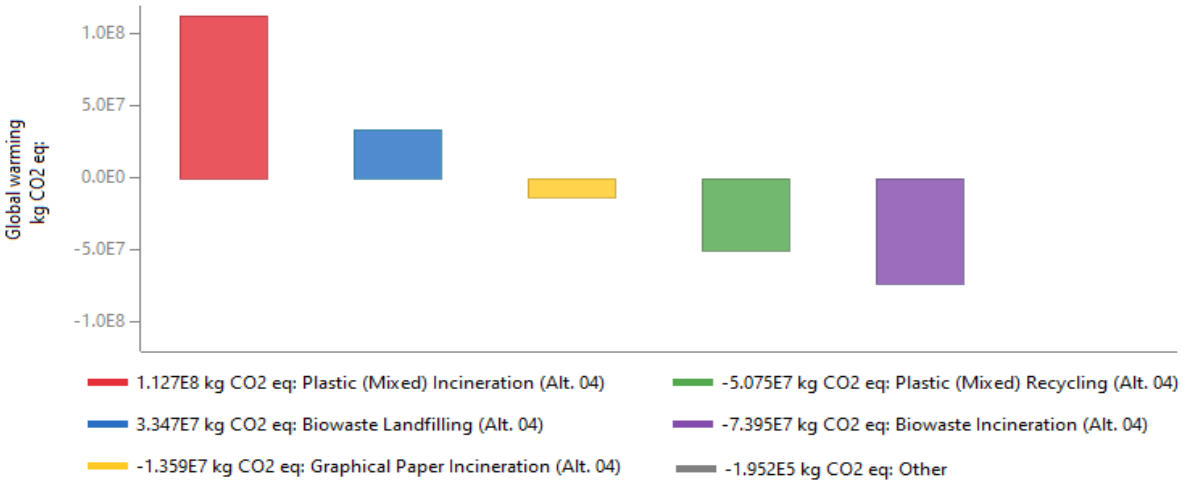

Figure D.20: Major contributors for global warming in alternative A4

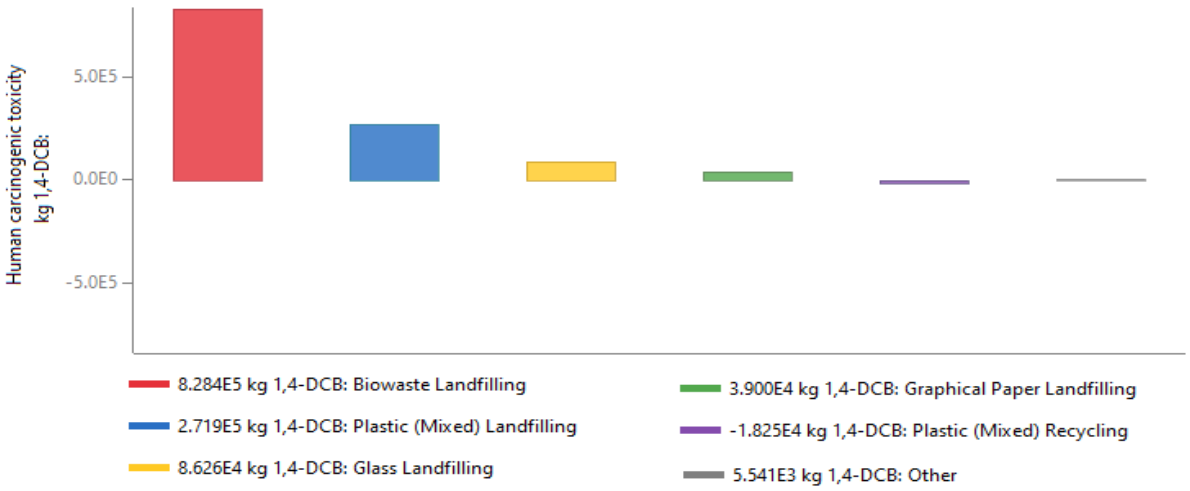

Figure D.21: Major contributors for human carcinogenic toxicity in baseline B0

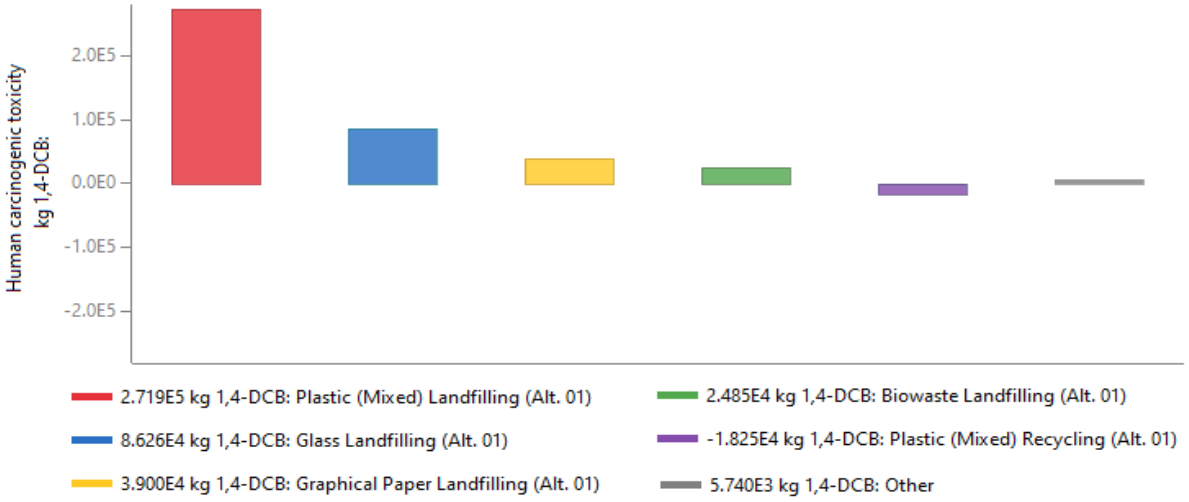

Figure D.22: Major contributors for human carcinogenic toxicity in alternative A1

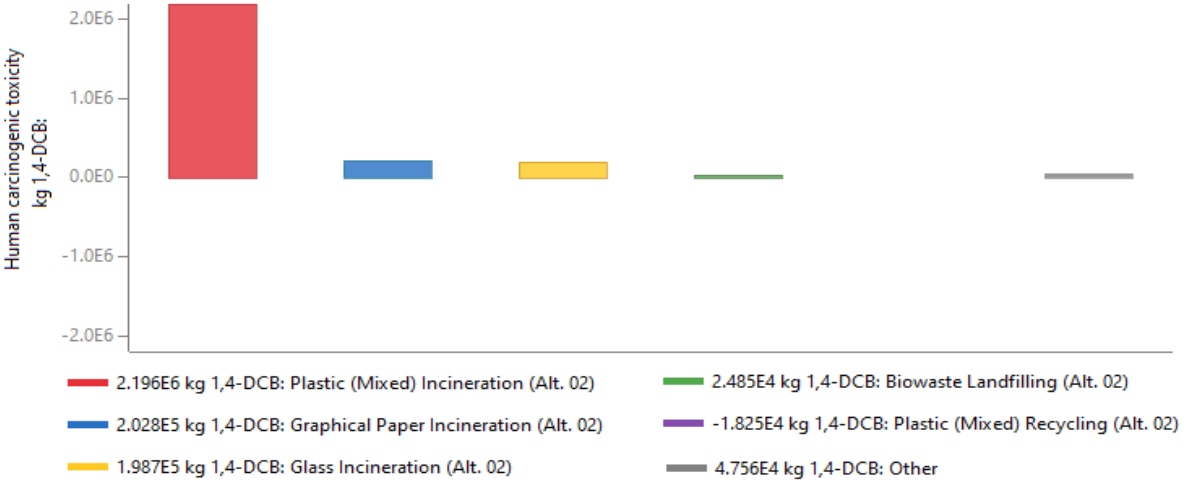

Figure D.23: Major contributors for human carcinogenic toxicity in alternative A2

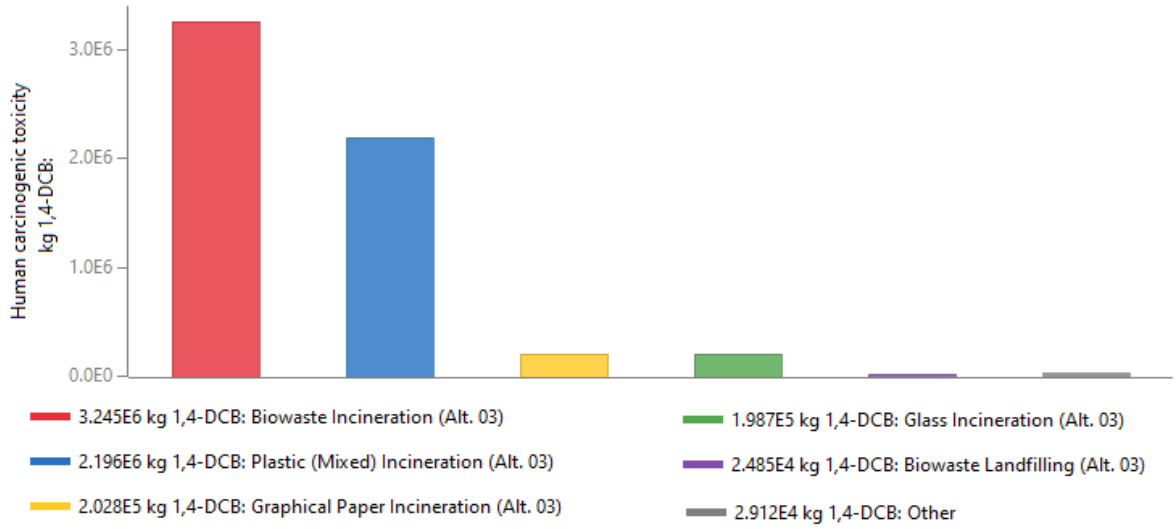

Figure D.24: Major contributors for human carcinogenic toxicity in alternative A3

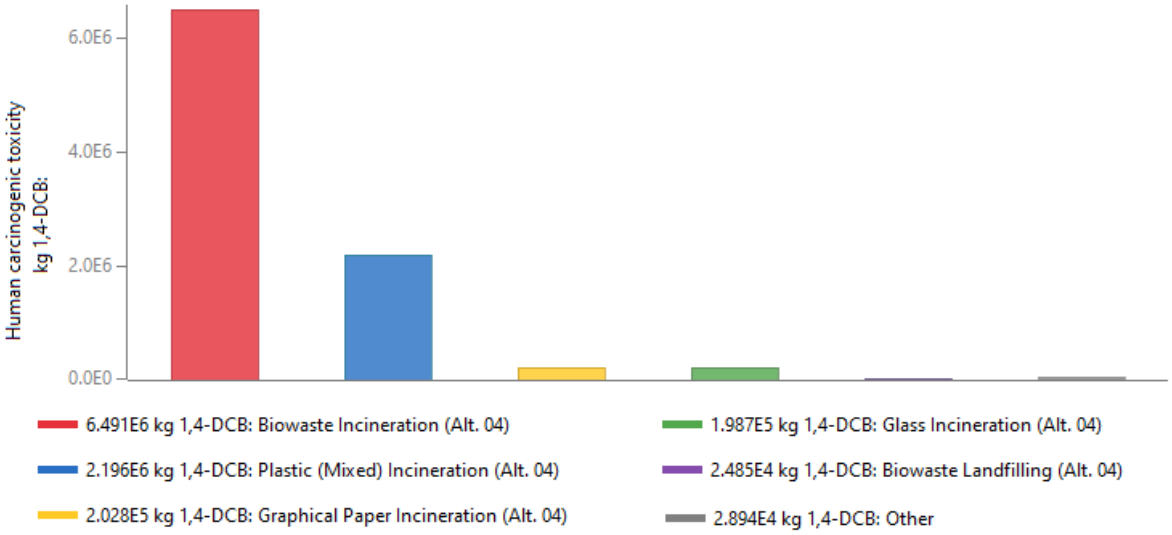

Figure D.25: Major contributors for human carcinogenic toxicity in alternative A4

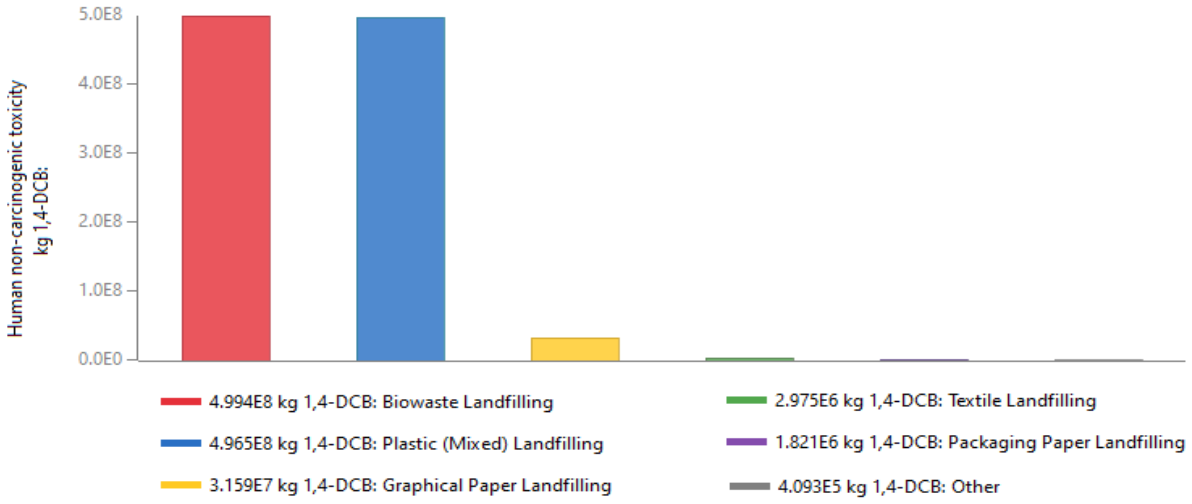

Figure D.26: Major contributors for human non-carcinogenic toxicity in baseline B0

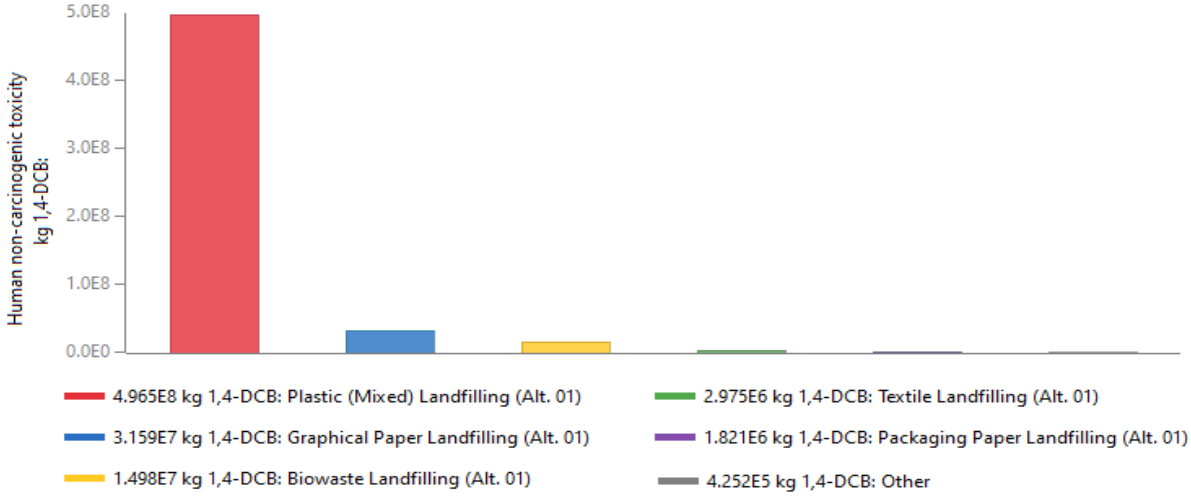

Figure D.27: Major contributors for human non-carcinogenic toxicity in alternative A1

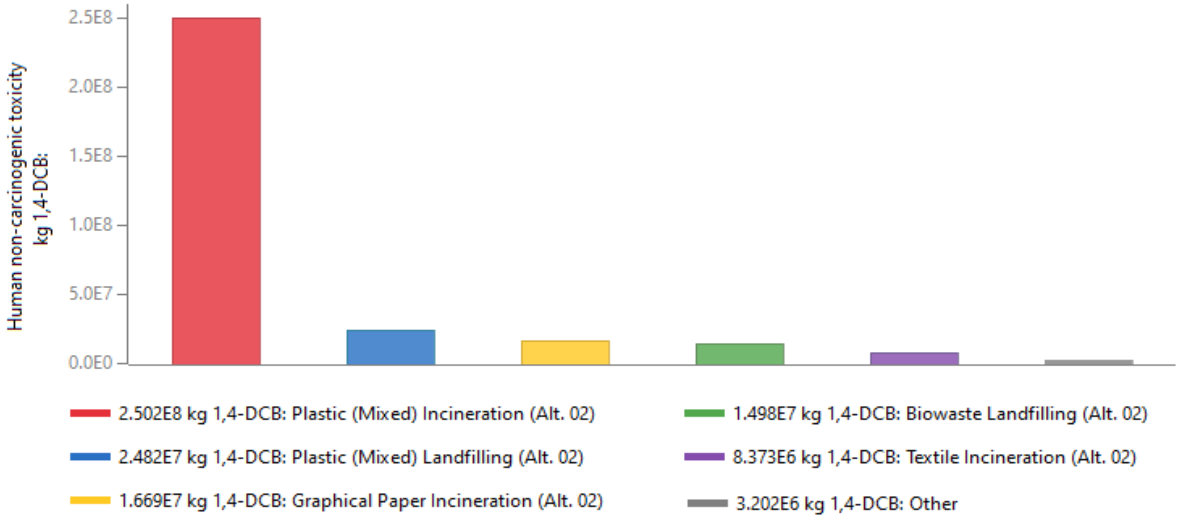

Figure D.28: Major contributors for human non-carcinogenic toxicity in alternative A2

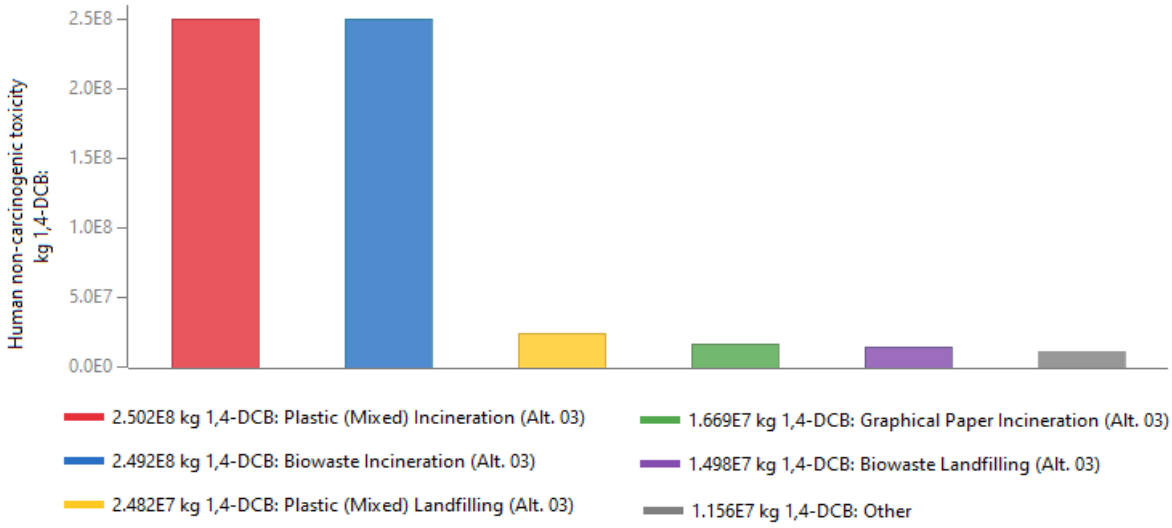

Figure D.29: Major contributors for human non-carcinogenic toxicity in alternative A3

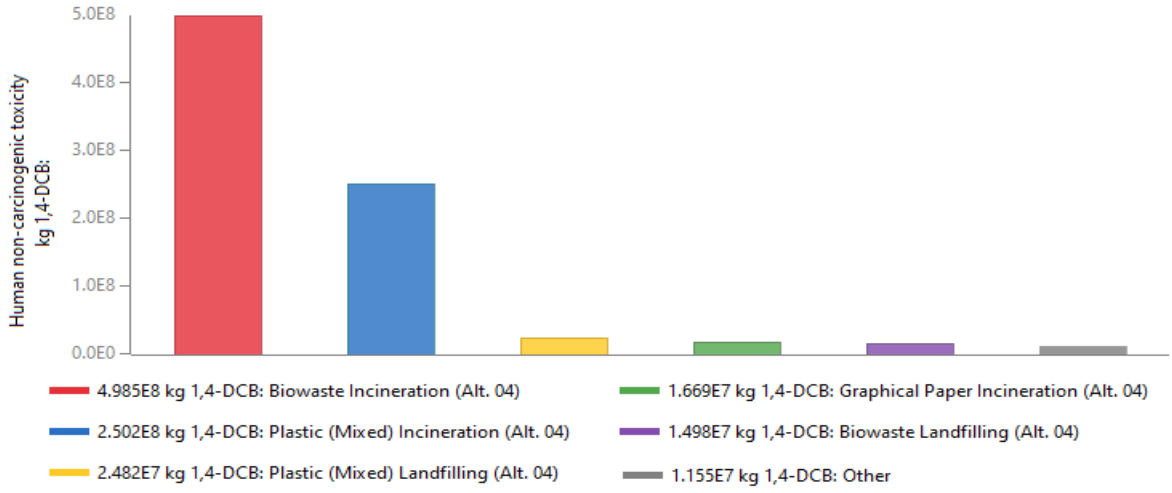

Figure D.30: Major contributors for human non-carcinogenic toxicity in alternative A4

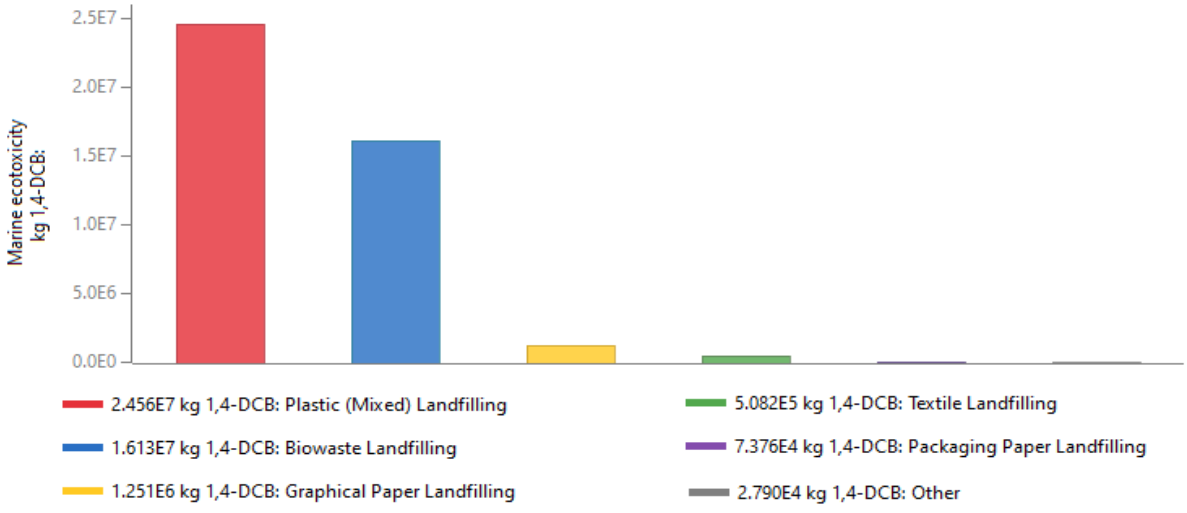

Figure D.31: Major contributors for marine ecotoxicity in baseline B0

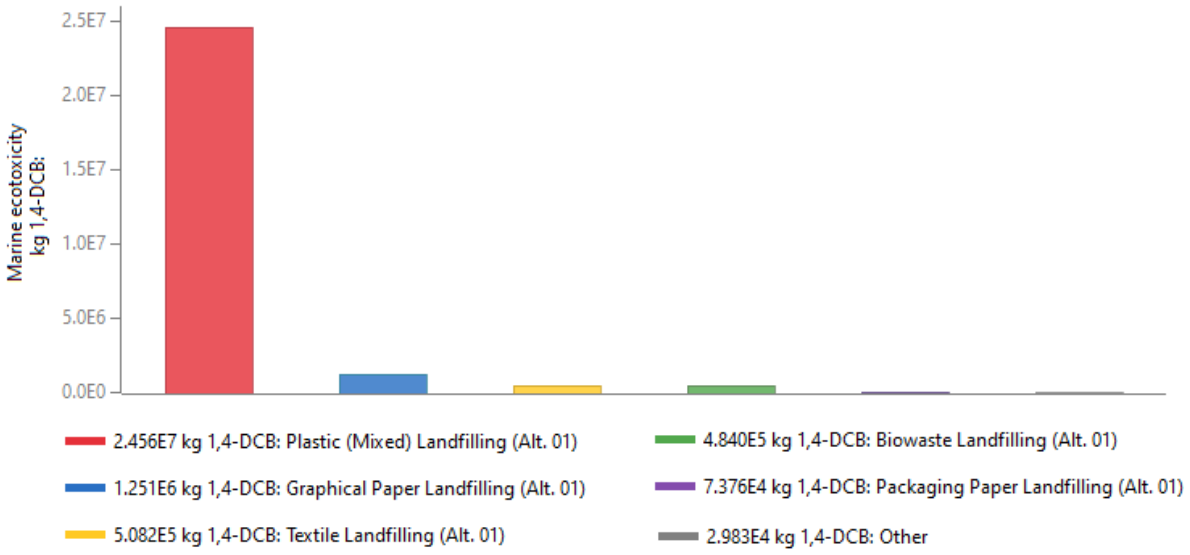

Figure D.32: Major contributors for marine ecotoxicity in alternative A1

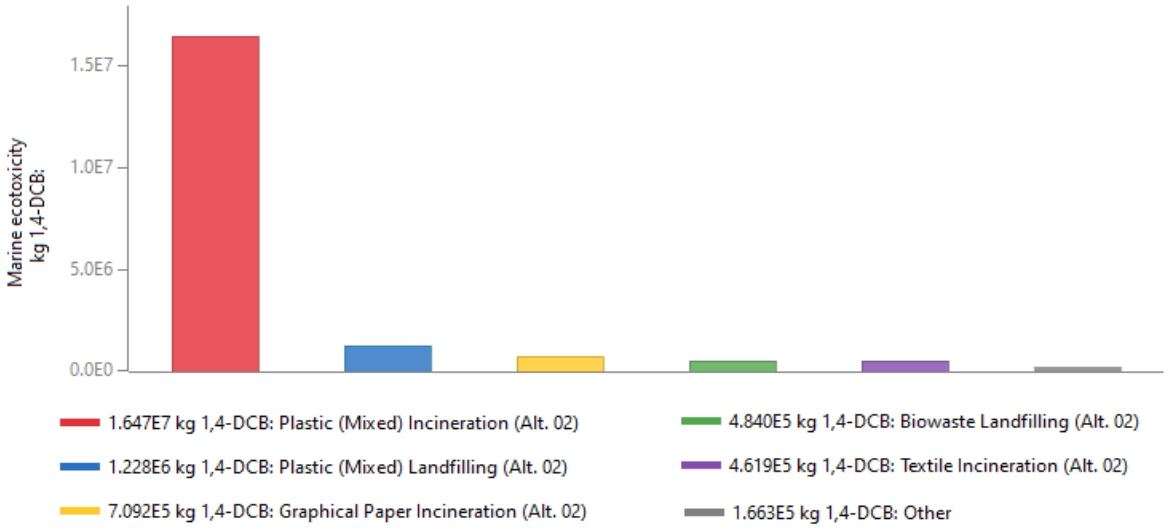

Figure D.33: Major contributors for marine ecotoxicity in alternative A2

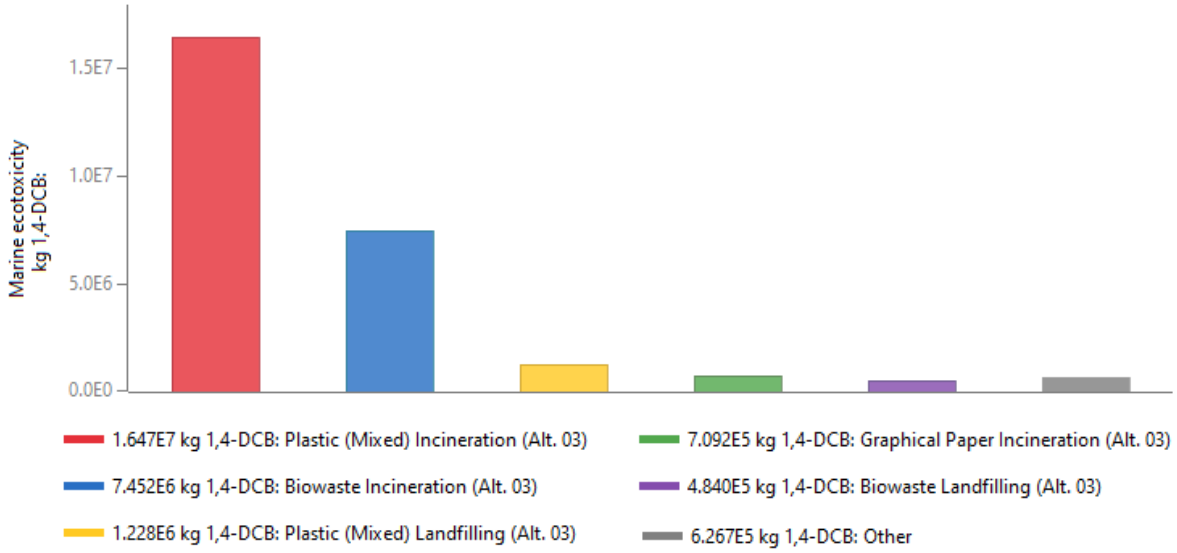

Figure D.34: Major contributors for marine ecotoxicity in alternative A3

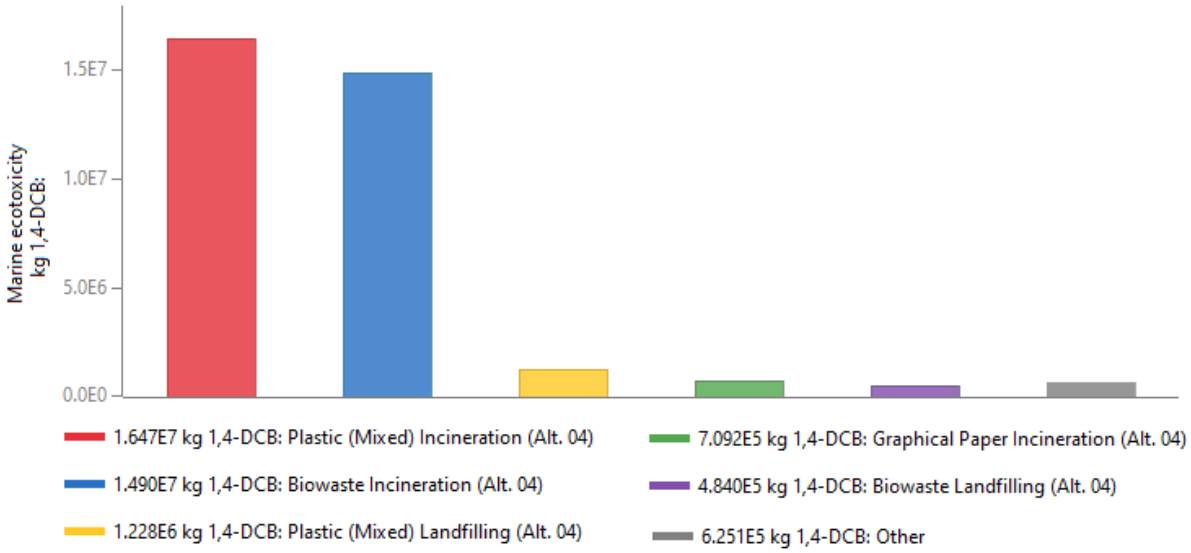

Figure D.35: Major contributors for marine ecotoxicity in alternative A4

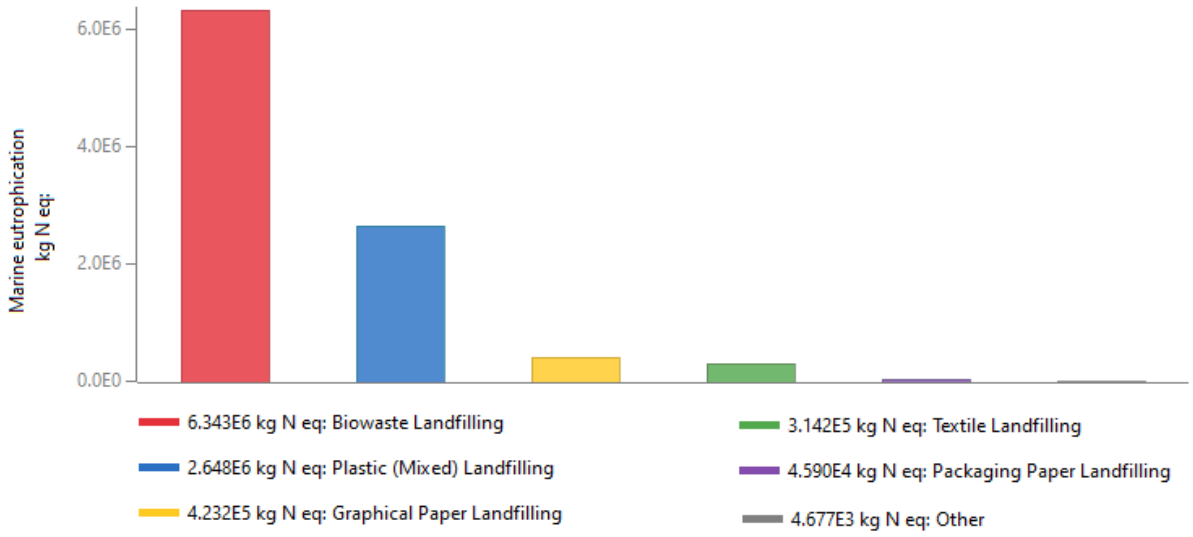

Figure D.36: Major contributors for marine eutrophication in baseline B0

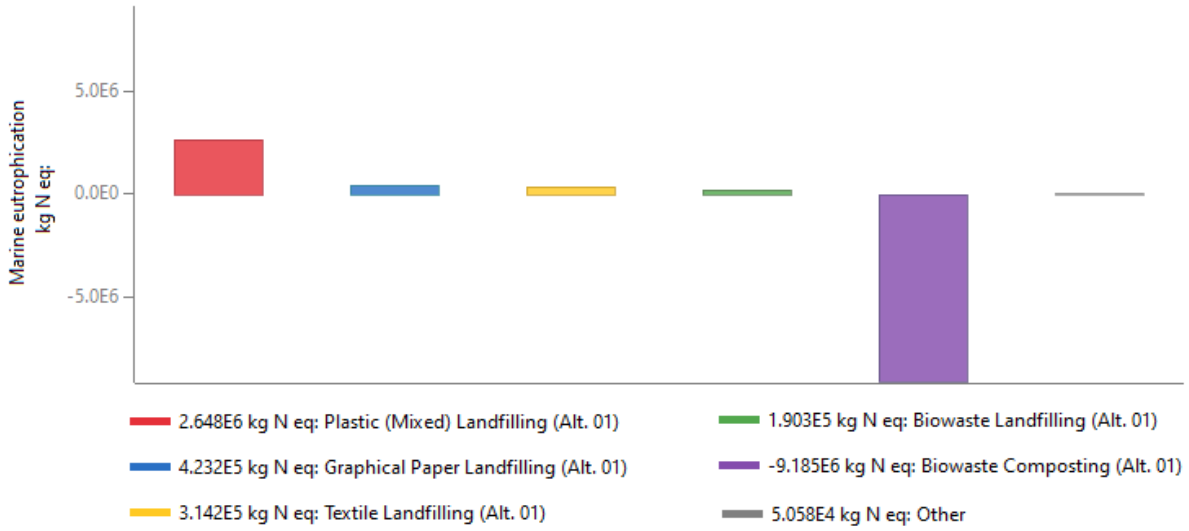

Figure D.37: Major contributors for marine eutrophication in alternative A1

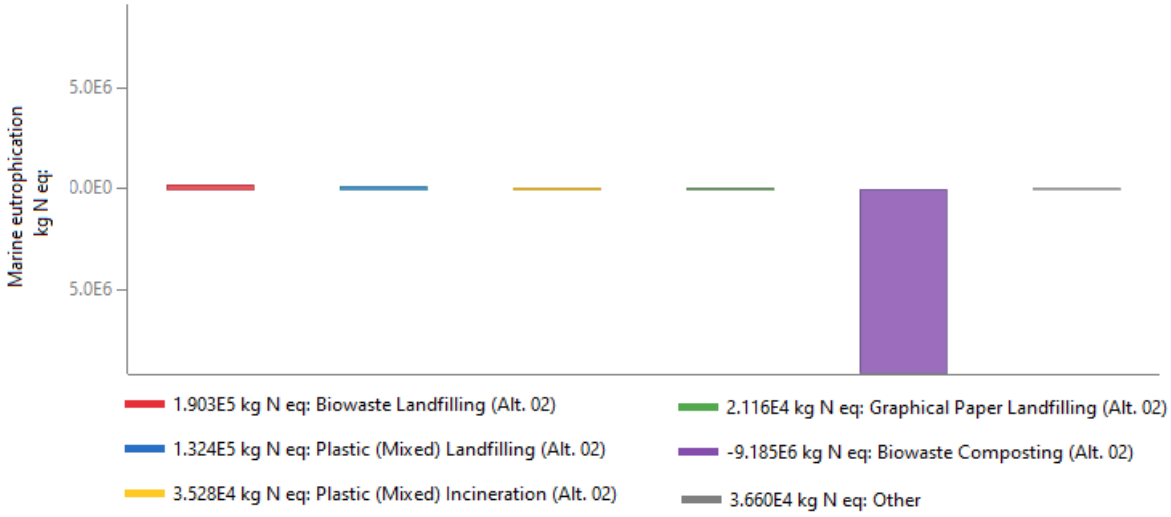

Figure D.38: Major contributors for marine eutrophication in alternative A2

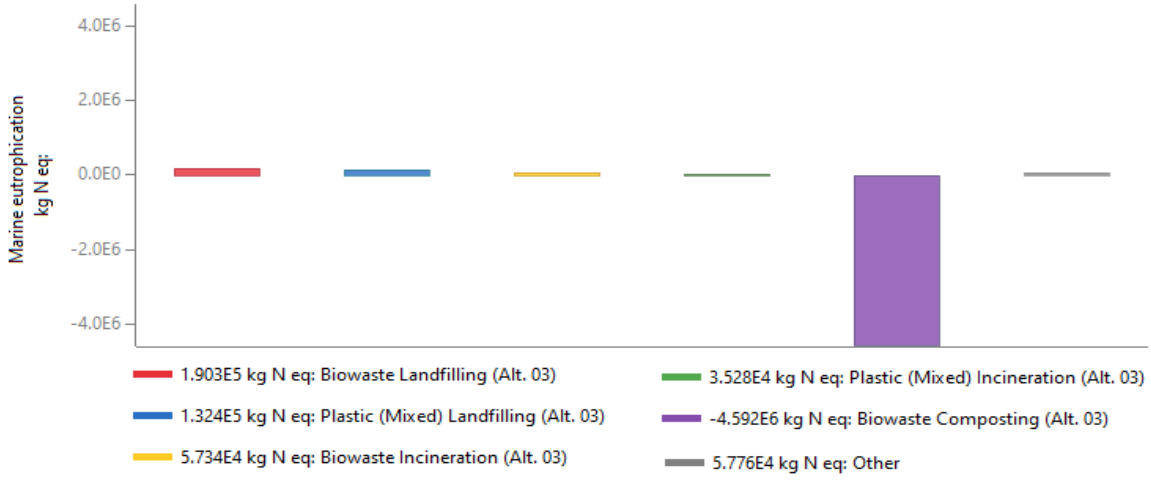

Figure D.39: Major contributors for marine eutrophication in alternative A3

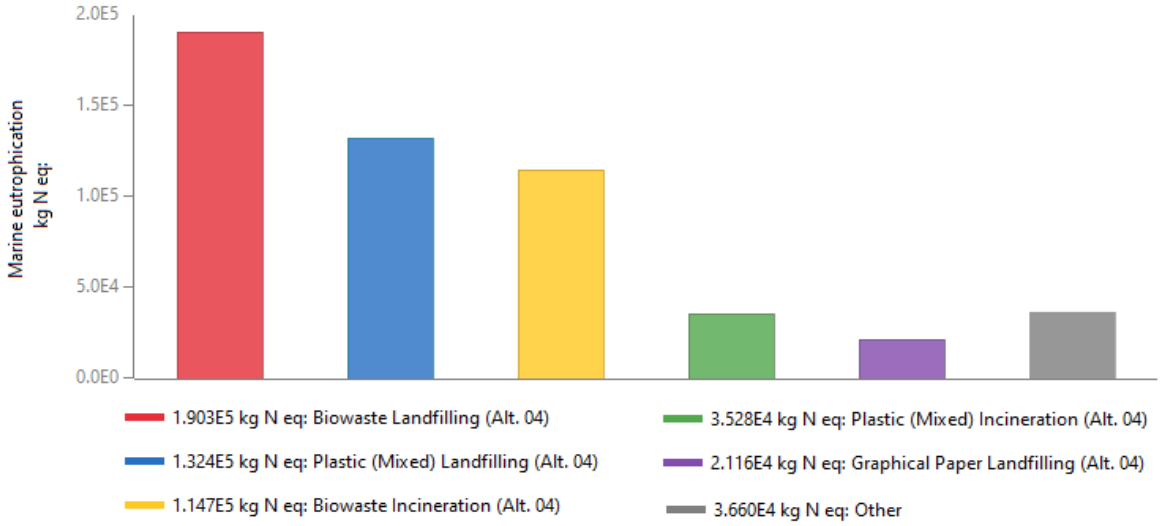

Figure D.40: Major contributors for marine eutrophication in alternative A4

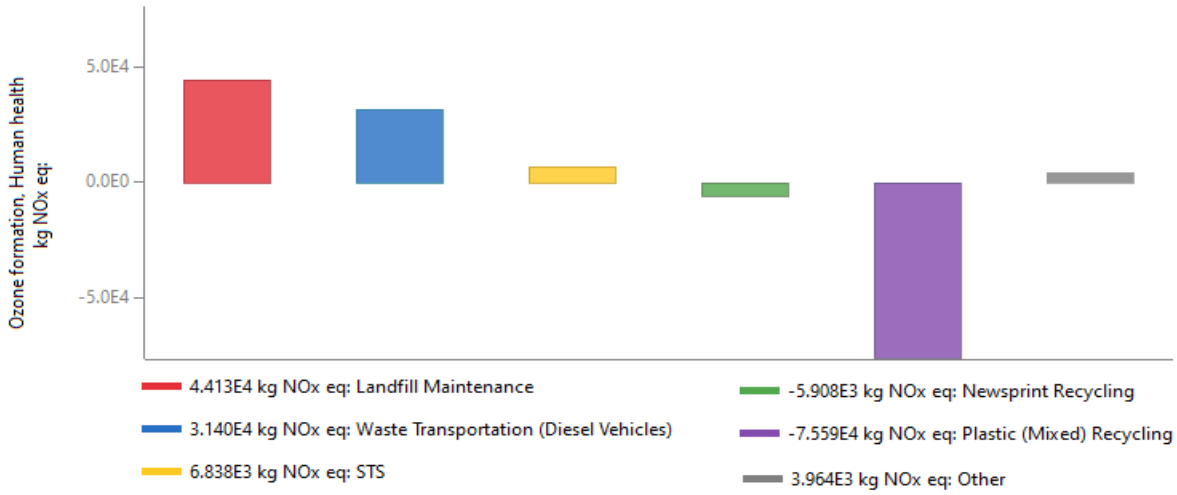

Figure D.41: Major contributors for ozone formation, human health in baseline B0

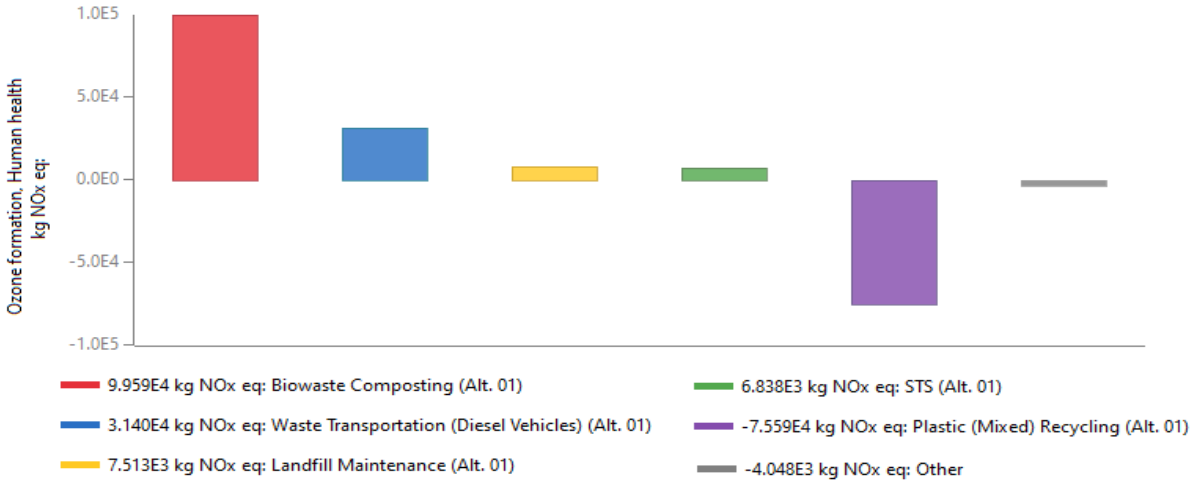

Figure D.42: Major contributors for ozone formation, human health in alternative A1

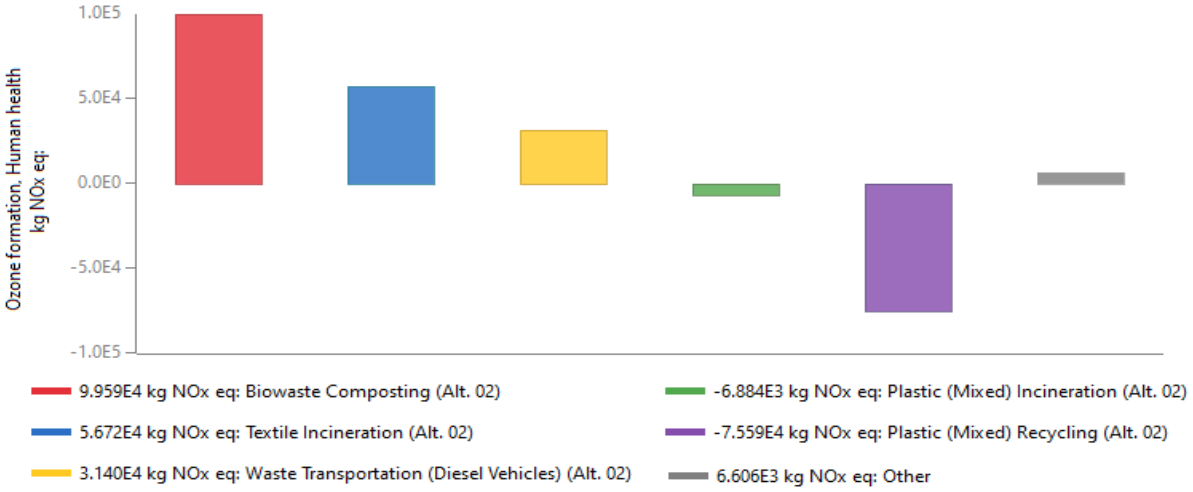

Figure D.43: Major contributors for ozone formation, human health in alternative A2

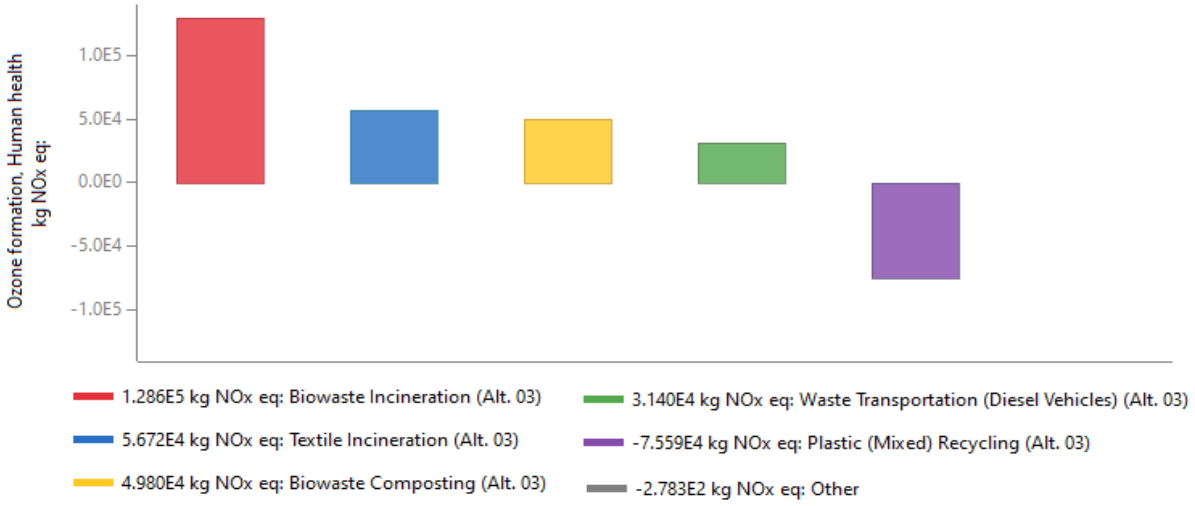

Figure D.44: Major contributors for ozone formation, human health in alternative A3

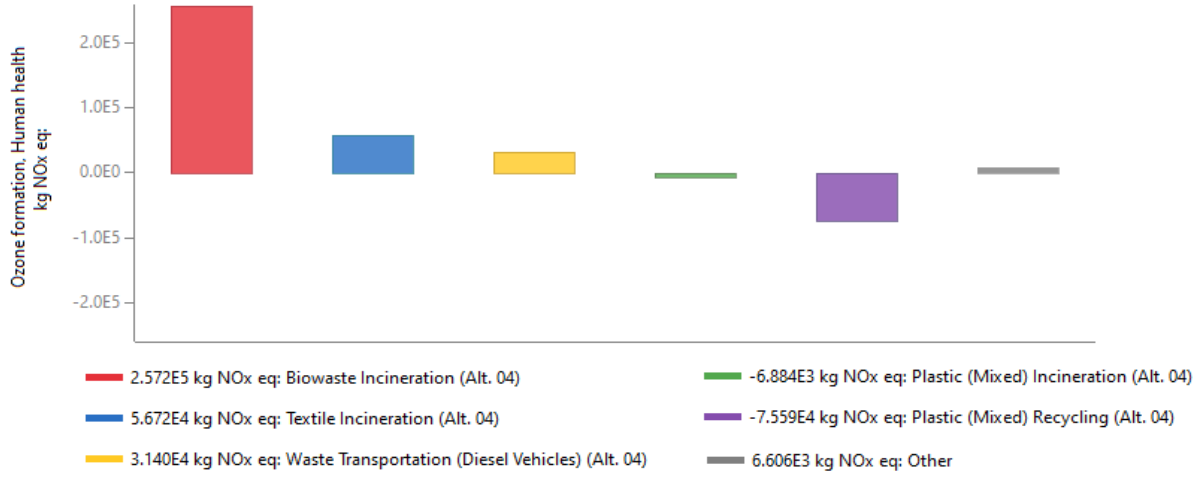

Figure D.45: Major contributors for ozone formation, human health in alternative A4

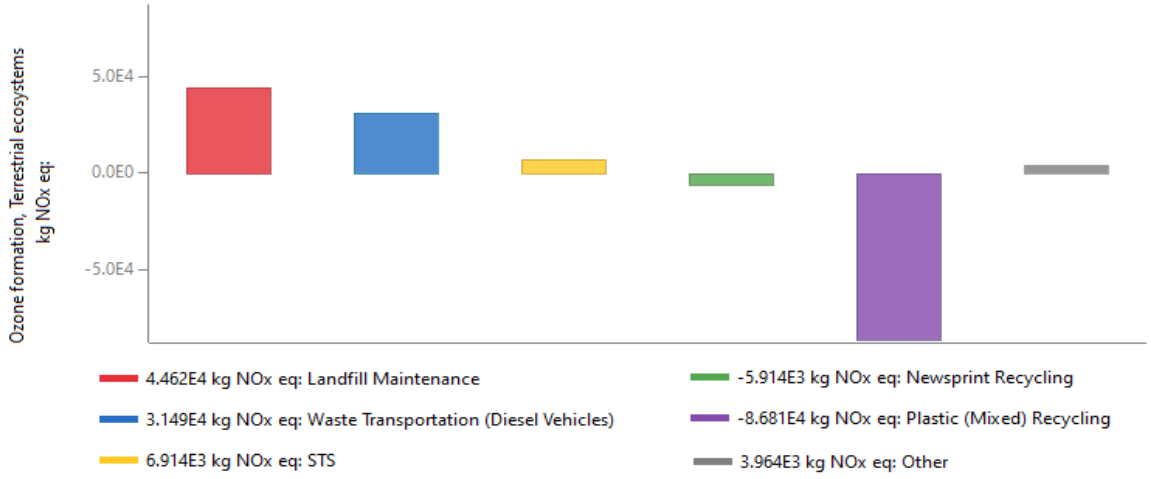

Figure D.46: Major contributors for ozone formation, terrestrial ecosystems in baseline B0

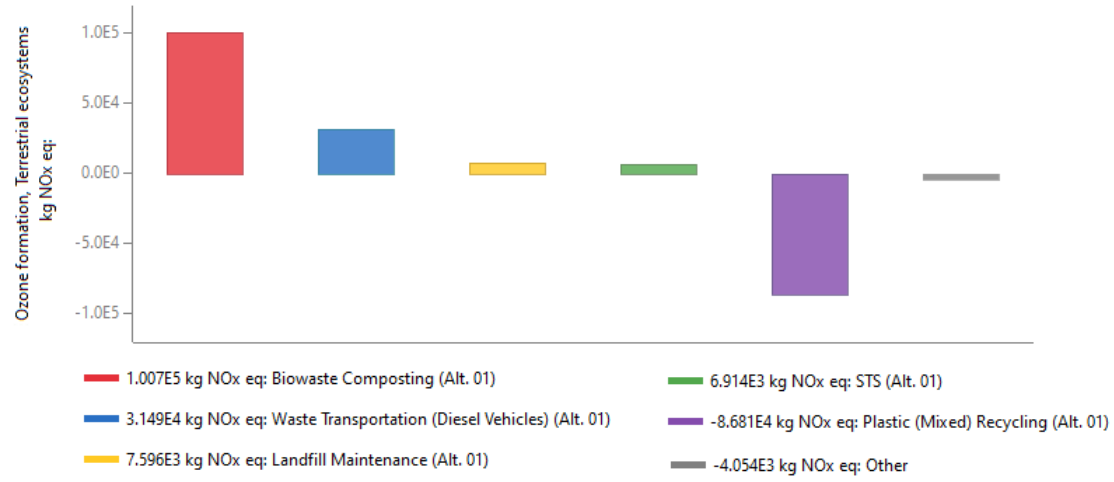

Figure D.47: Major contributors for ozone formation, terrestrial ecosystems in alt. A1

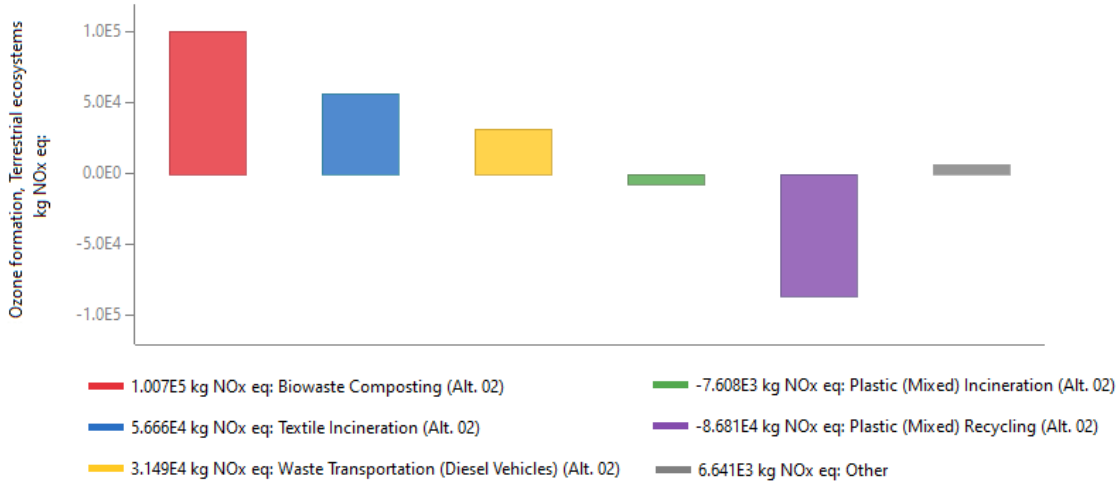

Figure D.48: Major contributors for ozone formation, terrestrial ecosystems in alt. A2

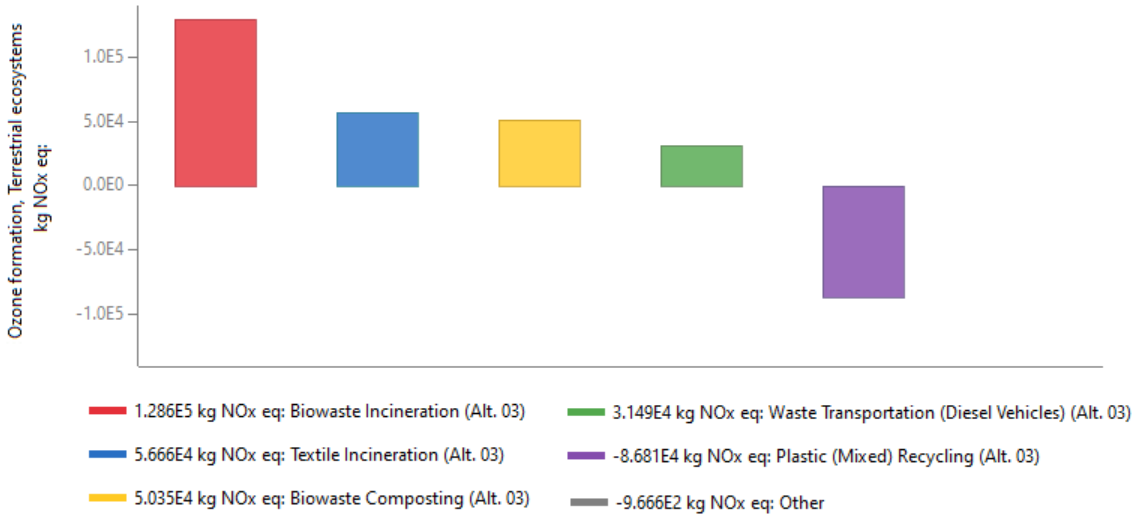

Figure D.49: Major contributors for ozone formation, terrestrial ecosystems in alt. A3

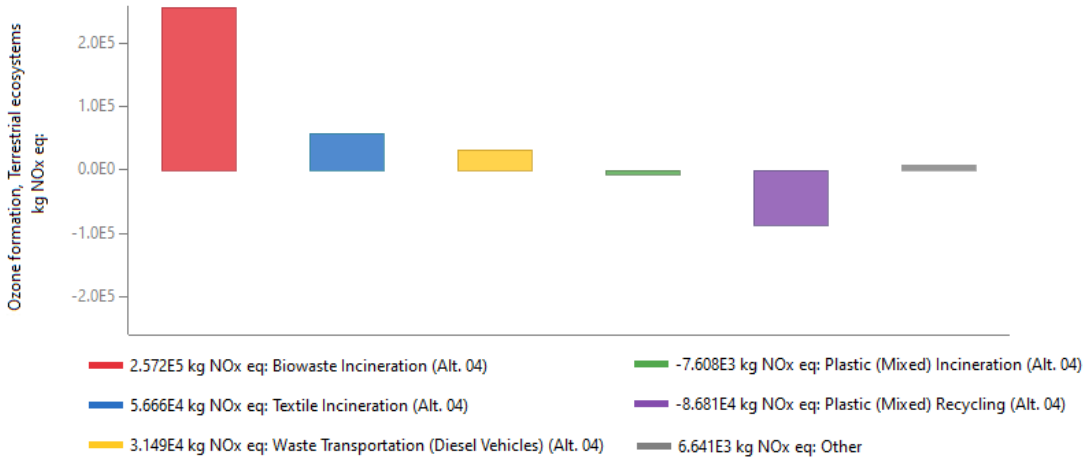

Figure D.50: Major contributors for ozone formation, terrestrial ecosystems in alt. A4

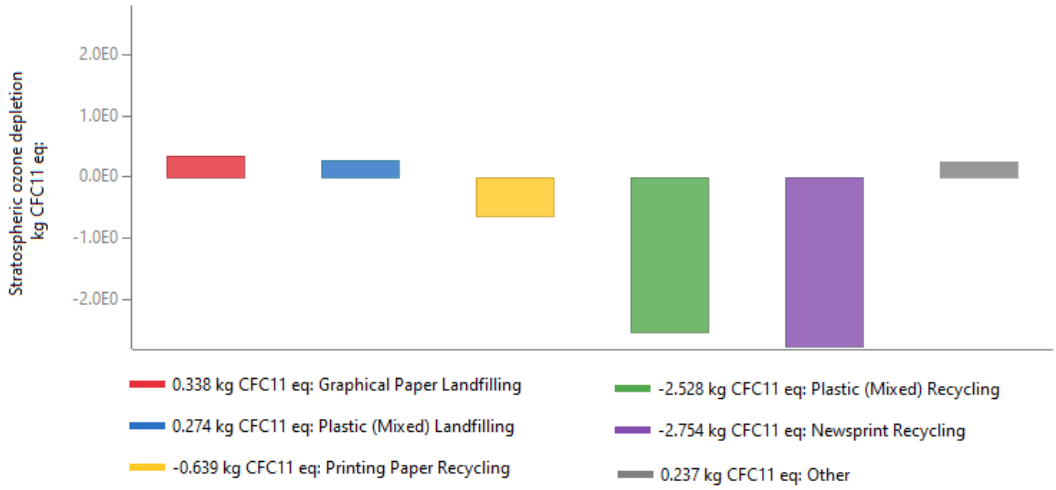

Figure D.51: Major contributors for stratospheric ozone depletion in baseline B0

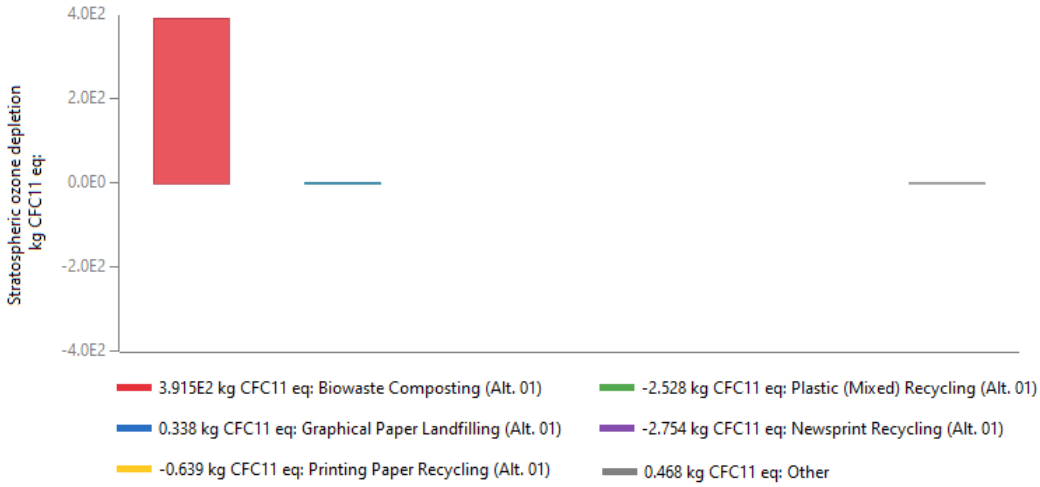

Figure D.52: Major contributors for stratospheric ozone depletion in alternative 01

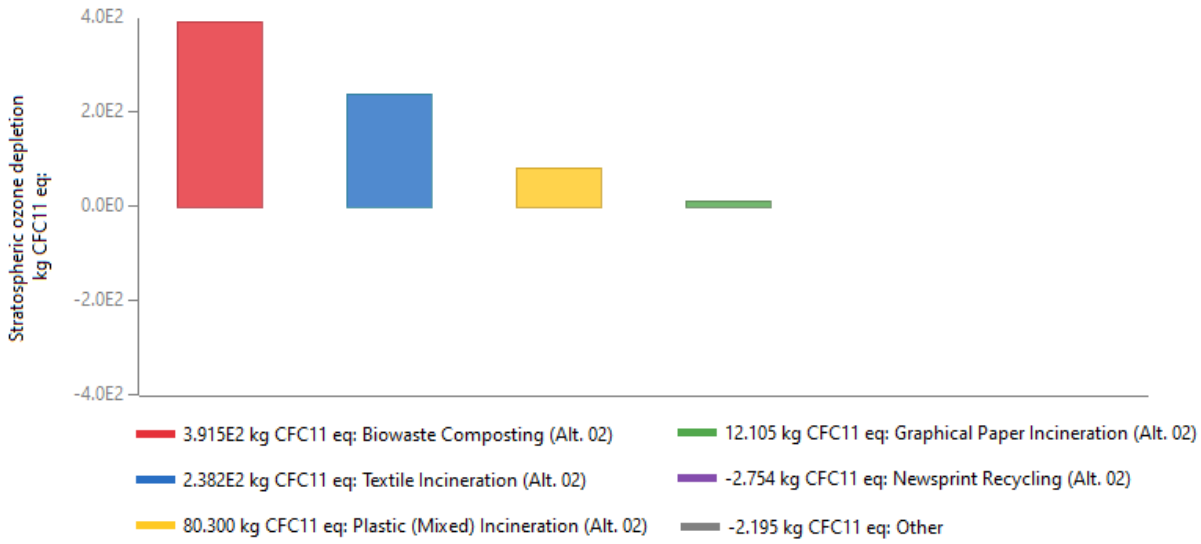

Figure D.53: Major contributors for stratospheric ozone depletion in alternative 02

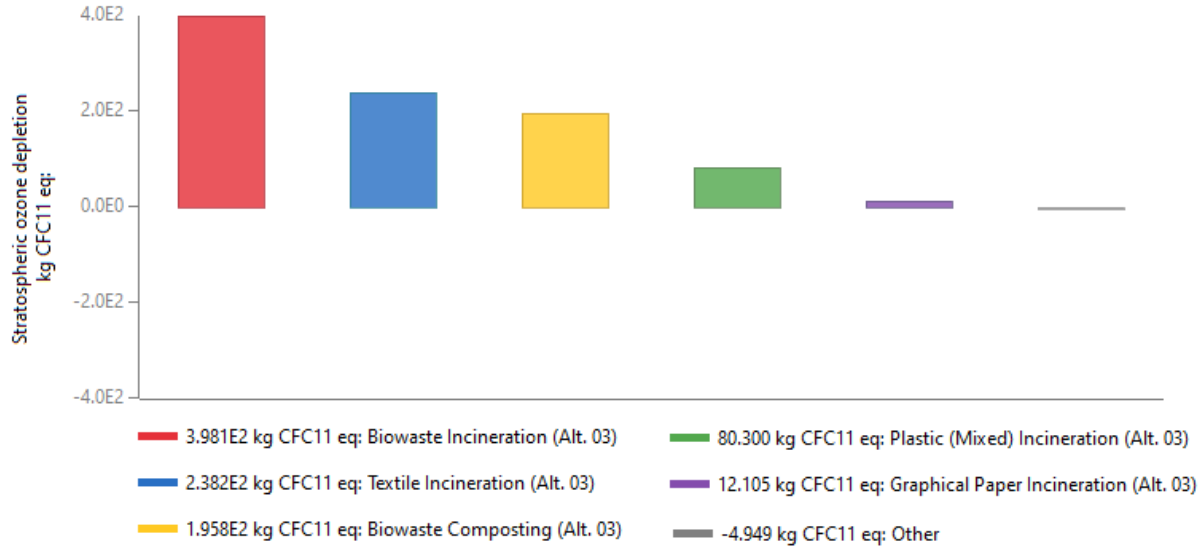

Figure D.54: Major contributors for stratospheric ozone depletion in alternative 03

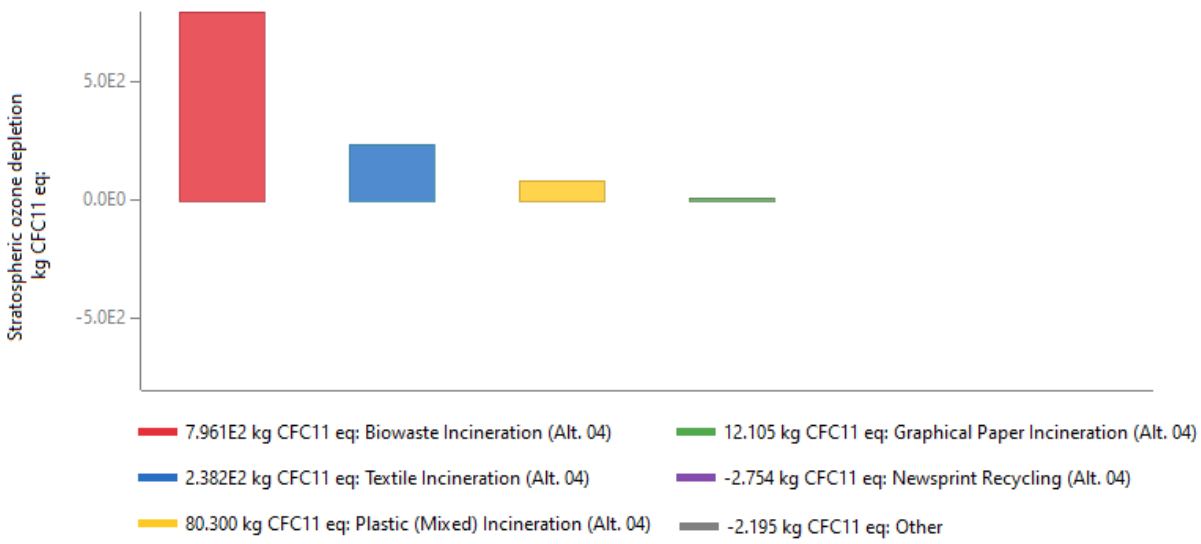

Figure D.55: Major contributors for stratospheric ozone depletion in alternative 04

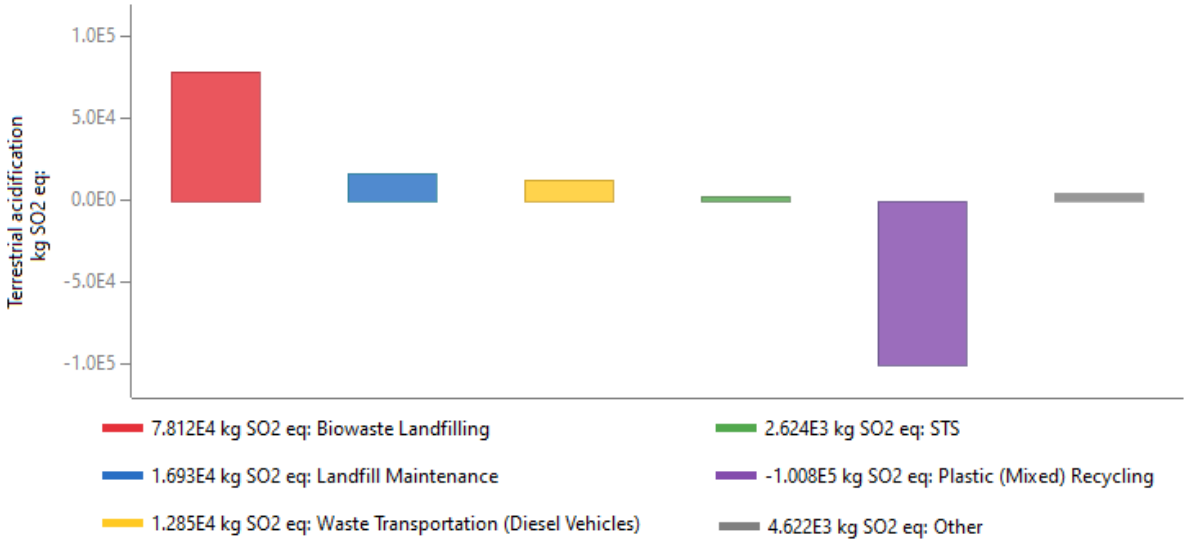

Figure D.56: Major contributors for terrestrial acidification in baseline B0

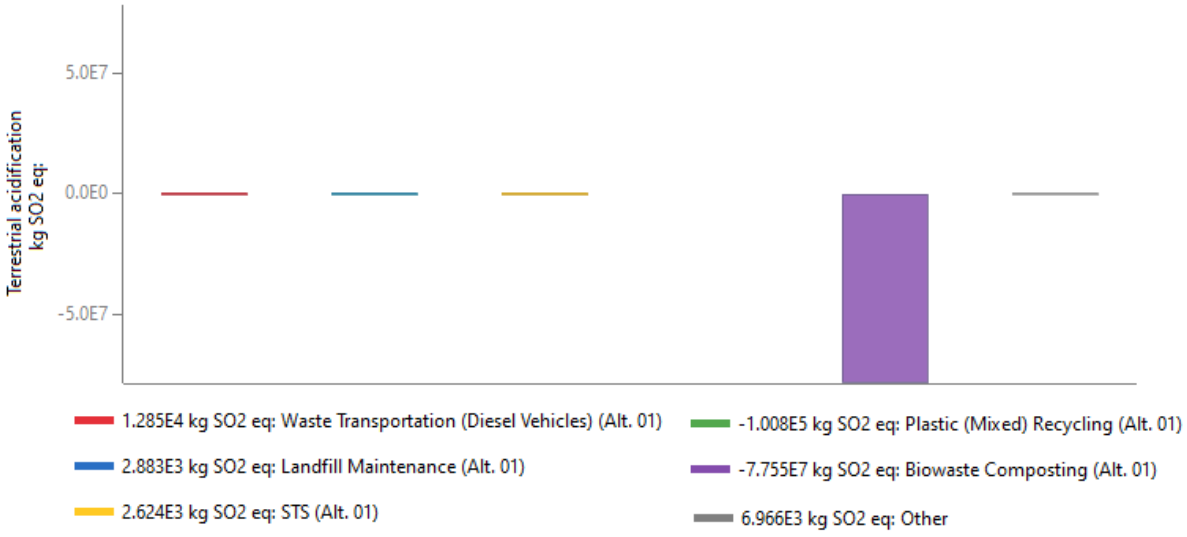

Figure D.57: Major contributors for terrestrial acidification in alternative A1

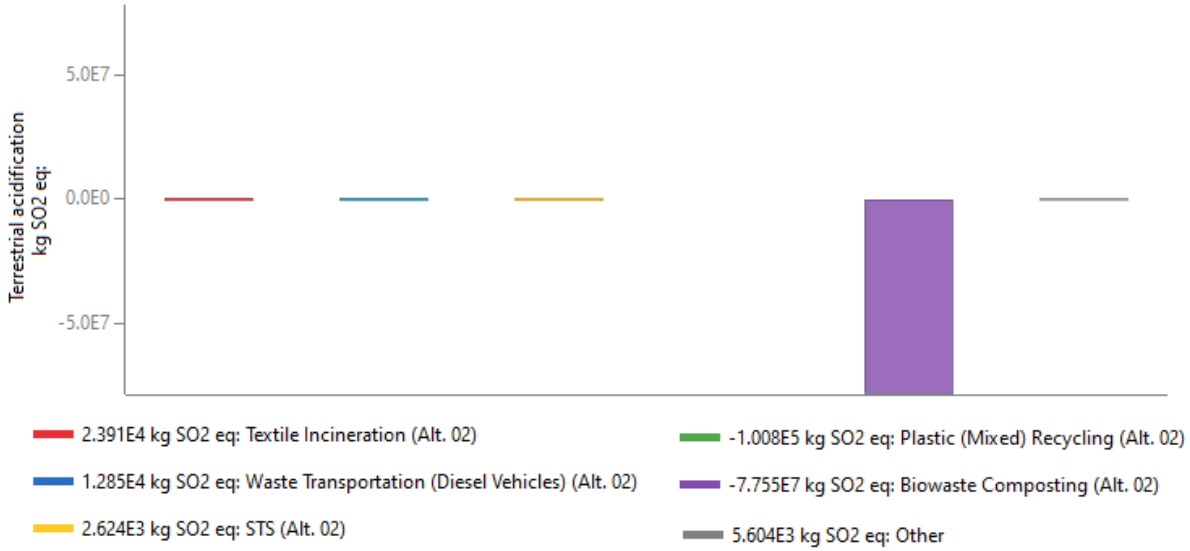

Figure D.58: Major contributors for terrestrial acidification in alternative A2

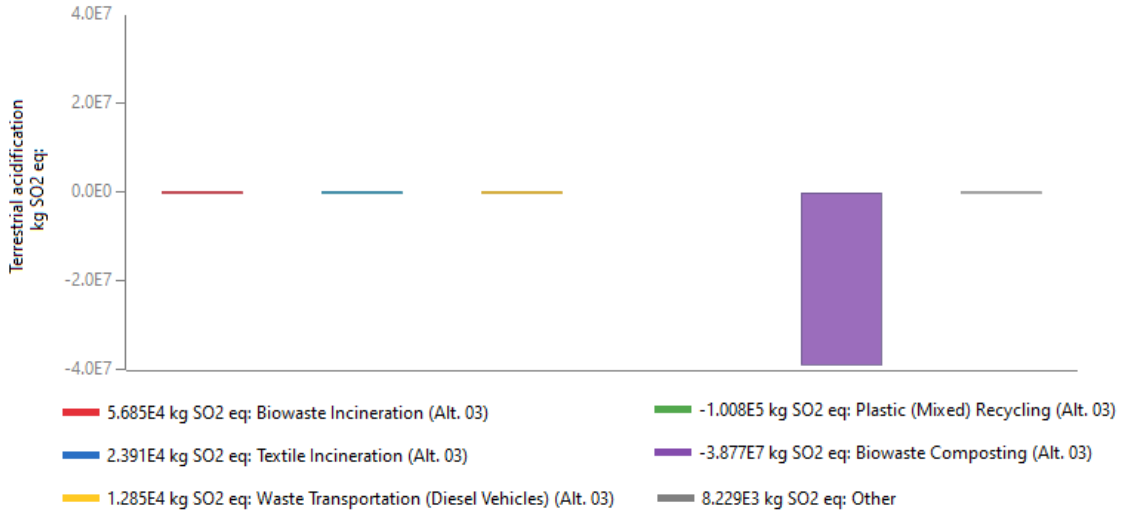

Figure D.59: Major contributors for terrestrial acidification in alternative A3

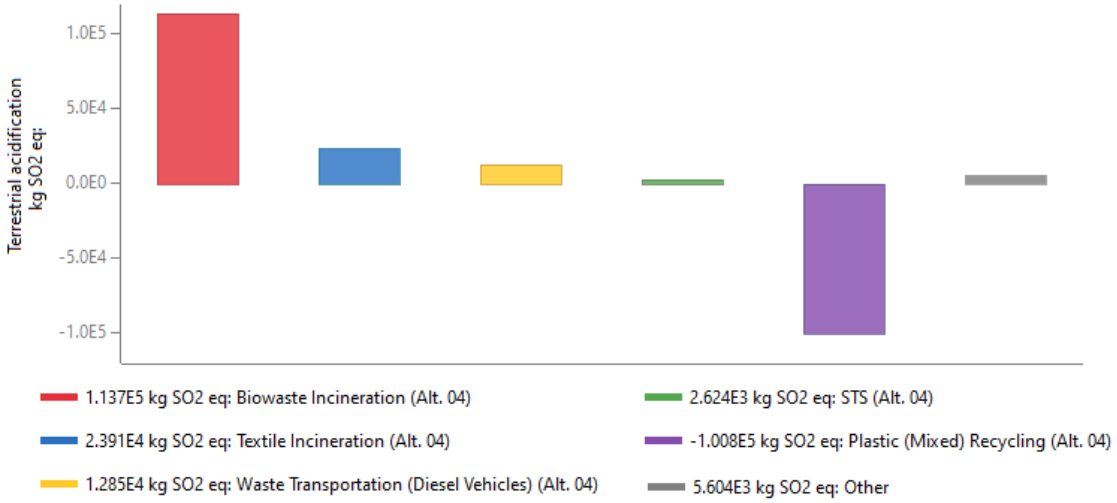

Figure D.60: Major contributors for terrestrial acidification in alternative A4

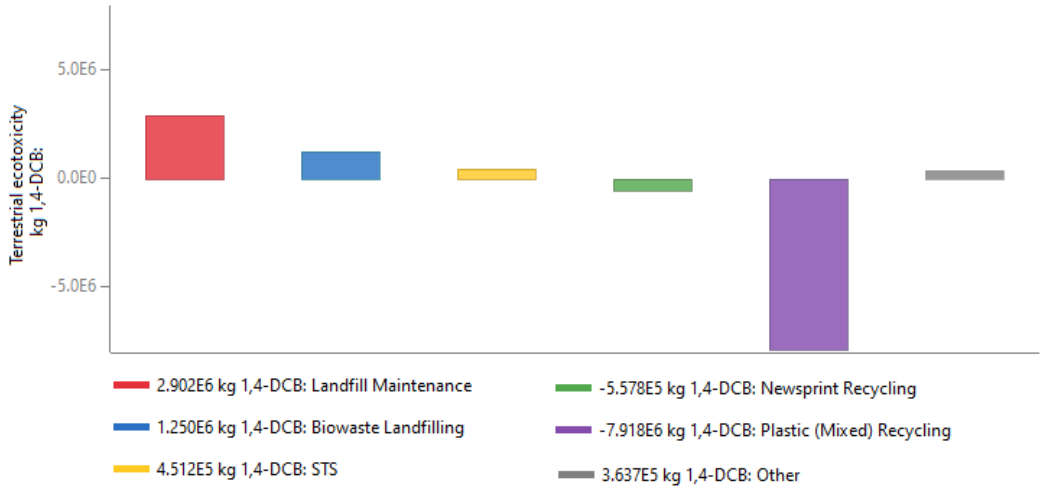

Figure D.61: Major contributors for terrestrial ecotoxicity in baseline B0

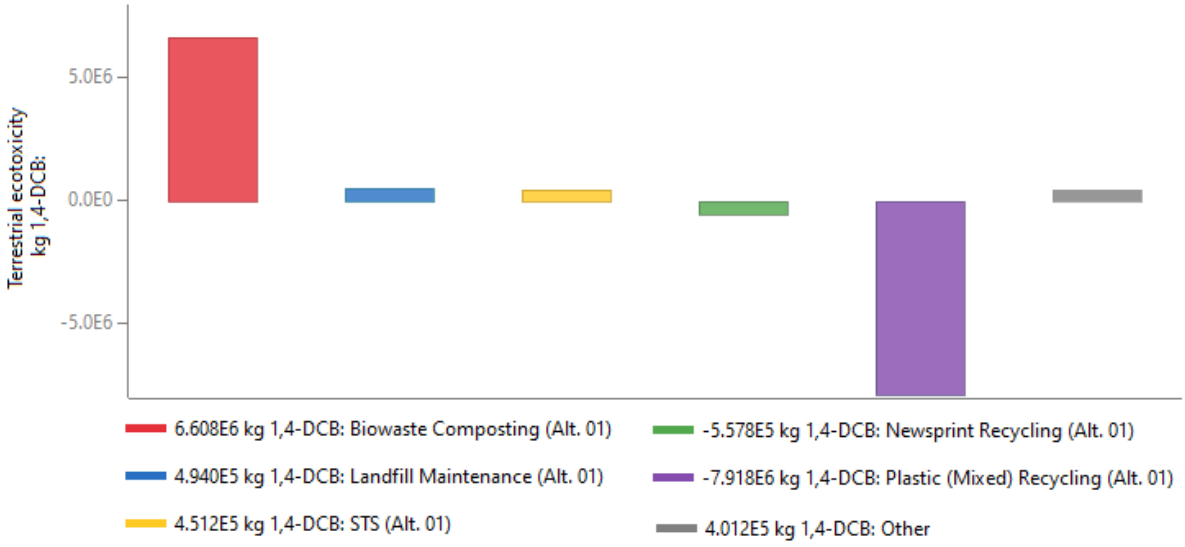

Figure D.62: Major contributors for terrestrial ecotoxicity in alternative A1

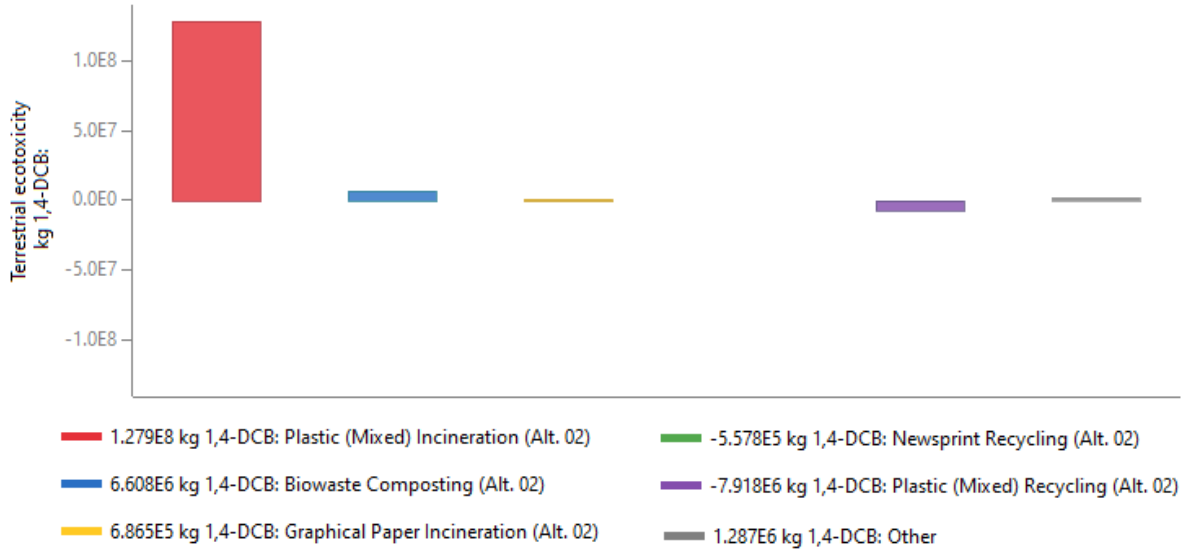

Figure D.63: Major contributors for terrestrial ecotoxicity in alternative A2

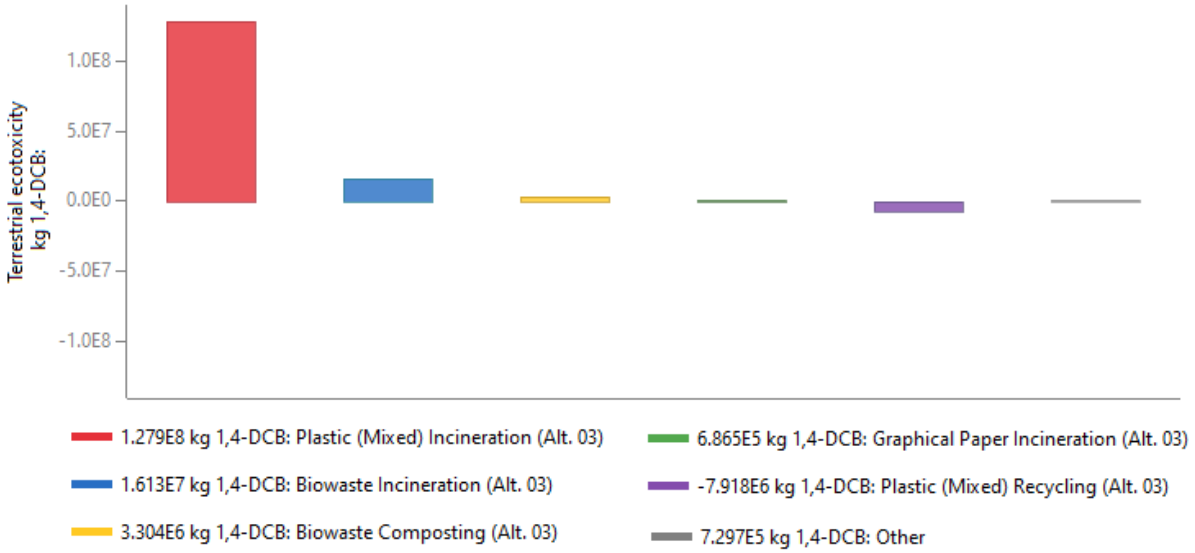

Figure D.64: Major contributors for terrestrial ecotoxicity in alternative A3

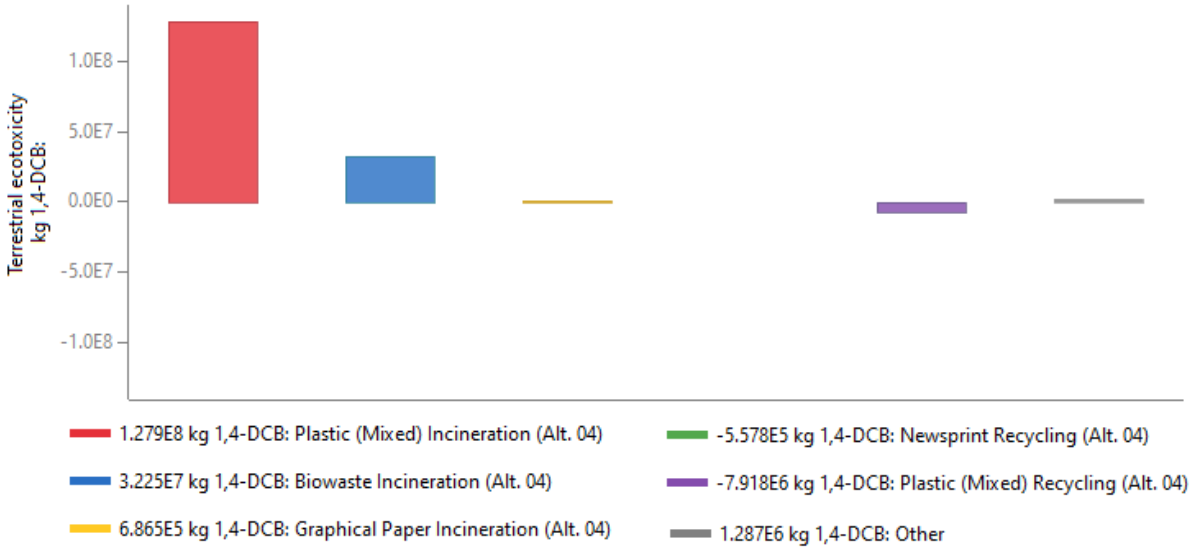

Figure D.65: Major contributors for terrestrial ecotoxicity in alternative A4

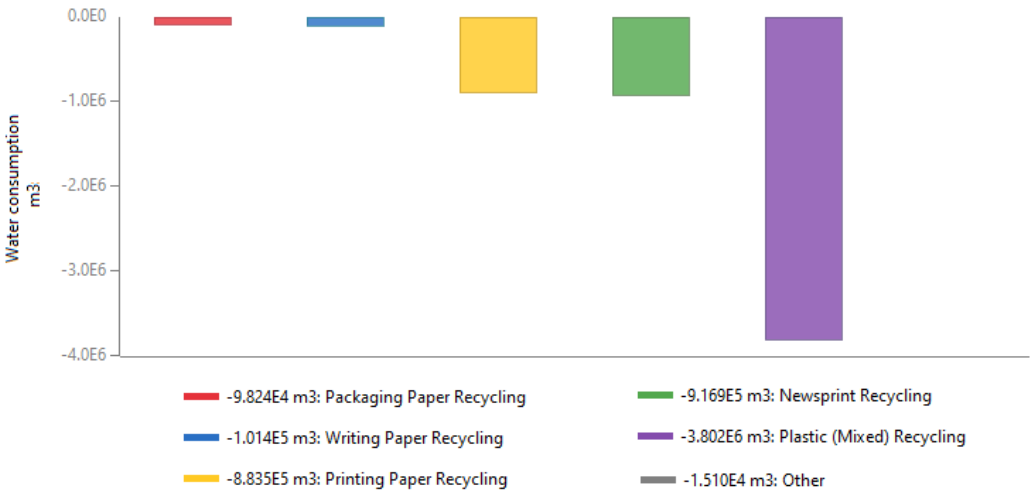

Figure D.66: Major contributors for water use in baseline B0

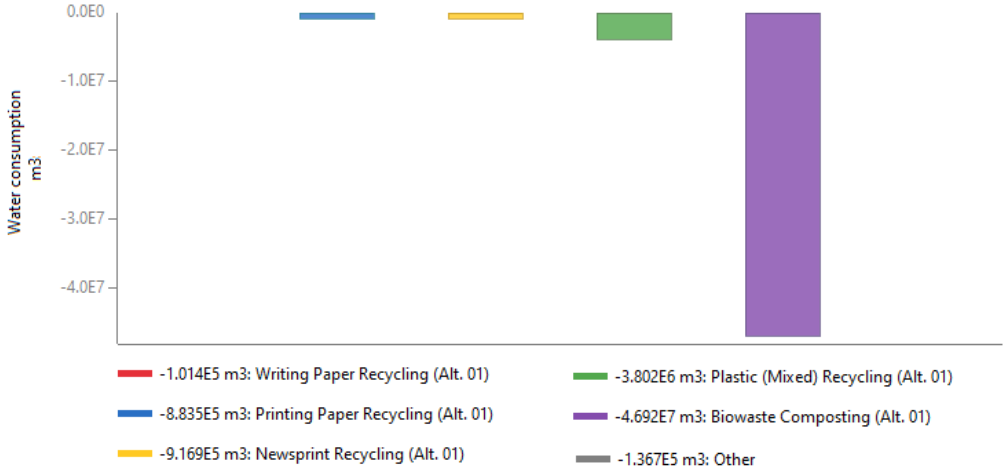

Figure D.67: Major contributors for water use in alternative A1

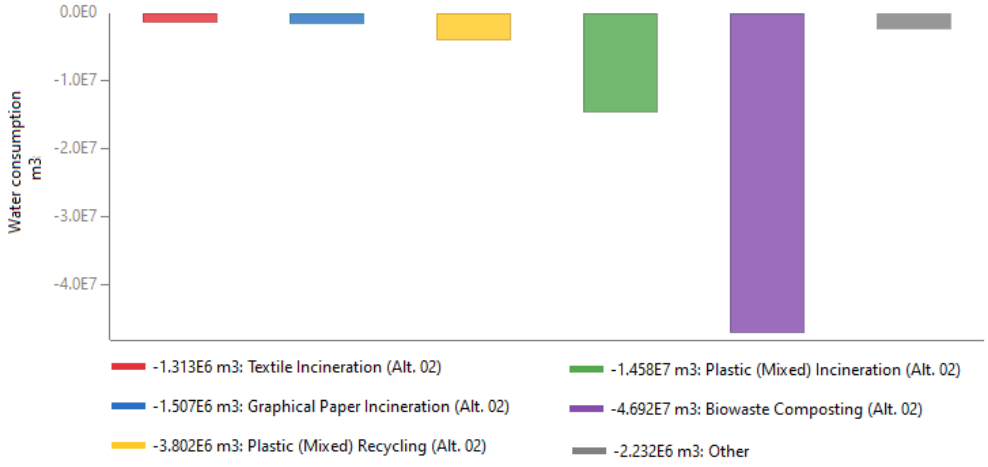

Figure D.68: Major contributors for water use in alternative A2

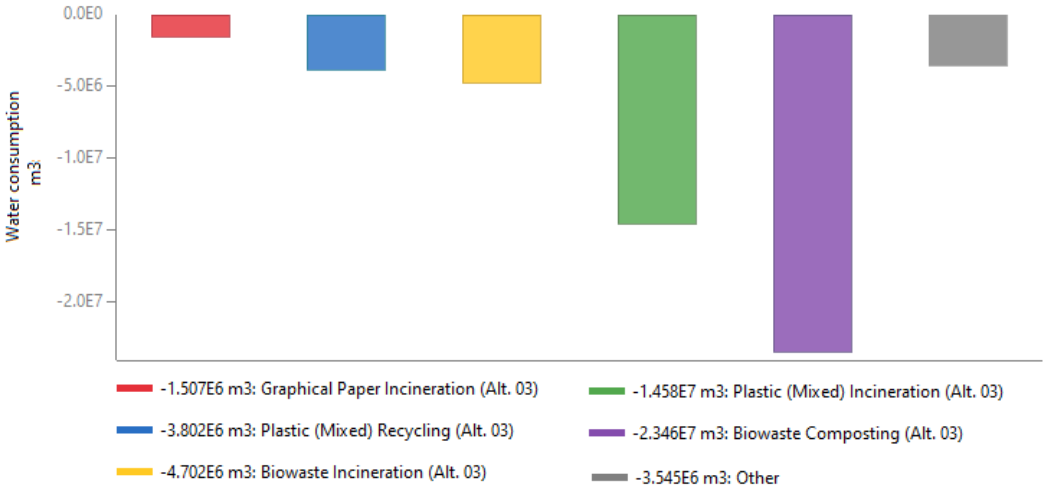

Figure D.69: Major contributors for water use in alternative A3

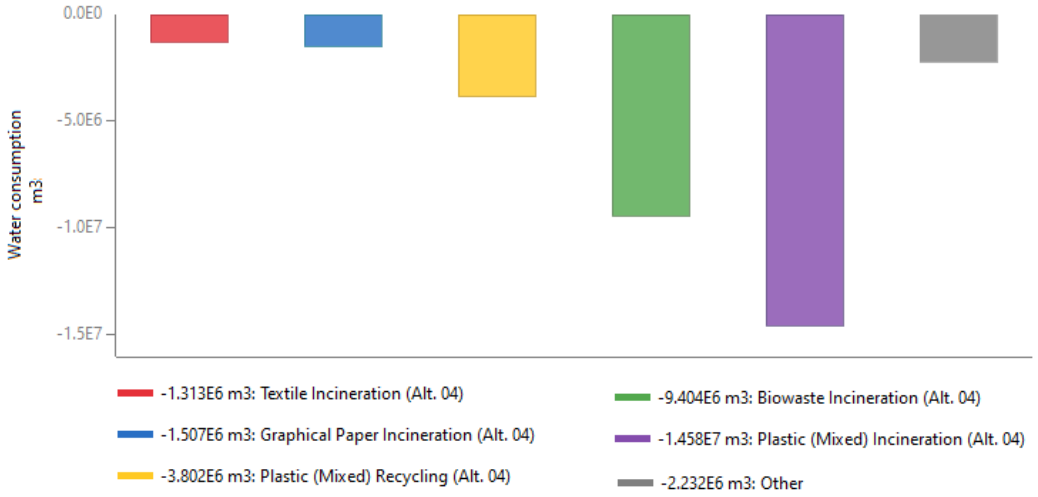

Figure D.70: Major contributors for water use in alternative A4

APPENDIX E

Table E.1: Endpoint LCIA results, DNCC vs DSCC

Indicator	Unit	DNCC	DSCC
Fine particulate matter formation	DALY	5.14E+00	1.81E+00
Freshwater ecotoxicity	species. yr	1.05E-02	1.12E-02
Freshwater eutrophication	species. yr	2.46E-02	2.23E-02
Global warming, Freshwater ecosystems	species. yr	4.96E-05	4.03E-05
Global warming, Human health	DALY	6.03E+02	4.90E+02
Global warming, Terrestrial ecosystems	species. yr	1.82E+00	1.48E+00
Human carcinogenic toxicity	DALY	2.00E+00	2.02E+00
Human non-carcinogenic toxicity	DALY	1.18E+02	1.17E+02
Land use	species. yr	1.20E-03	1.10E-03
Marine ecotoxicity	species. yr	2.17E-03	2.30E-03
Marine eutrophication	species. yr	9.46E-04	9.05E-04
Ozone formation, Human health	DALY	6.29E-03	-1.89E-03
Ozone formation, Terrestrial ecosystems	species. yr	3.22E-04	-1.06E-03
Stratospheric ozone depletion	DALY	-1.28E-03	-1.42E-03
Terrestrial acidification	species. yr	3.47E-03	-4.40E-04
Terrestrial ecotoxicity	species. yr	-1.31E-05	-2.69E-05
Water consumption, Aquatic ecosystems	species. yr	-1.48E-06	-2.03E-06
Water consumption, Human health	DALY	-5.44E+00	-7.47E+00
Water consumption, Terrestrial ecosystem	species. yr	-3.31E-02	-4.54E-02

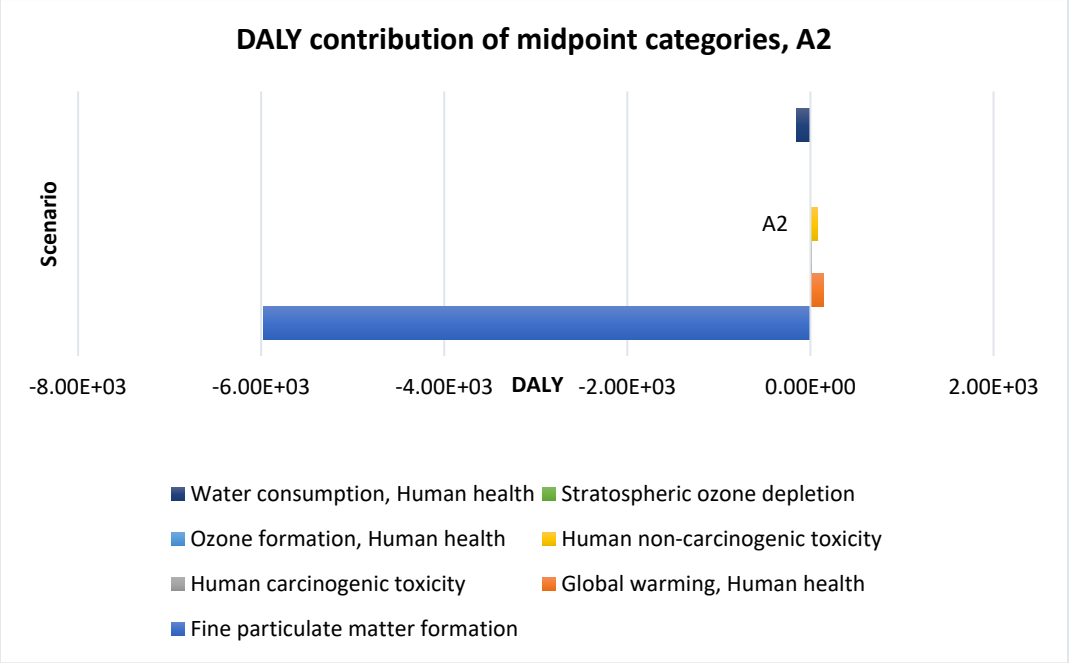

Figure E.1: DALY contribution of midpoint categories, A2

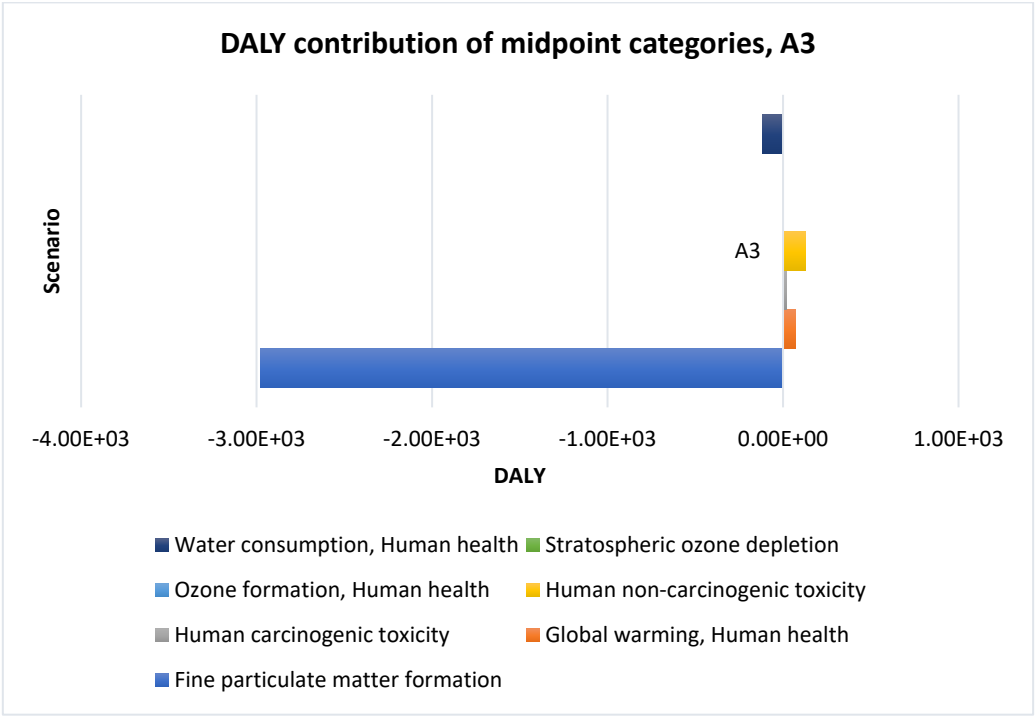

Figure E.2: : DALY contribution of midpoint categories, A3

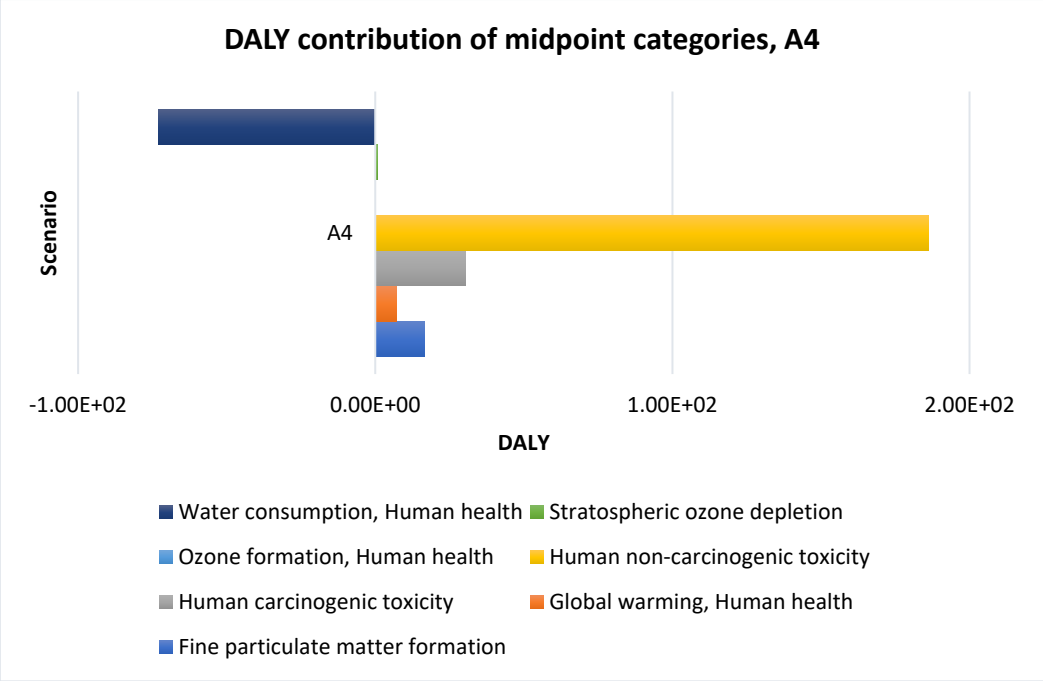

Figure E.3: DALY contribution of midpoint categories, A4

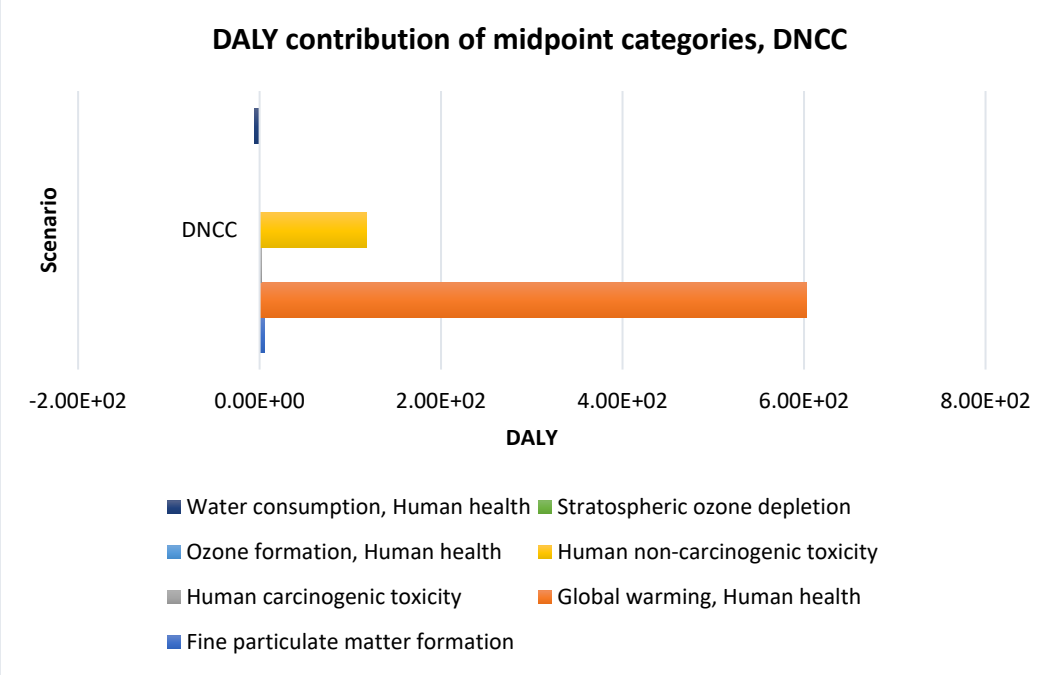

Figure E.4: DALY contribution of midpoint categories, DNCC

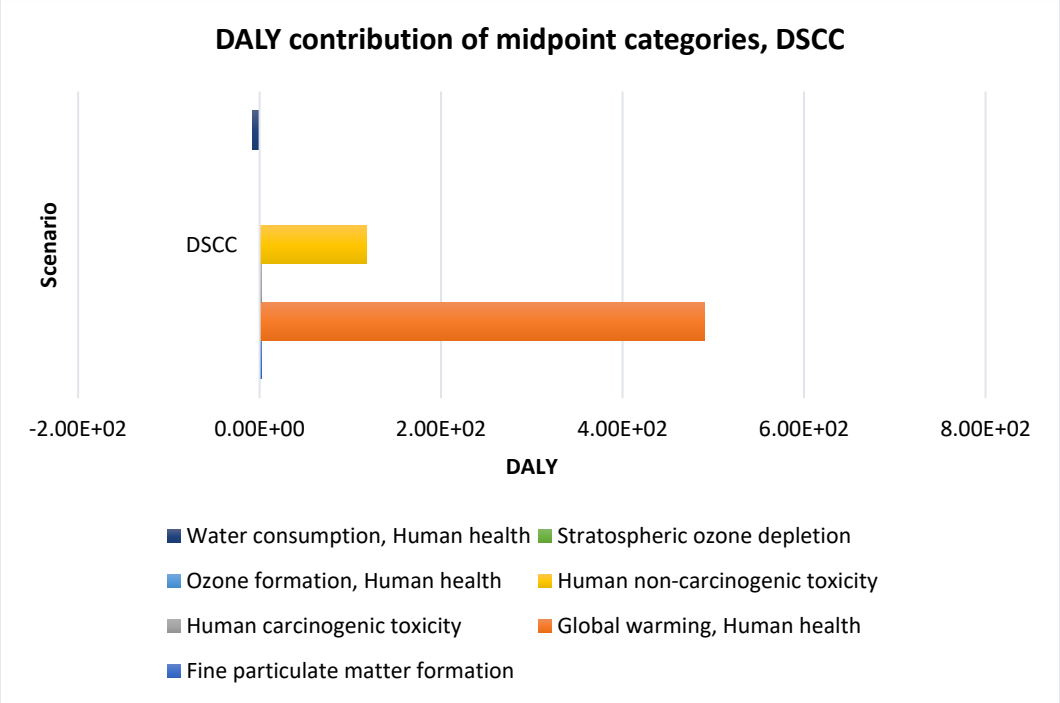

Figure E.5: DALY contribution of midpoint categories, DSCC

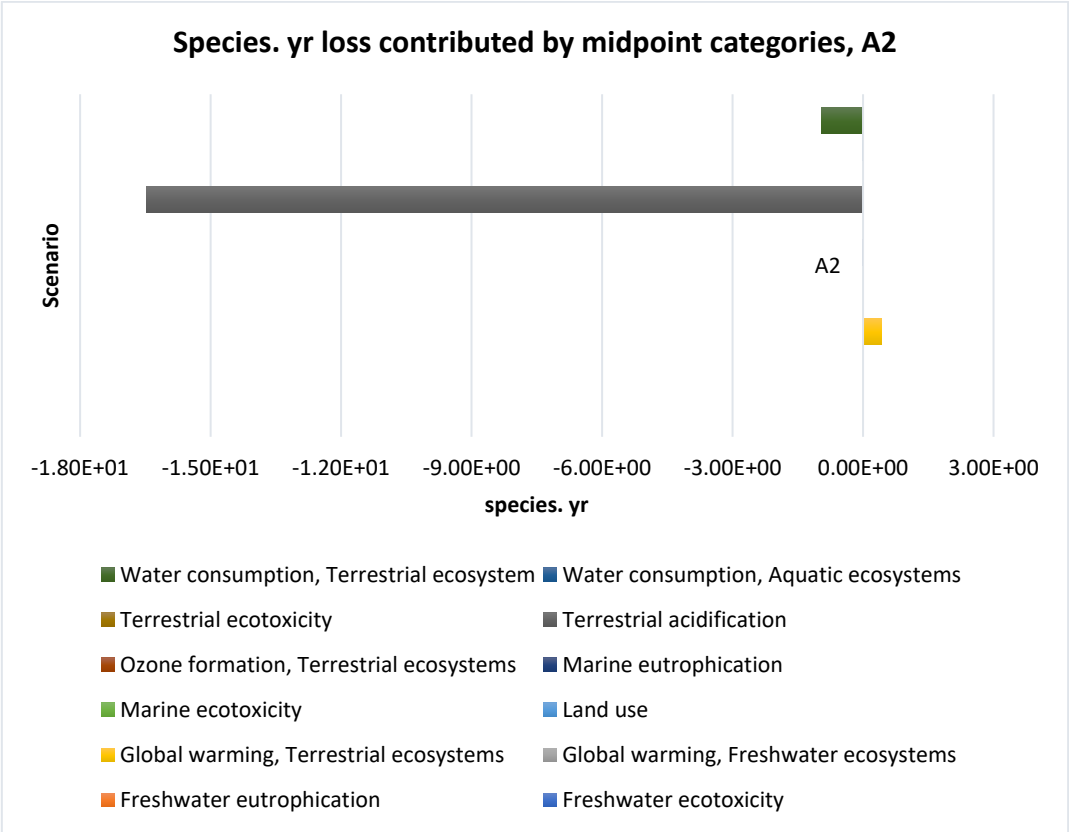

Figure E.6: Species. yr loss contributed by midpoint categories, A2

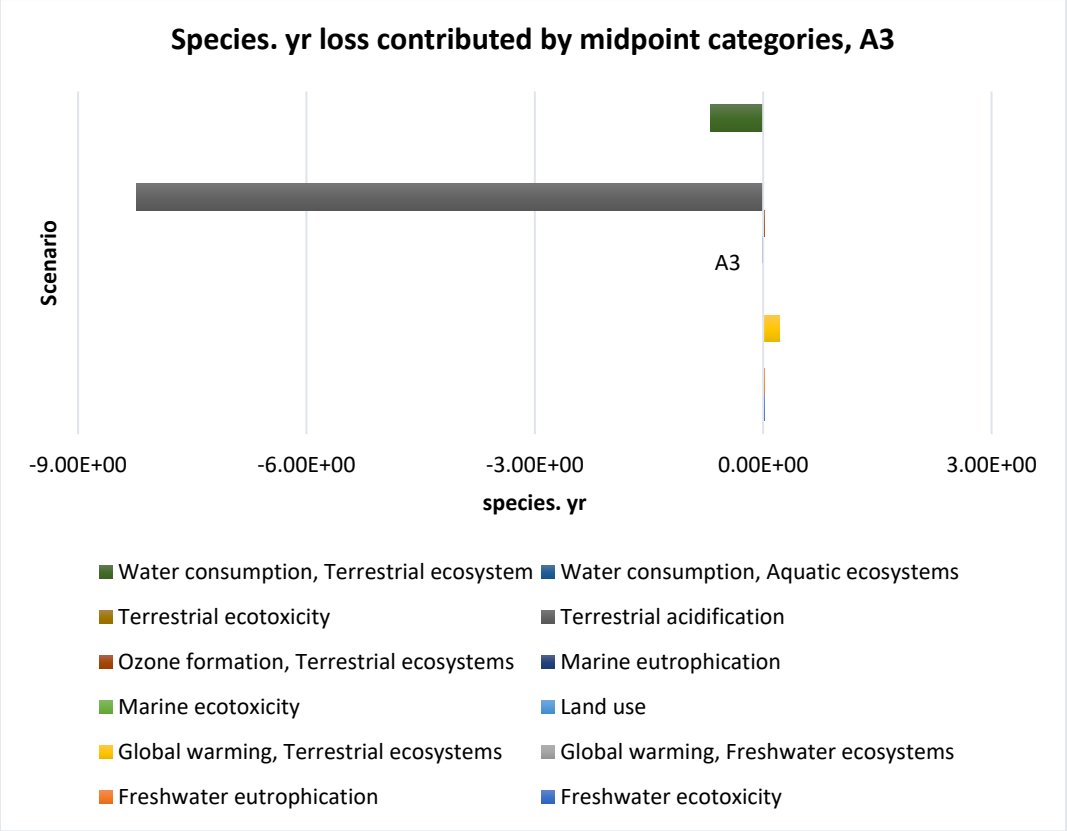

Figure E.7: Species. yr loss contributed by midpoint categories, A3

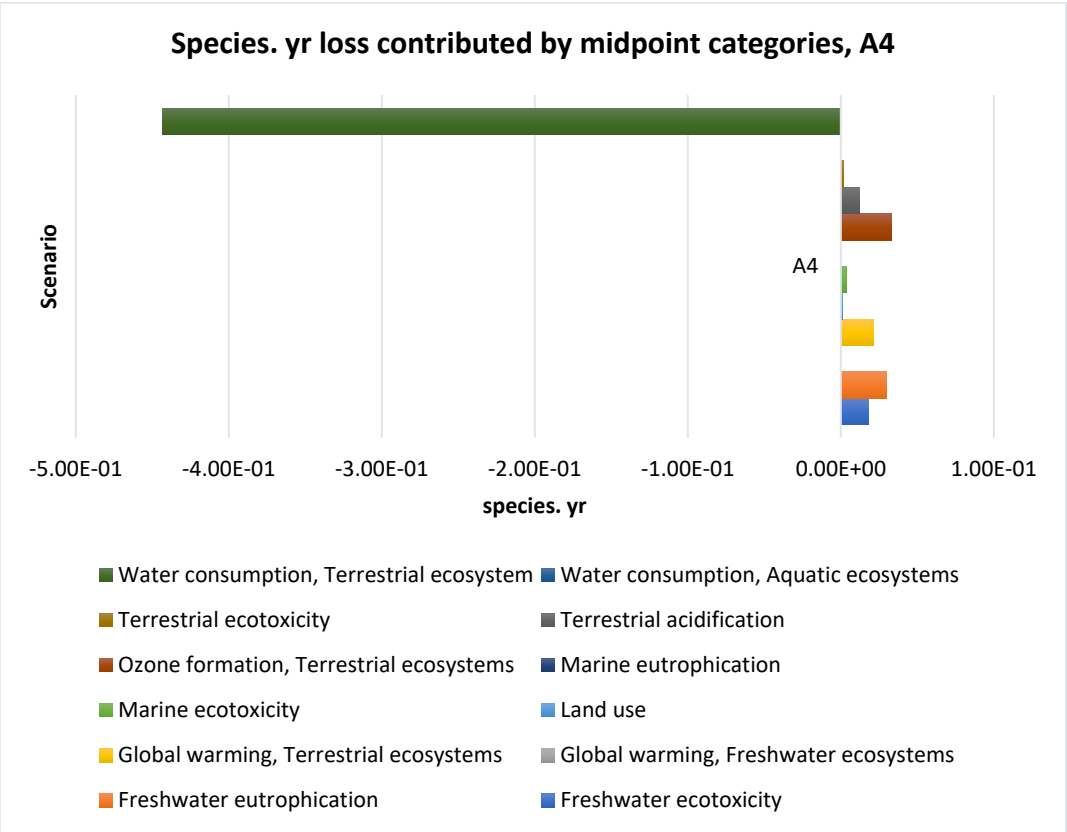

Figure E.8: Species. yr loss contributed by midpoint categories, A4

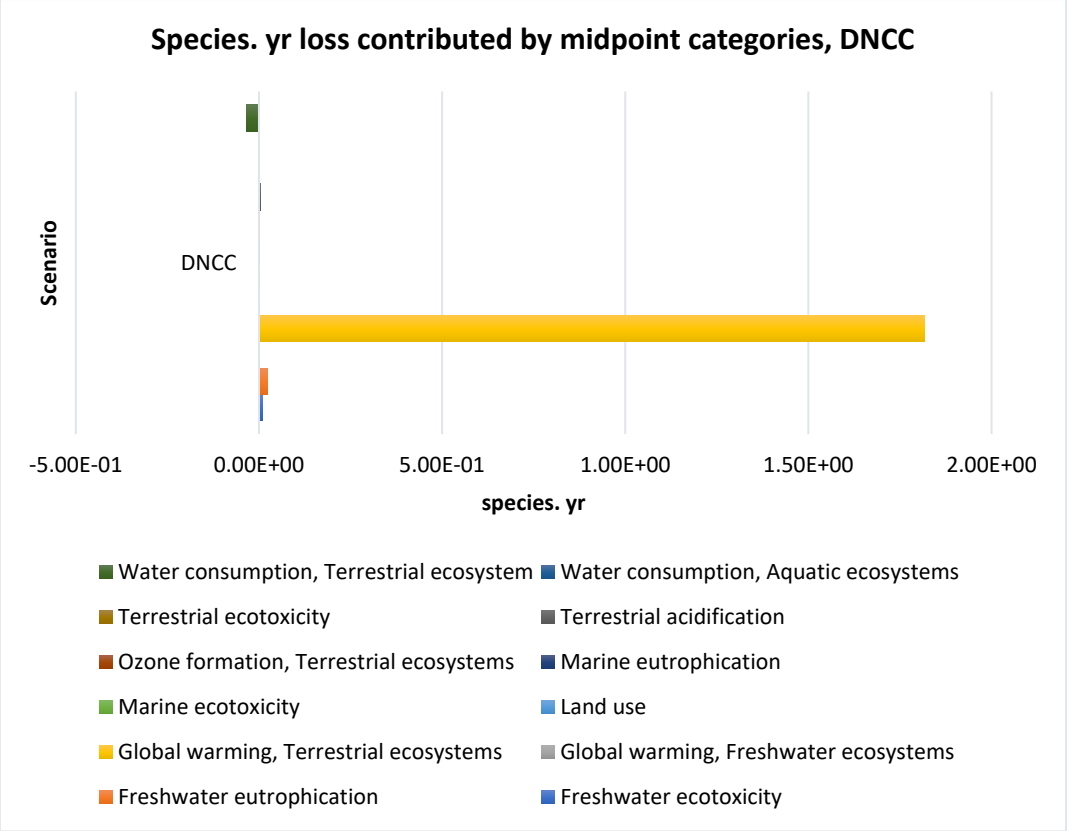

Figure E.9: Species. yr loss contributed by midpoint categories, DNCC

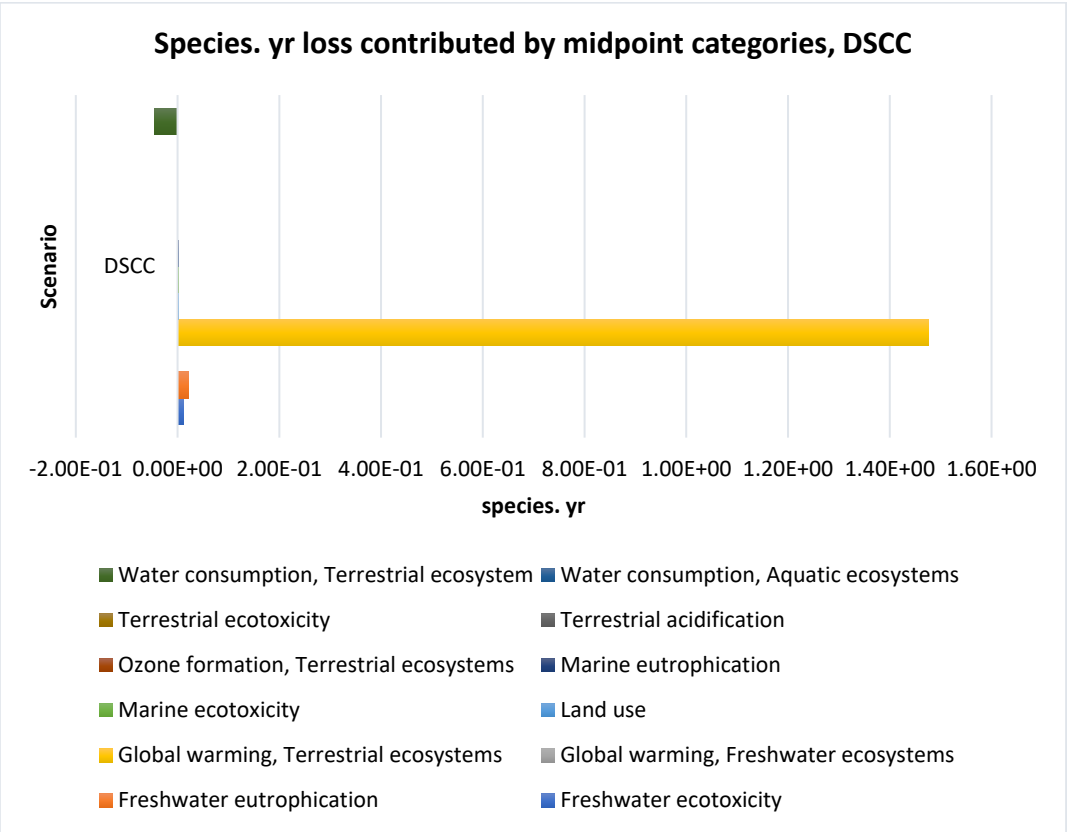

Figure E.10: Species. yr loss contributed by midpoint categories, DSCC