EVALUATION OF BEST AVAILABLE TECHNIQUES FOR THE SELECTED INTEGRATED SOLID WASTE PLANT USING LIFE CYCLE ASSESSMENT

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ABSTRACT

EVALUATION OF BEST AVAILABLE TECHNIQUES FOR THE SELECTED INTEGRATED SOLID WASTE PLANT USING LIFE CYCLE ASSESSMENT

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The Industrial Emissions Directive (IED) addresses the best available techniques (BATs) through BREF documents to be implemented in various processes to achieve the least environmental impact at a minimal cost. Waste management BREF is one of those and describes the numbers of BATs for various waste processing stages. These BATs are just those guided and the determination of the applicable ones for a given plant is a challenge. In this respect, Life Cycle Assessment (LCA) appears to be a valuable tool for assessing the environmental impacts of various BAT implementations within the waste management systems, like for many other industrial production systems. Therefore, in this study, LCA was used to evaluate and identify the most suitable BATs for the selected Closed Integrated Solid Waste Separation, Processing and Power Generation Plant, in Turkey. The functional unit was selected as 1 ton of municipal solid waste processed. Moreover, the system boundary was defined as “gate to gate” for the entire facility as well as for the individual processing units.

The cyclone separator, fabric filter, and wet scrubber have been implemented as effective technologies for minimizing dust emissions in mechanical treatment. These technologies have been guided by BAT25 in order to achieve optimal results. In a similar manner, various scenarios were developed to assess the effectiveness of biofilter, fabric filter, wet scrubber, thermal oxidation, and adsorption approaches in reducing H2S emissions within the desulphurization unit, based on the BAT34 guidelines. The environmental impact of the scenarios was assessed using the use of LCA.

The significance of electricity is particularly notable in relation to its substantial influence on the category of Global Warming and Human Health (GWHH). The environmental impact of thermal oxidation for H2S removal in desulphurization is notably high due to its substantial energy demands. Conversely, the utilization of fabric filters in the desulphurisation unit was determined to have the least environmental impact. When comparing the environmental impacts of the techniques to reduce dust emissions in mechanical treatment, the observed differences in the findings were minimal.

Keywords: Life Cycle Assessment, Waste Management, BREF, Best Available Techniques

ÖZ

YAŞAM DÖNGÜSÜ ANALİZİ KULLANILARAK SEÇİLMİŞ ENTEGRE KATI ATIK TESİSİ İÇİN MEVCUT EN İYİ TEKNİKLERİN DEĞERLENDİRİLMESİ

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Endüstriyel Emisyon Direktifi (IED), minimum maliyetle en az çevresel etkiyi elde etmek için çeşitli süreçlerde uygulanacak BREF belgeleri aracılığıyla mevcut en iyi teknikleri (BAT'ler) ele almaktadır. Atık yönetimi BREF bunlardan biridir ve çeşitli atık işleme aşamaları için çeşitli BAT'ları tanımlar. Bu BAT'lar yalnızca yönlendirilmiş olanlardır ve belirli bir tesis için uygulanabilir olanların belirlenmesi zordur. Bu bakımdan Yaşam Döngüsü Analizi (LCA), diğer birçok endüstriyel üretim sisteminde olduğu gibi atık yönetim sistemlerindeki çeşitli BAT uygulamalarının çevresel etkilerini değerlendirmek için değerli bir araç olarak karşımıza çıkmaktadır. Bu nedenle, bu çalışmada, Türkiye'de seçilen Kapalı Entegre Katı Atık Ayırma, İşleme ve Enerji Üretim Tesisi için en uygun BAT'ları değerlendirmek ve belirlemek amacıyla LCA kullanılmıştır. Fonksiyonel ünite 1 ton belediye katı atıklarının işlenmesi olarak seçilmiştir. Ayrıca sistem sınırı, tesisin tamamı ve bireysel işlem birimleri için kapıdan kapıya olarak tanımlanmıştır.

Siklon ayırıcı, kumaş filtre ve ıslak gaz temizleyici, mekanik arıtmada toz emisyonlarını en aza indirmek için etkili teknolojiler olarak uygulanmıştır. Bu teknolojiler, optimum sonuçlara ulaşmak için seçilen BAT tarafından yönlendirilmektedir. Benzer şekilde, seçilen BAT çerçevesinde kükürt giderme ünitesi içindeki H2S emisyonlarının azaltılmasında biyofiltre, kumaş filtre, ıslak yıkayıcı, termal oksidasyon ve adsorpsiyon yaklaşımlarının etkinliğini değerlendirmek için çeşitli senaryolar geliştirilmiştir. Senaryoların çevresel etkisi LCA kullanılarak değerlendirilmiştir.

Elektriğin önemi, Küresel Isınma ve İnsan Sağlığı (GWHH) kategorisi üzerindeki önemli etkisiyle bağlantılı olarak özellikle dikkat çekicidir. Desülfürizasyonda H2S giderimi için termal oksidasyonun çevresel etkisi, önemli enerji talepleri nedeniyle oldukça yüksektir. Buna karşılık, desülfürizasyon ünitesinde kumaş filtre kullanımının en az çevresel etkiye sahip olduğu belirlenmiştir. Mekanik arıtma prosedürlerinde toz emisyonlarını azaltmak için kullanılan tekniklerin çevresel etkileri karşılaştırıldığında, bulgularda gözlemlenen farklılıklar ihmal edilebilir düzeydedir.

Anahtar Kelimeler: Yaşam Döngüsü Analizi, Atık Yönetimi, BREF, Mevcut En İyi Teknikler

To my family

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AD: Anaerobic Digestion

BAT: Best Available Techniques

BREF: BAT Reference Document

CCW: Composting in Confined Windrows

CF: Characterization Factor

CHP: Combined Heat and Power

CT: Composting Tunnels

DALY: Disability Adjusted Life Years

EIPPCB: European Integrated Pollution Prevention and Control Bureau

EMPA: Swiss Federal Materials Testing and Research Laboratories

EPA: Environmental Protection Agency

EU: European Union

FPMF: Fine Particulate Matter Formation

FU: Functional Unit

GWHH: Global Warming, Human Health

GWP: Global Warming Potential

H2S: Hydrogen sulfide

HNCT: Human Non- Carcinogenic Toxicity

IEA: International Energy Agency

IED: Industrial Emissions Directive

IPPC: Integrated Pollution Prevention and Control

ISO: International Organization for Standardization

JRC: Joint Research Centre

LCA: Life Cycle Assessment

LCC: Life Cycle Costing

LCI: Life Cycle Inventory

LCIA: Life Cycle Impact Assessment

MBT: Mechanical Biological Treatment

MSW: Municipal Solid Waste

NGO: Non- Governmental Organization

OFMSW: Organic Fraction of Municipal Solid Waste

RDF: Refused Derived Fuel

RIVM: Dutch National Institute for Public Health and the Environment

SETAC: Society of Environmental Toxicology and Chemistry

STP: Standard Temperature And Pressure

TS: Total Solid

WCAE: Water Consumption, Aquatic Ecosystems

WWTP: Wastewater Treatment Plant

CHAPTER 1

INTRODUCTION

1.1 General

The global increase in waste generation, including municipal solid waste (MSW), is likely attributed to rapid population growth, urbanization, and the adoption of diverse consumption patterns. Initially, the resolution to these issues involved the implementation of restrictions on the emissions generated by manufacturing procedures. The strategy that came to be known as the "integrated" approach entailed the utilization of environmentally sustainable technologies throughout all stages of a product's life cycle (Messineo & Panno, 2008).

The composition of MSW exhibits significant variability. The diversity of emissions and emission sources in waste treatment activities can be related to the diverse composition involved. In other words, the emissions (to air, water, and soil) and pollutants (dust, hydrogen sulfide, biodegradable organic compounds etc.) that arise from waste treatment are subject to the effect of waste composition and local variables. (Brinkmann et al., 2016).

The Industrial Emissions Directive (IED), which was released on November 24, 2010, establishes the regulations governing the comprehensive prevention and management of pollutants arising from industrial operations. Furthermore, it sets regulations aimed at mitigating or, if not achievable, minimizing emissions to the atmosphere, water bodies, and land, as well as preventing the formation of waste. The primary objective is to have a comprehensive environmental protection framework (IED, 2010).

According to Article 3(10) of Directive 2010/75/EU, Best Available Techniques (BAT) refer to the most efficient and advanced methods that demonstrate the practical suitability of specific techniques in establishing emission limit values and other permit conditions aimed at preventing adverse impacts during the implementation of activities and operational procedures (IED, 2010). The Seville process refers to the operational framework that facilitates the preparation and evaluation of the BAT Reference Document (BREF), which encompasses the findings and recommendations on BAT. The European Integrated Pollution Prevention and Control Bureau (EIPPCB) of the Joint Research Centre (JRC) is responsible for the development of BREFs and BAT conclusions. This process involves the collaboration of industry specialists, public agencies, environmental non-governmental organizations (NGOs), and other services within the European Commission (European Union, 2017).

The scope of the Waste Treatment BREF document encompasses a range of activities, including physicochemical treatments, biological treatments, waste material recovery treatments, conventional treatments, and fuel production treatments. Although the reference to mechanical biological treatment (MBT) plants is absent, it is worth noting that there are two sections within the text that address certain aspects related to MBT plants (Rotter, 2006).

The Life Cycle Assessment (LCA) is a methodology employed to evaluate the environmental consequences and resource consumption associated with the whole life cycle of a product. This encompasses many stages, including the acquisition of raw materials, production, utilization, and waste management (ISO, 2006). LCA offers a comprehensive evaluation of environmental impacts across many impact categories, enabling the opportunity to conduct comparisons between these categories.

While there exist some LCA studies in the current collection of literature that aim to identify suitable treatment methods for waste treatment plants, there is currently a lack of research focused on the selection of the most suitable approach for a given plant based on the BATs outlined in the Waste Treatment BREF document. The present study employed the LCA technique to analyze the environmental implications associated with the implementation of BATs in the chosen waste treatment plant in Turkey.

1.2 Objective and Scope of This Study

This study focused on evaluating and identifying the most appropriate BATs guided by Waste Treatment BREF BAT Conclusion for the chosen Closed Integrated Solid Waste Separation, Processing and Power Generation Plant, in Turkey by using the LCA approach. BAT25 and BAT34 were evaluated to reduce dust emissions in the mechanical treatment unit and H2S concentration in the desulphurization unit, respectively.

The concentration of H2S in the biogas needs to be decreased. The reason for this is that the retention of H2S in biogas has adverse effects on both human health and the durability of equipment. Inhaling and using biogas containing H2S as a biofuel for boilers can have detrimental effects on both the lifespan of the equipment and human health. This is because H2S is corrosive in nature and can cause catastrophic repercussions (Okoro & Sun, 2019). Thus, four different alternatives: (a) wet scrubbing, (b) fabric filter, (c) thermal oxidation and (d) adsorption were examined rather than biofilter, which already exists in Scenario 1 by leading BAT34 to reduce H2S concentration in desulphurization unit. The mechanical treatment process can generate dust emissions that may consist of inhalable and non-respirable small particles, posing a risk to human health. (Waskow et al., 2020). Furthermore, three different options: (a) cyclone separator, (b) fabric filter, (c) wet scrubbing, were studied to reduce dust emissions in mechanical treatment unit. The data utilized in this study comprised ten distinct scenarios: the baseline scenario, two composting scenarios, four alternative desulphurization scenarios, and three mechanical treatment scenarios. The EIA report of the study facility and relevant literature were consulted for the development of these scenarios.

Furthermore, evaluating the practices guided by Waste Treatment BREF is also the aim of this study. Landfill and composting alternatives were analyzed by LCA to manage the solid digestate. The recirculation of water is also interpreted in composting alternatives.

The analysis was done within the designated system boundary, which is gate to gate from the entire facility, and the determined functional unit, which is 1 ton of municipal solid waste, based on the comparison of generated scenarios. SimaPro 9.3.0.3 was used.

All constructed scenarios were modeled using the consequential system model, with allocation being avoided. The present study employed the ReCipe 2016 impact assessment method, and the interpretation of the results incorporated both mid-point and end-point single score outcomes.

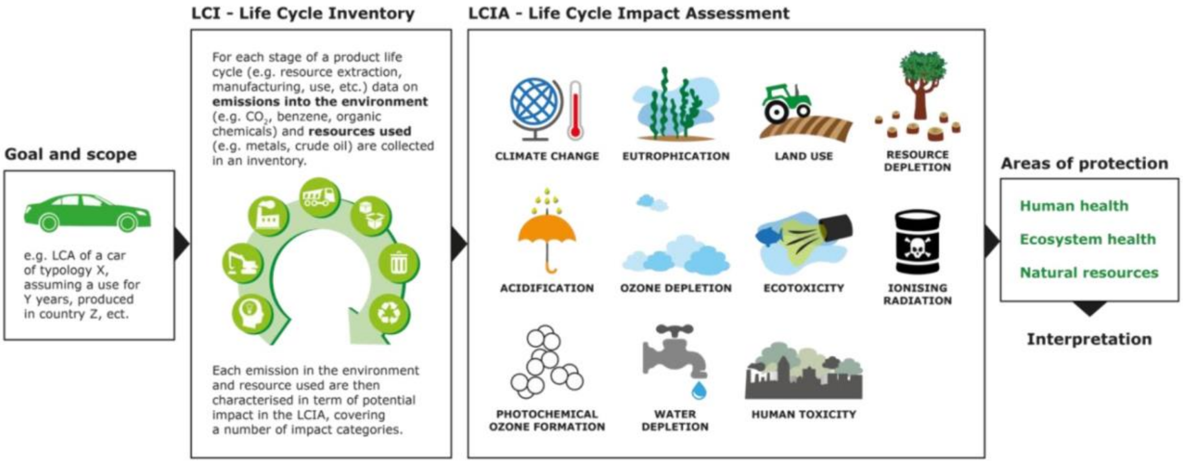
CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Life Cycle Assessment (LCA)

The tool used to analyze potential environmental impacts and resources throughout the life cycle of a product, i.e., from raw material extraction through material processing, production, distribution, use, repair and maintenance and final disposal or recycling, is termed Life Cycle Assessment (Finnveden et al., 2009). LCA assesses the environmental aspects and potential impacts of a product, process, or service. The method involves compiling an inventory of the system's resource (raw materials, water, energy, etc.) inputs and associated environmental releases, assessing the potential environmental impacts associated with the identified inputs and outputs, and finally interpreting the results (Curran, 2006). LCA studies can cover processes from raw material extraction to factory gate (cradle to gate), production processes (gate to gate), or all processes from raw material extraction to final disposal (cradle to grave) (Golsteijn, 2018).

In the late 1960s and early 1970s, when environmental issues such as resource efficiency, pollution control and waste management were of significant public interest, the first studies now recognized as (partial) LCA began. These studies were later extended to include generated waste, emission loads and resource requirements. Since the early 1980s, interest in the subject has overgrown; a report was published by the Swiss Federal Materials Testing and Research Laboratories (EMPA) in 1984, providing a comprehensive list of data required for LCA studies (Zhu et al., 2020). This study included the first impact assessment method that divided air and waterborne emissions according to specific standards and named "critical air volumes" and "critical water volumes" (Gordon et al., 2022). LCA studies continued with different scopes and terminologies in the following years without a specific standard. However, the Society of Environmental Toxicology and Chemistry (SETAC), which aims to make LCA a commonly accepted assessment tool, has brought together LCA users, practitioners, and other researchers (Sharp & Miller, 2016). On the other hand, since 1994, the International Organization for Standardization (ISO) has been working to standardize methods and terminology. In this context, ISO has published two international standards: **(i)** ISO 14040 (2006E): "Environmental management - Life cycle assessment - Principles and framework" and **(ii)** ISO 14044 (2006E): "Environmental management - Life cycle assessment - Requirements and guidelines"(Guinée et al., 2011). These standards define the four main steps: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation. These steps are depicted in Figure 2.1.



e.g. LCA of a car of typology X, assuming a use for Y years, produced in country Z, ect.

For each stage of a product life cycle (e.g. resource extraction, manufacturing, use, etc.) data on **emissions into the environment** (e.g. CO_2, benzene, organic chemicals) and **resources used** (e.g. metals, crude oil) are collected in an inventory.

Each emission in the environment and resource used are then characterised in term of potential impact in the LCIA, covering a number of impact categories.

Figure 2.1 Life cycle assessment steps (Sala & Reale, 2016).

In the first step of LCA, the study's purpose and scope, the study's reason, and the target audience are determined. In other words, system boundaries, the functional unit, preferred software, and lifecycle impact assessment (LCIA) categories are defined at this step. The Life Cycle Inventory (LCI) step includes all inputs and outputs processed into the system. At this step, the sources of the data used and the procedures for all calculations are given. All data, including energy, raw materials and other physical inputs, products and by-products and wastes, air/water/soil emissions and other environmental factors, constitute inputs and outputs. Finally, the collected data is verified and associated with the process and functional units. The third step, in which LCI results are related to environmental impact categories and indicators, is the LCIA. At this step, emissions are classified according to impact categories while evaluating them through different methods that characterize them with standard units to allow comparison. Finally, in the Life Cycle Interpretation step, the results from the previous steps are interpreted according to the goals defined in the study's first step, the Goal and scope Definition. In this step, precision and consistency checks are also carried out (Sala & Reale, 2016). The details about these steps are given in the following parts.

2.1.1 Goal and Scope Definition

LCA work used to model the life cycle of a product, service, or system involves simplifications as much as possible. It is critical to determine the purpose and scope of the study so that simplifications made in this direction, in other words, assumptions, do not cause deviations in the results or minimize this deviation. This stage reveals the specific points of the study. For example, what will the study serve, its functional unit (FU), and system boundaries (Golsteijn, 2018)?

According to ISO (2006), FU evaluates the efficiency of a product system's functioning outputs and serves as a frame for competitive comparisons. The system boundaries shape which aspects of the life cycle and processes correspond to the examined system and are necessary to perform its function as described by its FU. Meanwhile, the system boundaries specify the border between the investigated system and the environment.

2.1.2 Life Cycle Inventory (LCI)

In line with the objectives defined in the first stage of the assessment (goal and scope), LCI quantifies the environmental impact. The resources used, data required, and collection procedures for an LCI study are entirely different (Kikuchi, 2016). The inventory consists of data from multiple sources, such as primary data, academic literature, LCI databases and expert opinions. The evaluation scale of the study determines the sources used (Fraval et al., 2019).

Different LCI data requirements exist for each life cycle stage. The data collected for LCI are either primary or secondary data, depending on the time, data types, and details required in the study to achieve the goal and scope (Saavedra-Rubio et al., 2022).

2.1.3 Life Cycle Impact Assessment (LCIA)

The LCA impact assessment phase is a mechanism to improve the relevance and interpretability of life cycle inventory data for decision-makers and other interested parties. This is accomplished by converting raw inventory data (which frequently contains hundreds of raw emissions to air, water, and land) into a collection of smaller impact categories representing the project's most significant environmental or human health effects.

The selection of impact categories, category indicators, and models is an essential component of the LCIA study. This process includes the precise identification and determination of the impact categories that are fundamental to the research subject. Furthermore, it is critical to diligently choose suitable category indicators in order to measure and evaluate the impacts within each category with precision. In conclusion, the choice of models is crucial in establishing a structure for the examination and interpretation of the gathered data.

The objective of this undertaking is to allocate LCI outcomes to distinct impact categories via a classification procedure.

- **Characterization:** The process of determining category markers by mathematical calculations. In this calculation process, the substances that contribute to an impact category are multiplied by a characterization factor (CF) that expresses the relative contribution of the substance. The midpoint to endpoint CF for ReciPe 2016 is given in Table F.1 in the Appendix part. One illustration of this concept is the potential characterization factor of 25 for methane and one for carbon dioxide within the climate change impact category. Thus, 1 kg of methane emissions are equivalent to 25 kg of carbon dioxide emissions in terms of climate change. Indicators of impact categories represent the full outcome (*SimaPro Database Manual Methods Library*, 2020).

- **Normalization:** A reference value, also known as the normal value, can be utilized in numerous approaches to compare the impact category indicator results. Consequently, the reference classifies the impact category. The ratio of the average annual environmental impact to the population of a given country or continent is a frequently cited comparison (*SimaPro Database Manual Methods Library*, 2020).
- **Weighting:** This is a feature of certain methodologies. Consequently, a sum or singular score is obtained by multiplying the impact (or damage) category indicator results by weighting factors (*SimaPro Database Manual Methods Library*, 2020).

Environmental impact is evaluated by an endpoint method at the conclusion of this cause-and-effect chain. In contrast, a midpoint method evaluates the impact prior to the endpoint being attained, earlier in the cause-and-effect chain (*SimaPro Database Manual Methods Library*, 2020). The end- point and mid-point categories are presented in Table 2.1. Human health impact category, which is integrated with lifetime loss, defines the damage to human health. Similarly, ecosystems impact category which is integrated with species loss in a specific time, defines the damage to ecosystems quality. Lastly, resources impact category, which is integrated with surplus cost, defines the damage to resource availability.

Table 2.1 End- Point and Mid- Point Impact Categories

End-Point Impact Categories	**Mid- Point Impact Categories**
Human Health	Global warming, human health
	Stratospheric ozone depletion
	Human carcinogenic toxicity
	Human non-carcinogenic toxicity
	Ozone formation, human health
	Fine particulate matter formation
	Ionizing radiation
	Water consumption, human health
Ecosystems	Global warming, terrestrial ecosystems
	Terrestrial acidification
	Freshwater ecotoxicity
	Terrestrial ecotoxicity
	Marine ecotoxicity
	Water consumption, terrestrial ecosystem
	Land use
	Ozone formation, terrestrial ecosystems
	Water consumption, aquatic ecosystems
Resources	Mineral resource scarcity
	Fossil resource scarcity

There are several methods used for LCIA, such as CML, ReciPe (2016), IMPACT World+, TRACI 2.1, LC Impact, IPCC 2021, and USEtox 2. These methods are comparatively presented in Table 2.2. Among these methods, Recipe (2016) and

IMPACT World+ stand out for their global relevance and consideration of impact categories at both the midpoint and endpoint levels. These two methods which are most widely used in LCA studies are summarized in the following subsections.

Table 2.2 Summary of Some of the Impact Assessment Methods (SimaPro Software Version 9.3.0.3)

Method name	**Remarks**
CML	European. It considers only midpoint impacts.
ReciPe 2016	Global. It is a follow up of Eco-indicator 99 and CML 2002 methods, which integrates and harmonizes midpoint and endpoint approaches.
IMPACT World+	Global. It implements impact modeling approaches developed as a major joint update to existing LCIA methods, including IMPACT 2002+ (Europe), EDIP (Scandinavia), and LUCAS (Canada). It considers both midpoint and endpoint impacts.
TRACI 2.1	North American. Developed specifically for the United States using input parameters consistent with U.S. locations. Midpoint oriented approach.
LC-Impact	Global. Although it aims to evaluate the equality systems, human health, and resources at the global level, only the most essential regionalized flows are included.
IPCC 2021	Single issue. It deals with global warming issues only.
USEtox 2	Single issue. It deals with human and ecotoxicological issues of chemicals.

2.1.3.1 ReCiPe (2016) Method

The ReCiPe methodology is a widely used approach for conducting LCIAs. The initial development of the project occurred in 2008 through a collaborative effort with RIVM, Radboud University Nijmegen, Leiden University, and PRé Sustainability (Huijregts et al., 2017).

The main aim of the ReCiPe method is to condense the extensive array of LCI outcomes into a restricted set of indicator scores. The indicator scores serve to quantify the comparative magnitude of environmental impacts within a certain impact category (Huijregts et al., 2017). In the ReCiPe methodology, indicators are determined at two distinct levels: (i) 18 midpoint indicators and (ii) 3 markers of endpoints.

The midpoint and endpoint methods each incorporate considerations based on three distinct cultural views. These viewpoints encompass a range of options about matters such as time or expectations, which can be mitigated by effective management or the advancement of future technologies to prevent potential harm (Huijregts et al., 2017).

- **The individualist perspective** entails a belief in the short-term (20 years) efficacy of technology in mitigating numerous challenges that may arise in the future, hence fostering an optimistic outlook.
- **The hierarchist approach,** commonly observed in scientific models, is widely regarded as the default model. Time horizon considered is typically 100 years.
- **The concept of egalitarianism** is grounded in a precautionary principle approach, which emphasizes long-term (>1000 years) considerations.

Whenever feasible, it employs effect mechanisms that possess a worldwide reach. The collaborative development of ReCiPe 2016 involved the Dutch National Institute for Public Health and the Environment (RIVM), Radboud University Nijmegen, Norwegian University of Science and Technology, and PRé (Huijregts et al., 2017).

Figure 2.2 illustrates the correlation between the environmental processes, specifically the midpoints, and the three areas of protection.

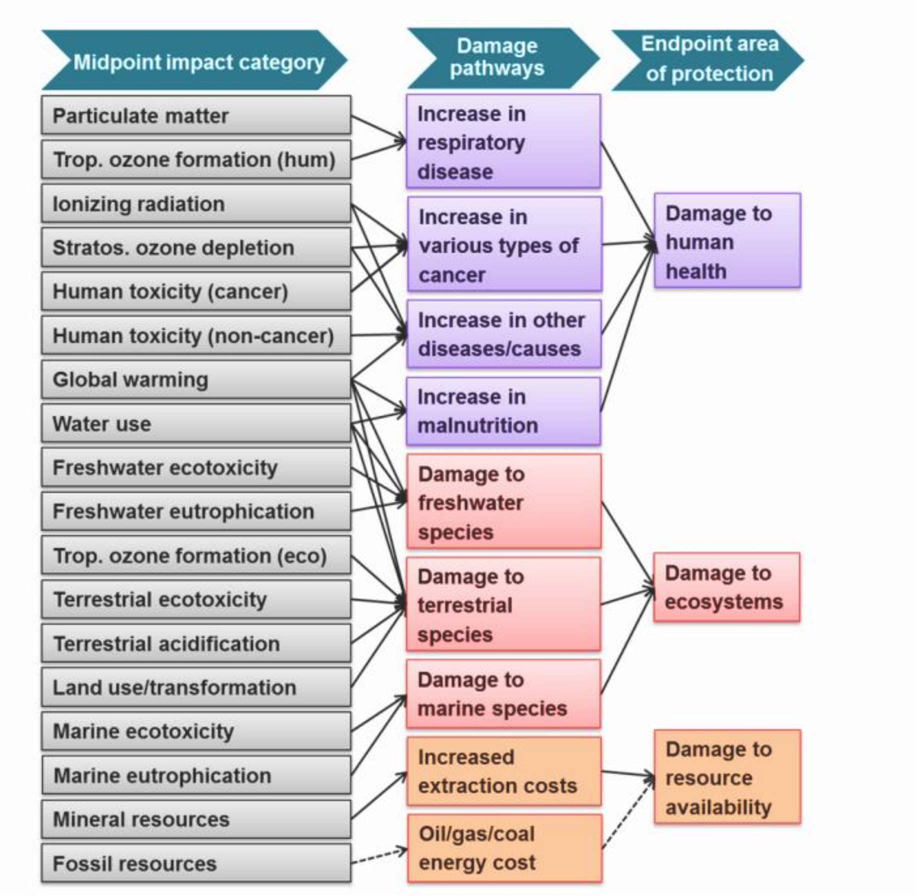


Figure 2.2 Overview of the ReCiPe2016 impact categories (Huijregts et al., 2017).

Table 2.3 presents characterization factors used in ReCipe2016 method. Also, midpoint to endpoint characterization factors, endpoint normalization scores and midpoint normalization scores used in ReCipe2016 are given in Table F.1, Table F.2 and Table F.3 in Appendix part.

Table 2.3 Characterization Factors Used in ReCipe2016 Method (Huijregts et al., 2017).

Impact Category	**Indicator**	**Unit**	**CFm**	**Unit**
Climate change	Infra-red radiative forcing increase	W x yr/m2	Global warming potential	kg CO2 to air
Ozone depletion	Stratospheric ozone decrease	ppt x yr	Ozone depletion potential	kg CFC-11 to air
Ionizing radiation	Absorbed dose increase	Man x Sv	Ionizing radiation potential	kBq Co-60 to air
Fine particulate matter formation	PM2.5 population intake increase	kg	Particulate matter formation potential	kg PM2.5 to air
Photochemical oxidant formation: ecosystem quality	Tropospheric ozone increase (AOT40)	ppb. yr	Photochemical oxidant formation: ecosystem	kg NOx to air
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase (M6M)	kg	Photochemical oxidant formation: human	kg NOx to air
Terrestrial acidification	Proton increases natural soils	yr x m2 x mol x L	Terrestrial acidification potential	kg SO2 to air

Table 2.3 Characterization Factors Used in ReCipe2016 Method (Huijregts et al., 2017). (cont'd)

Impact Category	**Indicator**	**Unit**	**CFm**	**Unit**
Human toxicity: cancer	Risk increase of cancer disease incidence	-	Human toxicity potential	kg 1,4- DCB to urban air
Human toxicity: non-cancer	Risk increase of non- cancer disease incidence	-	Human toxicity potential	kg 1,4- DCB to urban air
Terrestrial ecotoxicity	Hazard- weighted increase in natural soils	yr x m2	Terrestrial ecotoxicity potential	kg 1,4- DCB to industrial soil
Freshwater ecotoxicity	Hazard- weighted increase in fresh waters	yr x m3	Freshwater ecotoxicity potential	kg 1,4- DCB to fresh water
Marine ecotoxicity	Hazard- weighted increase in marine waters	yr x m3	Marine ecotoxicity potential	kg 1,4- DCB to marine water
Land use	Occupation and time- integrated transformation	yr x m2	Agricultural land occupation potential	m2 x yr annual cropland

Table 2.3 Characterization Factors Used in ReCipe2016 Method (Huijregts et al., 2017). (cont’d)

Impact Category	**Indicator**	**Unit**	**CFm**	**Unit**
Water use	Increase in water consumed	m3	Water consumption potential	m3 water consumed
Mineral resource scarcity	Ore grade decrease	kg	Surplus ore potential	kg Cu
Fossil resource scarcity	Upper heating value	MJ	Fossil fuel potential	kg oil

2.1.3.2 IMPACT World+ Method

The IMPACT World+ framework is a comprehensive approach to LCIA that is implemented on a global scale. It incorporates several advanced advancements and considers damages in the water and carbon sectors, resulting in a unified LCIA framework. The methodology is founded around a midpoint damage paradigm that incorporates four distinct complementing viewpoints (Bulle et al., 2019). These perspectives are utilized to provide a comprehensive LCIA profile:

- the effects of the midway,
- the impacts of destruction,
- the adverse effects on human health, the condition of ecosystems, resources, and the provision of ecosystem services within protected areas,
- the degradation of water and carbon ecosystems (Bulle et al., 2019).

Figure 2.3 presents four coherent and mutually reinforcing perspectives for articulating a profile of life cycle impact evaluation.

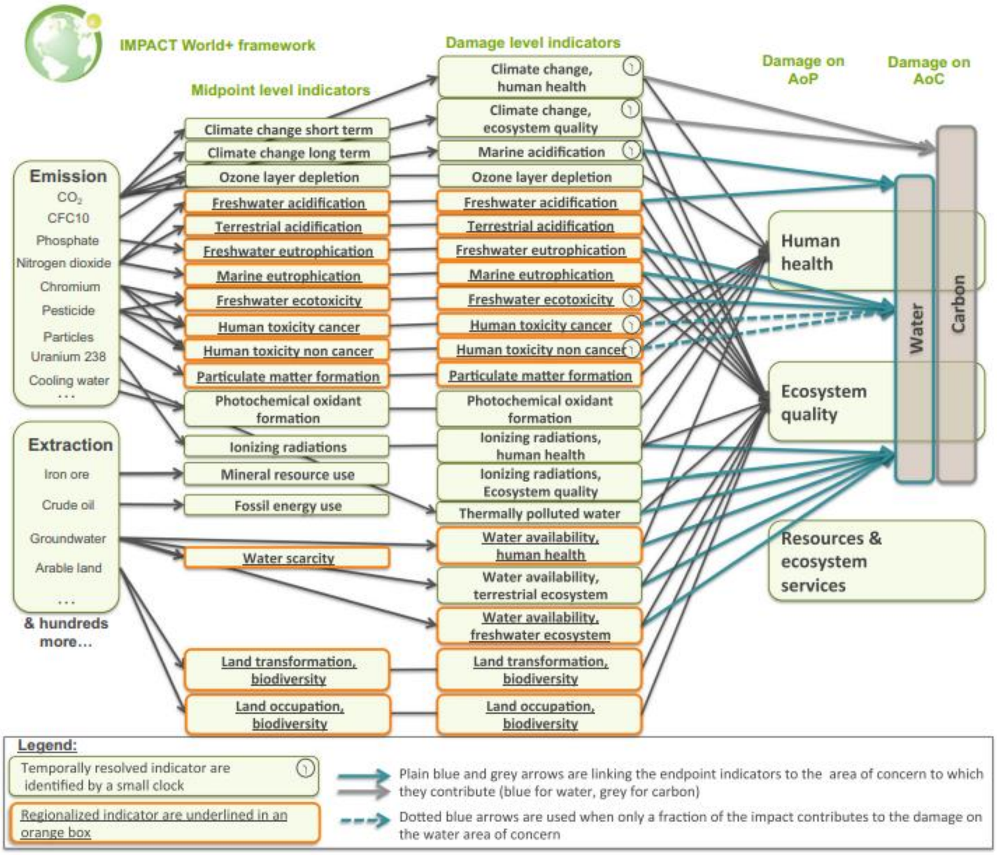


Figure 2.3 Overview of the IMPACT World+ impact categories (Bulle et al., 2019).

The endpoint outcomes encompass the ultimate effects on human health or the environment, considering all the intermediate stages in the causal pathway. As an illustration, a potential outcome for the impact category "climate change" could involve quantifying the rise in world temperature resulting from the emissions of greenhouse gases attributable to the product during its life cycle. Midpoint results serve to assess the environmental consequences at a certain juncture within the causal chain connecting the emissions or extractions stemming from a product and the ultimate ramifications on human health or the environment. For instance, a preliminary outcome pertaining to the impact category of "climate change" could involve quantifying the quantity of greenhouse gases released by the product across its whole life cycle (Bulle et al., 2019).

Both the midway and endpoint outcomes have utility for practitioners of LCA. The utilization of midpoint data facilitates the identification of hotspots within the life cycle of a product, whereas endpoint results enable the comparison of the comprehensive environmental impact among various products (Bulle et al., 2019).

2.2 Integrated Pollution Prevention and Control (IPPC) & BREF Documents

EU regularly monitors and develops environmental norms to reduce air, water, and land emissions with experts from member states, industry, NGOs and commission services. This approach, known internationally as the Seville Process, also enables legislative consensus for the most significant environmental impact sectors. The Joint Research Centre established in Seville for this purpose has been coordinated for years by the European Integrated Pollution Prevention and Control Bureau (EIPPCB). In the process, the decision-making mechanism has been based on scientific and techno-economic knowledge and data, with the participation of all relevant stakeholders (IPPC Bureau, 2022). The European Commission revises the existing norms after a detailed review of all data on the use of state-of-the-art processes and technologies for each sector in this process, which supports the efficient implementation of the IED across the EU (European IPPC Bureau, 2010).

The existing and revised norms define BAT, which refers to techniques that are best for avoiding or minimizing emissions and environmental impacts. In other words, BREFs represent the results of the Seville process. At the end of the process, which involves stakeholders and factual data from the relevant sector, sectoral BREFs are approved by the European Commission and then become environmental legislation by the Member States (European Union, 2022).

The first BREFs were established under Directive 96/1/EC and later repealed by the IED 2010/75/EU. This directive serves as a reference for setting emission limits and issuing operating permits for large industrial installations (European IPPC Bureau, 2010).

Industrial production processes account for a significant share of overall pollution in Europe, with consequences such as emissions of air pollutants, wastewater discharges and waste generation. To manage and improve the process, the EU adopted the IED in 2010. The IED targets preserving the environment and human health by reducing industrial emissions across the EU (European Union, 2022).

The emission limit values guided by the IED are based on BAT, which integrally assesses issues such as minimizing emissions to air, water and land, waste generation and raw material use, and energy and water efficiency (European IPPC Bureau, 2010).

The term 'BAT conclusions' refers to a document described in Article 3(12) of Directive 2010/75/EU (IED, 2010). This document comprises the sixth section of BREF documents that provide specific conclusions regarding the BATs. These conclusions encompass the description of these techniques, information necessary for evaluating their applicability, emission levels associated with BATs, related monitoring procedures, and relevant consumption levels (IED, 2010)

2.3 Solid Waste Management

According to the US Environmental Protection Agency (EPA), MSW which is generally referred to as trash or rubbish, encompasses a wide range of ordinary goods that are utilized and subsequently discarded. These items include furniture, food scraps, paint, bottles, grass clippings, batteries, newspapers, product packaging, clothing, and appliances. This phenomenon originates from various societal institutions such as, commercial enterprises, medical facilities, residential dwellings, and educational institutions.

Based on data provided by the World Bank, the global production of MSW in the year 2022 amounted to 2.01 billion metric tons. It is anticipated that the quantity will experience a rise to 3.40 billion metric tons by the year 2050. There is considerable variation in the per capita generation of MSW across different countries, with high-income nations exhibiting a substantially higher waste generation rate compared to low-income nations. In the year 2022, the mean per capita production of MSW was recorded at 0.74 kg per day. However, this value exhibited significant variation among different countries based on their income levels. Specifically, low-income countries reported an average daily generation of 0.11 kg, while high-income countries exhibited a substantially higher average of 4.54 kg per day (Kaza et al., 2018).

The MSW in Turkey predominantly comprises waste materials originating from residential and commercial sectors, industrial activities, public parks, and streets. Notably, waste segregation at the point of origin is not practiced, and instead, all rubbish is collected and deposited in a unified waste receptacle (Berkun et al., 2011).

The general processes in the solid waste management facility, and where appropriate, the methods guided by the BATs identified in the Waste Treatment BREF document are summarized below.

2.3.1 Mechanical Treatment

MBT plants refer to facilities that integrate the biological treatment of diverse waste streams and fractions (the mechanical separation of recyclable materials, biodegradable waste, waste with high calorific value, and inert waste) alongside the biodegradable fraction (Byström, 2010). The first development of MBT facilities aimed to mitigate the adverse environmental consequences associated with the disposal of residual material in landfills. MBT serves as a valuable addition to, rather than a substitute for, alternative waste management technologies like anaerobic digestion (AD) and composting within the framework of an integrated waste management system. One notable benefit of MBT is its configurability, which allows for the attainment of various objectives (DEFRA, 2013).

Mechanical treatment, which serves as the initial phase in MBT facilities employed for MSW management, involves the utilization of mechanical methods to segregate heterogeneous waste into distinct fractions. Waste fractionation facilitates the process of MBT by effectively segregating diverse components that possess distinct properties and can be utilized for various purposes. Potential applications encompass material recycling, biological treatment, energy recovery via RDF (Refuse- derived fuel) /biomass generation, and landfill. Mechanical treatment facilities integrate several methodologies and equipment to fulfill the ultimate disposal criteria for diverse categories of waste. Separation technologies exploit the diverse characteristics shown by distinct components included in waste. The attributes encompass several characteristics of objects, such as their dimensions and configuration, mass per unit volume, gravitational force exerted, susceptibility to magnetic fields, and ability to conduct electric current.

Waste Treatment BREF Document (Pinasseau et al., 2018c), published by the European Community in 2018, identifies four techniques (BATs) (cyclone, fabric filter, water injection to shredder, and wet scrubbing) that can be utilized to mitigate airborne dust emissions. These techniques are summarized in the following subsections.

2.3.1.1 Mechanical Treatment via Cyclone Separator

The cyclone separator is a technique employed to eliminate particles from a flow of air, gas, or liquid by means of vortex separation, thereby obviating the need for filtration. Cyclones are cylindrical or conical vessels that generate a high-speed rotating airflow. The airflow within the cyclone follows a helical trajectory, commencing at the wider upper end and concluding at the narrower lower end. Upon exiting the cyclone, the airflow maintains a linear path from the top, traversing through the central region of the cyclone. The particles with greater size and density in the rotational flow exhibit excessive inertia, preventing them from effectively tracing the steep descent trajectory. Consequently, these particles fail to reach the bottom of the cyclone, instead colliding with the outer wall and then descending to the cyclone's base, where they can be eliminated. In a conical system, such as a cyclone, the radius of rotation of the flow is diminished, resulting in the separation of smaller particles (Taiwo & Mokwa, 2016). Figure 2.4 indicates the working principle of the cyclone separator.

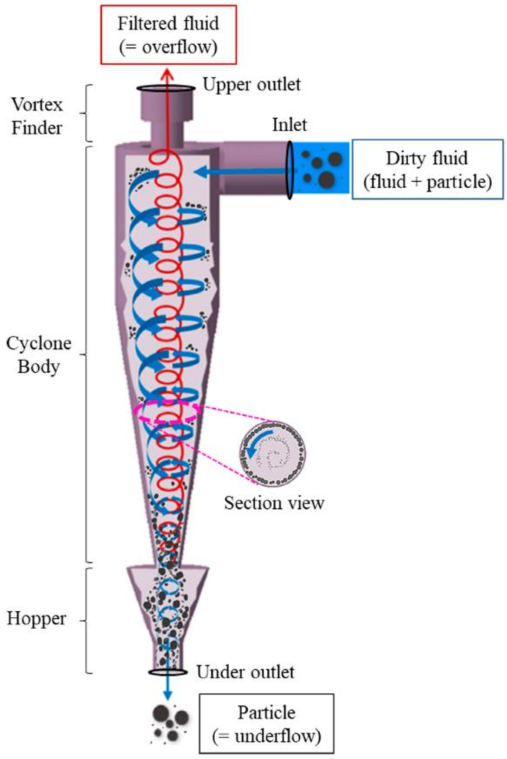


Figure 2.4 Schematic representation of cyclone separator (Kang & Kwak, 2023).

2.3.1.2 Mechanical Treatment via Fabric Filter

In the context of a fabric filter, commonly referred to as a bag filter, the gas undergoes a process whereby it traverses a densely woven or felted fabric medium. This action facilitates the accumulation of particulate matter on the fabric surface, employing a sieve or other comparable mechanisms for this purpose (Brinkmann et al., 2016). Figure 2.5 presents the mechanism of the fabric filter for dust removal. Fabric filter pieces are often grouped together in several quantities. The accumulation of dust particles on the filters dramatically increases particle collection efficiency (Brinkmann et al., 2016).

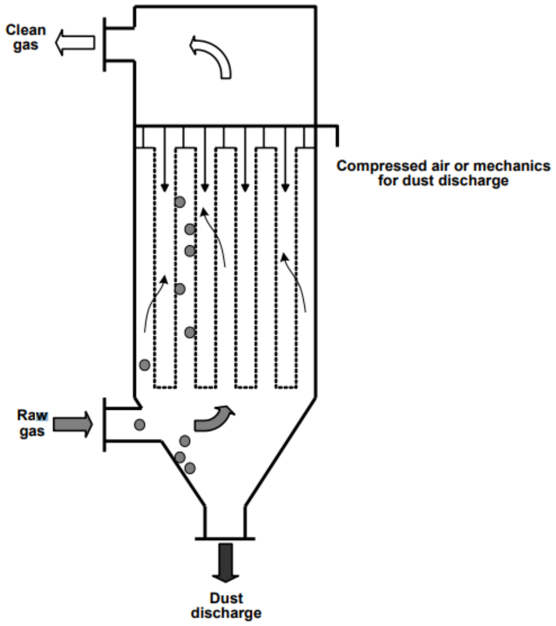


Figure 2.5 The mechanism of fabric filter for dust removal (Schenk et al., 2014).

2.3.1.3 Mechanical Treatment via Water Scrubbing

Wet scrubbing (or absorption) technique consists of the steps of intensively stirring the incoming gas with water to remove the dust and the coarse particles using centrifugal force. Wet scrubbing can be used in processes such as the treatment of pollutant gases (ammonia, H_2S, VOC etc.) and the reduction of dust emissions (Pinasseau et al., 2018a).

2.3.2 Anaerobic Digestion (AD)

The organic fraction of municipal solid waste (OFMSW) is the most valuable fraction of municipal organic waste due to its composition. The composition and volume of OFMSW are influenced by various factors, including the time of year, geographic location, population size, community income level, and garbage collection infrastructure. In low-income nations, the proportion of organic fraction in MSW is significantly higher, ranging from 50 to 70 percent. In contrast, high-income countries typically have a lower percentage of organic fraction in their MSW, ranging from 20 to 40 percent (Franca & Bassin, 2020).

There are various techniques for the management of MSW, encompassing landfilling, incineration, and biological treatment. The practice of landfilling is well acknowledged as an unfavorable approach due to its significant land resource demands and the associated environmental apprehensions (Mu et al., 2018). The energy recovery during the incineration process is observed to be negatively impacted by the presence of significant levels of moisture and organic content. The significant presence of organic matter in MSW renders biological treatment methods, particularly anaerobic digestion, ecologically advantageous. The most viable strategy suggested entails employing biological treatment for the biodegradable portions and burning for the components possessing high calorific value, with landfilling as a potential subsequent step, if practicable. Hence, AD is regarded as a viable alternative approach for the treatment of the OFMSW (Jiang et al., 2020). AD is a biological phenomenon characterized by the decomposition of organic matter in the absence of oxygen. This process results in the generation of biogas, a type of biofuel primarily consisting of methane, as well as digestate, a byproduct that can be effectively utilized as a biofertilizer (Lanko et al., 2020).

The temperature of a system is a critical factor in determining the efficacy of microbiological activities, as the metabolic activity of microorganisms is contingent upon a specific temperature range. The development of AD is influenced by a diverse population, resulting in the possibility of different temperature ranges for the process. There are two primary temperature ranges associated with AD, namely mesophilic (M) and thermophilic (T), characterized by optimal temperatures of 35°C and 55°C, respectively (Fernández-Rodríguez et al., 2013). Similarly, batch or continuous and single or two-stage systems are also available for AD.

The dry AD process has been demonstrated to possess numerous advantages compared to the wet digestion process. These advantages include a reduced requirement for water addition per unit of organic matter loaded, a smaller reactor volume, technical simplicity in design due to the plug flow movement of the substrate, the absence of mechanical devices within the reactor for mixing, and convenient handling of digested residues (Zeshan et al., 2012).

Figure 2.6 indicates the comparison between single stage and two stage AD systems. AD process typically comprises four primary steps, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis. As shown in Figure 2.6, these stages occur within a single reactor in the case of one-stage AD. The implementation of a two-stage AD system allows for the distinct functioning of the initial thermophilic stage, which involves hydrolysis and acidogenesis, and the subsequent mesophilic stage, which involves acetogenesis and methanogenesis (Cao et al., 2020). This approach is employed to address the limitations associated with single-stage AD systems.

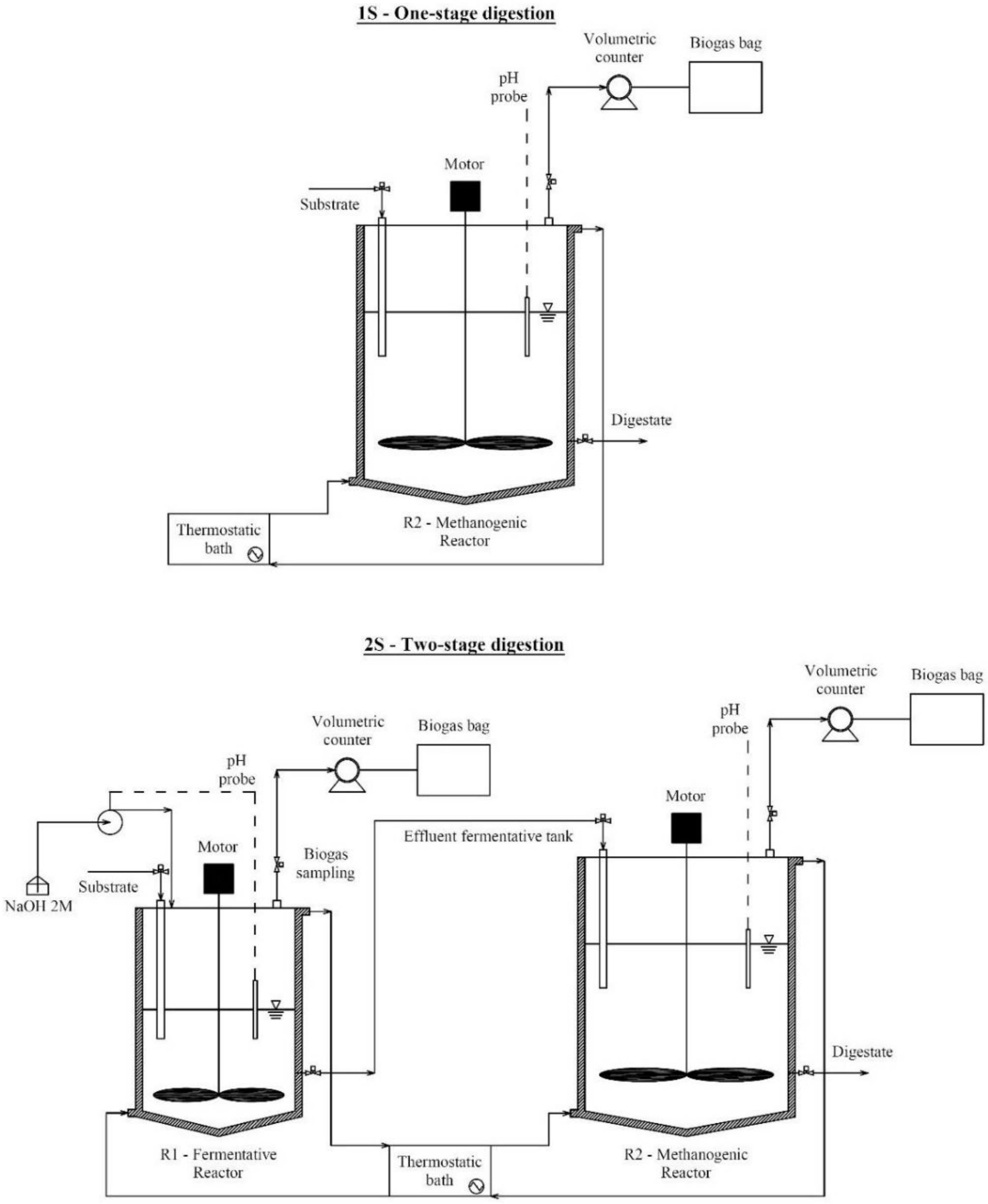


Figure 2.6 Comparison between single stage and two-stage AD (Baldi et al., 2019).

2.3.3 Landfill

Landfilling refers to the systematic and regulated process of disposing of solid waste at a designated landfill or sanitary landfill site located outside the urban core, within the specified jurisdiction of a municipality (Crawford & Smith, 2016). In accordance with the regulations established in Turkey, a sanitary landfill is legally defined as a designated location where waste materials are deposited either underground or above ground, adhering to specific technical criteria. It is important to note that this definition excludes units that temporarily store waste for the purposes of recovery, pre-treatment, or disposal within the same facility where the waste was generated. Additionally, facilities that store waste for a duration of less than three years for the purpose of recovery or pre-treatment, as well as facilities that store waste for no longer than one year for the purpose of disposal, are also exempt from this definition (Crawford & Smith, 2016).

Landfilling has historically been the conventional and economically efficient method of waste disposal adopted by numerous nations. Resource recovery technologies, such as composting, AD, pyrolysis, gasification, and liquefaction, offer potential alternatives to landfilling. However, these technologies are associated with significant upfront investment and ongoing maintenance expenses. Similarly, incineration technologies also entail substantial costs due to the requirement for sophisticated equipment and the need to maintain high temperatures (Nanda & Berruti, 2020). Landfilling is a more advantageous method compared to incineration and recycling for the management of municipal solid waste, mostly due to its lower cost and reduced labor demands. In addition, the implementation of a consolidated landfill enables the efficient utilization of landfill gas and leachate as sources of energy production.

2.3.4 Desulphurization

Biogas is primarily composed of carbon dioxide (CO_2) and methane (CH_4), with volumetric proportions ranging from 30% to 40% for CO2 and 60% to 70% for CH_4. Nevertheless, during the conversion of various organic streams into biogas through an anaerobic digester for biogas production, the activity of microorganisms might result in the generation of hydrogen sulfide (H_2S) as a byproduct, which occurs as a result of the decomposition of organic compounds containing sulfur (Okoro & Sun, 2019). The removal of impurities, such as H_2S, from biogas is necessary to safeguard

Combined Heat and Power (CHP) engines and comply with the European IED (Directive, 2010/75/EU). Biogas can be treated by both physicochemical and biological methods (Cano et al., 2018).

Waste Treatment BREF, released by the European Community in 2018, outlines five techniques (BATs) (adsorption, biofilter, fabric filter, thermal oxidation, and wet scrubbing) that can be employed to decrease the concentration of H_2S in biogas. These techniques are summarized in the following subsections.

2.3.4.1 Desulphurization via Biofiltration

Biofiltration is a gas treatment method that involves the interaction between the gas and a biofilm within a bioreactor of the fixed bed type. The effectiveness of pollutant biodegradation or bioconversion in biofiltration processes is contingent upon several crucial factors, including the selection of packing or filter bed materials, the microbial inoculum utilized, the features of the biofilm formed, and the specific operating conditions employed. The schematic representation of biofiltration for desulphurization is given in Figure 2.7.

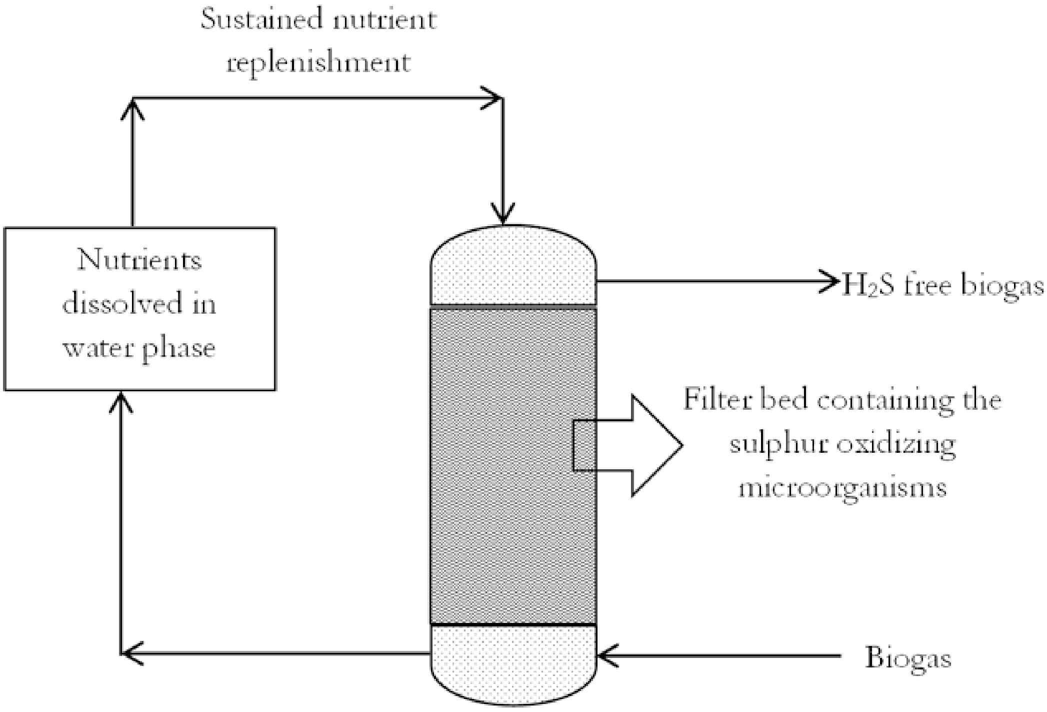


Figure 2.7 Schematic diagram of biofiltration for desulphurization (Okoro & Sun, 2019).

2.3.4.2 Desulphurization via Adsorption

The adsorption process occurs within vertical columns that are loaded with absorbents and undergo a series of steps including depressurization, desorption, and pressurization. Figure 2.8 demonstrates the scheme of adsorption process for desulphurization. Within the column under pressure, CO_2 is adsorbed while methane-rich biogas flows through. Zeolite, activated carbon, activated charcoal, silica gel, and synthetic resins are among the frequently employed adsorbents (Awe et al., 2017).

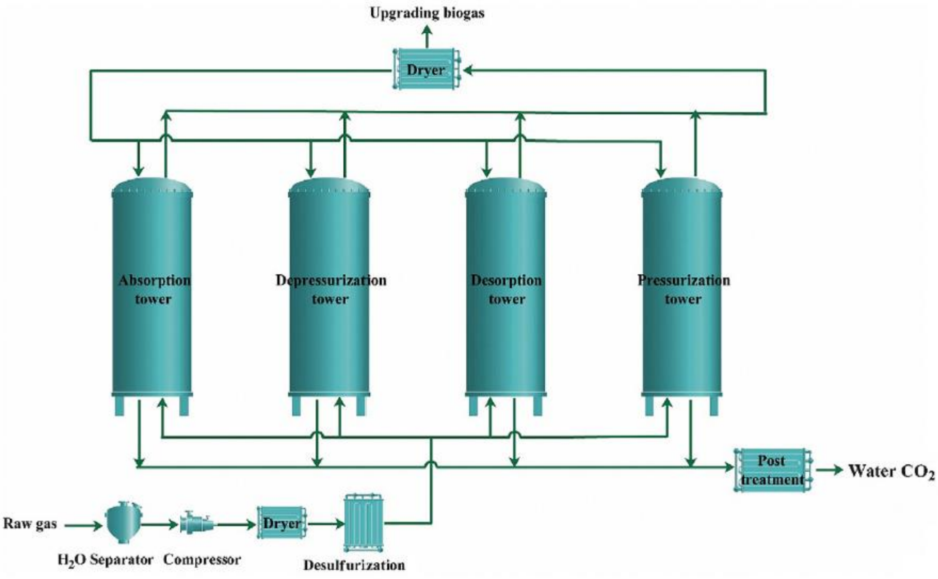


Figure 2.8 Schematic diagram of adsorption for desulphurization (Awe et al., 2017).

2.3.4.3 Desulphurization via Water Scrubbing

Water scrubbing is an absorptive method for biogas upgrading using only the inorganic solvent water. Unlike adsorption, absorption implies the dissolution of gas or vapor in a liquid (absorption agent). Water scrubbing is a typical physisorption based on the reversible absorption by physical bonding forces (Van der Waals force). Low temperatures and high pressures increase the absorption rate. The schematic demonstration of water/ wet scrubbing for desulphurization is given in Figure 2.9.

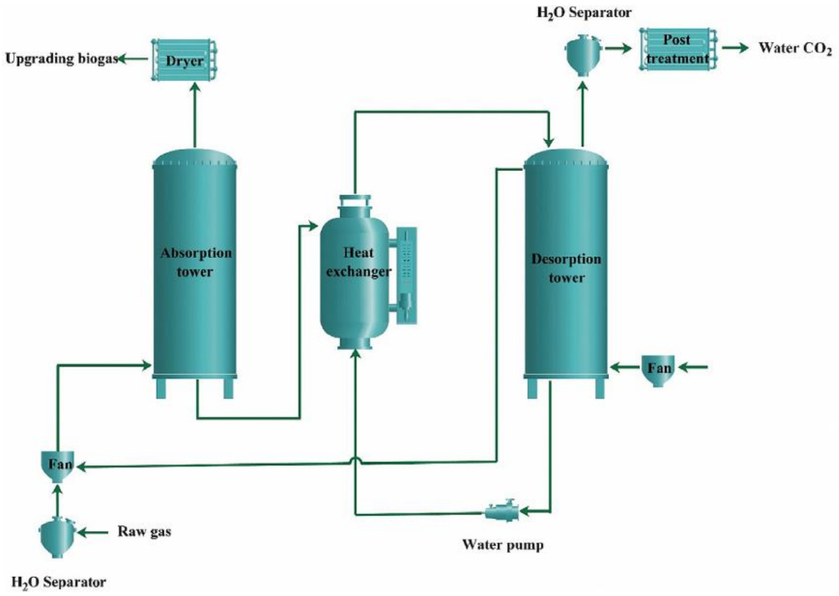


Figure 2.9 Schematic diagram of water/ wet scrubbing for desulphurization (Awe et al., 2017).

2.3.4.4 Desulphurization via Thermal Oxidation

Biogas from an AD plant rarely contains a high methane concentration. Oxidation is necessary to increase the methane concentration of this gas and to remove impurities. Alternatively, methane can be oxidized by thermal or catalytic oxidation (Bauer et al., 2013b). In other words, the variability of methane recovery is contingent upon the diverse range of applications and designs. Certain units have the potential to achieve recoveries ranging from 98% to 99%, while other units are anticipated to achieve recoveries in the range of 99% to 99.5%. The schematic demonstration of thermal oxidation for desulphurization is given in Figure 2.10. In contemporary practices, the removal of methane from the off-gas is typically achieved through either oxidation in a regenerative thermal oxidizer or use in combined heat and power plants in conjunction with raw biogas (Bauer et al., 2013a).

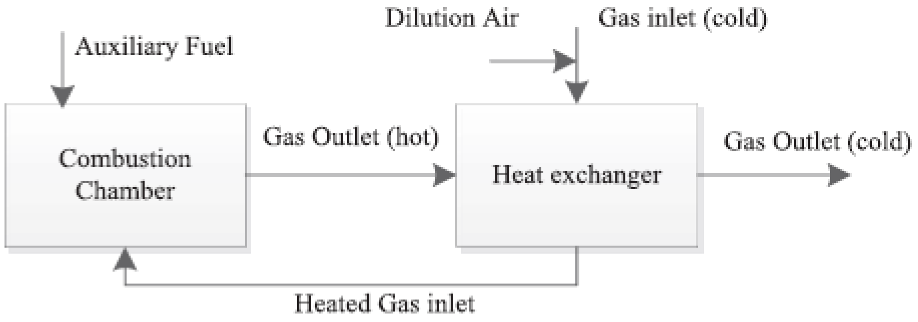


Figure 2.10 Schematic diagram of thermal oxidation for desulphurization (Tomatis et al., 2019).

2.3.4.5 Desulphurization via Fabric Filter

Particle removal gases pass through fabric filters, which are frequently called bag filters and are composed of permeable woven or felted fabric. Figure 2.11 represents the schematic diagram of the fabric filter for the desulphurization process. Fabric filtration necessitates the choice of a fabric that is appropriate for the waste gas's properties and the highest temperature (Pinasseau et al., 2018a).

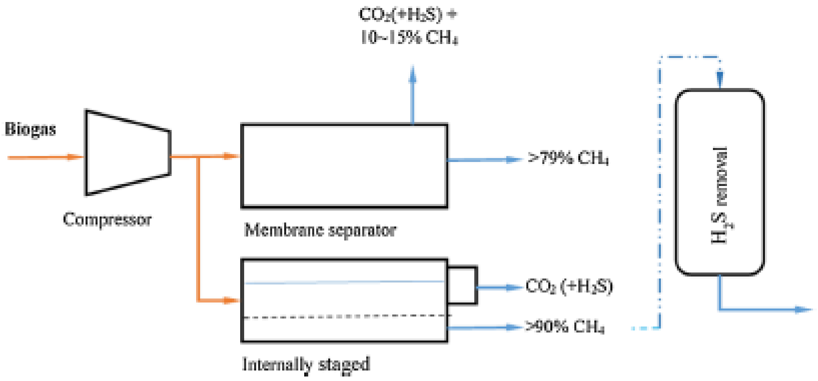


Figure 2.11 Schematic diagram of fabric filter for desulphurization (Awe et al., 2017).

2.3.5 Composting

For the processing of MSW, two major available options are thermal processing and bioprocessing (composting, biomethanization, and vermicomposting) (Kumar, 2010). The bioprocessing technique exhibits both technical feasibility and commercial viability, mostly attributed to the production of valuable byproducts. Composting is an effective method for converting organic waste into biofertilizers and soil conditioners, which may be utilized in a safe and advantageous manner. The utilization of raw and unstable organic wastes as soil supplements can give rise to several issues, which can be effectively mitigated by employing composting techniques. These issues include unpleasant odors, the presence of human pathogens, and unattractive chemical and physical characteristics (Kumar, 2010).

The process of composting facilitates the valorization of waste materials by reducing their size and volume, resulting in the production of a useful end-product known as compost. This compost can be utilized as a fertilizer or soil additive. Composting is a widely utilized technological process for the management of MSW, and it is also employed for the treatment of residual materials generated by industrial activities. The composting process is primarily categorized into two distinct phases, namely breakdown and curing. Cadena et al. (2009) state that composting on composting in confined windrows (CCW) and composting tunnels (CT) are two different methods used in industrial composting.

The schematic representation of CCW is given in Figure 2.12 . In the CCW principle, it is common practice to occasionally mix or turn the composting materials to evenly distribute moisture and ensure uniform distribution of oxygen. During this procedure, a range of equipment including front loaders, augers, and specialized turning machines are utilized as turner machines (Michel et al., 2022). The process of CCW involves a controlled decomposition phase in enclosed windrows with regulated aeration and watering for a duration of 4 weeks. This is then followed by a subsequent treatment phase in which the windrows are rotated (curing phase) for a period of 6-8 weeks (Cadena et al., 2009).

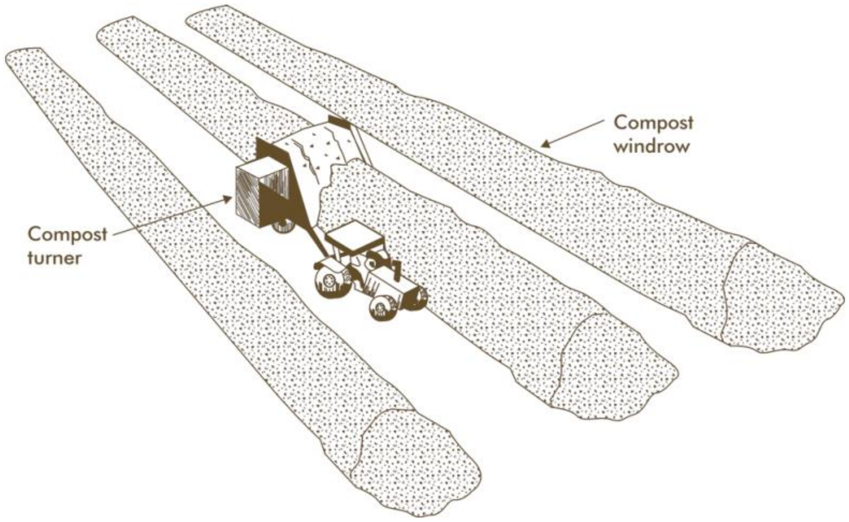


Figure 2.12 Schematic representation of a composting in confined windrows (Government of Alberta, 2019).

The process of CT involves the implementation of regulated aeration and watering conditions over a period of two weeks. The curing step occurs within aerated piles over a period of 6-8 weeks. The gaseous emissions originating from the pre-treatment area, specifically the trommel screen and mixing processes, as well as the composting tunnels, undergo treatment in a wet scrubber system, which is subsequently followed by a biofilter. Figure 2.13 shows the typical schematic representation of CT.

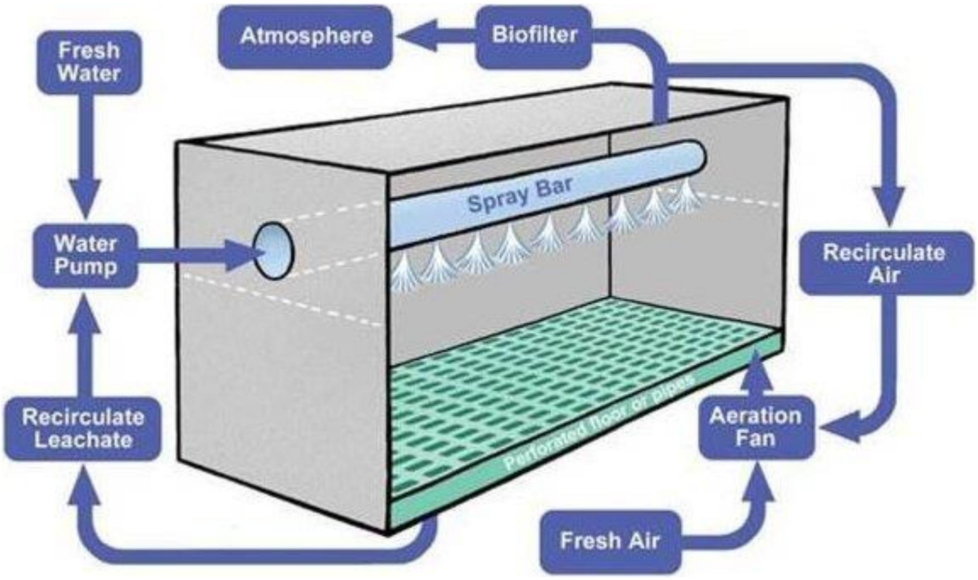


Figure 2.13 Typical schematic representation of a composting tunnel (Koutsoumanis et al., 2020).

2.4 Literature Studies on Solid Waste Management Using LCA

Table 2.4 presents the summary of the solid waste management studies employing LCA as a tool. As seen from this table, there are a few numbers of relevant studies in the Literature, conducted with different scopes, different FUs, different impact assessment methods and different software. Accordingly, the findings reported are not directly comparable and conclusive. Further, none of these evaluate the relevant alternative BATs guided by the Waste Treatment BREF document as a whole for a given specific facility.

Table 2.4 Summary of Literature Studies

Title	Authors	Objective and Scope	Software	Findings
Biogas-to-biomethane upgrading: A comparative review and assessment in a life cycle perspective	Ardolino et al. (2020)	This study examines and contrasts the predominant methodologies employed for producing high-quality biomethane through the enhancement of biogas derived from the anaerobic digestion process applied to the organic component of municipal solid waste. The environmental and economic dimensions of membrane separation, water scrubbing, chemical absorption using amine solvent, and pressure swing adsorption have been quantified from a life cycle perspective. 500 m3N/h of raw biogas was defined as FU and IMPACT 2002+ was selected as impact methodology.	GaBi	LCA was utilized to assess the effectiveness of each of the chosen remediation methods (membrane separation, water injection, absorption with amine solvent, and pressure swing adsorption) in addition to the provision of cost analyses. LCA and LCC (Life Cycle Costing) results indicate that membrane separation provides the highest level of performance.

Table 2.4 Summary of Literature Studies (cont'd)

Title	Authors	Objective and Scope	Software	Findings
Steps towards more environmentally sustainable municipal solid waste management – A life cycle assessment study of São Paulo, Brazil	Liikanen et al. (2018)	This study uses LCA methodology to evaluate the environmental impacts associated with various management options for MSW in São Paulo. The objective is to identify a trajectory that leads to enhanced environmental sustainability in the management of MSW within the city. The FU of this study is one year of treatment for formally collected mixed MSW in So Paulo. System boundary embodies from collection to final disposal. Lastly, CML 2001 was chosen as the impact assessment method.	GaBi	While landfill disposal has been the primary way of managing MSW in the city of São Paulo thus far, the environmental consequences necessitate a steady decrease in the reliance on landfills. The findings indicate that, among the suggested treatment options, the most efficient approach for mitigating the environmental consequences of MSW management in São Paulo is the combination of anaerobic digestion of source-separated organic waste and MBT of MSW. This is contingent upon utilizing the resulting RDF in cement production as a substitute for coal.

Table 2.4 Summary of Literature Studies (cont’d)

Title	Authors	Objective and Scope	Software	Findings
Environmental Impact Assessment of Food Waste Management Using Two Composting Techniques	Al-Rumaihi et al. (2020)	This study employed LCA to assess and contrast the environmental repercussions linked to two composting methods, windrow composting and the hybrid AD method utilized for the treatment of food refuse. In accordance with the findings of this case study in the State of Qatar, anaerobic digestion combined with composting imposes a reduced environmental impact when compared to windrow composting, using 1 ton of food waste as the FU. CML 2001 was applied as an impact assessment method.	SimaPro	The AD plus composting technique often offers greater environmental benefits compared to windrow composting across various categories, particularly in relation to global warming potential (GWP). The outcomes of a sensitivity analysis conducted in an LCA hold significance as they facilitate the identification of characteristics that have the potential to significantly influence the outcome. These parameters may necessitate further investigation to ensure a comprehensive understanding of their impact.

Table 2.4 Summary of Literature Studies (cont'd)

Title	Authors	Objective and Scope	Software	Findings
Comparative study of municipal solid waste treatment technologies using life cycle assessment method	Zaman AU (2010)	The scope of this study is to carry out a LCA of three distinct waste remediation technologies. The technologies of sanitary landfill, incineration, and gasification-pyrolysis for waste remediation are investigated. In this study, kg/ ton generated municipal solid waste was determined as FU, and CML2001 was selected as the impact assessment method.	SimaPro	One of the emerging technologies identified by pyrolysis-gasification has been discovered to have a reduced environmental impact compared to incineration. Energy-generating sanitary landfills have the least detrimental impact on the environment of the three waste treatment technologies.
Life cycle assessment of four municipal solid waste management scenarios in China	Hong et al. (2010)	LCA was utilized to determine the environmental impact of MSW management scenarios. To evaluate the environmental impact of various technologies, four scenarios were contrasted, the majority of which were implemented in China: (1) landfilling, (2) incineration, (3) landfilling plus composting, and (4) incineration plus composting.	SimaPro	• The impact resulting from HHGW and HNCT impact categories predominates in every scenario. • The primary sources of emissions resulting from land application, incineration, and landfill operations were the main parameters of GWHH and HNCT.

CHAPTER 3

METHODOLOGY

3.1 Study Approach

This study desires to evaluate the BATs described in the Waste Treatment BREF for improving the waste treatment performance of an integrated solid waste separation, processing and retrofitting plant using an LCA approach.

To this end, firstly, an integrated solid waste management plant located in Turkey was selected as a pilot study plant (i.e. Study Plant). This plant involves the waste processing units of mechanical treatment, AD, landfill, and desulphurization (Figure 3.1), with a total capacity of 3200 tons per year. As seen in Figure 3.1, the collected municipal solid waste entering the plant is subjected to mechanical sorting. The recyclable inorganic wastes are sent to the recycling facility located outside the boundary of the plant. The organic non-recyclable waste is digested anaerobically while the inorganic fraction is sent to the landfilling unit. Produced biogas from AD and landfill is turned into electricity and heat after removing its impurities (particularly H_2S) in the desulphurization unit.

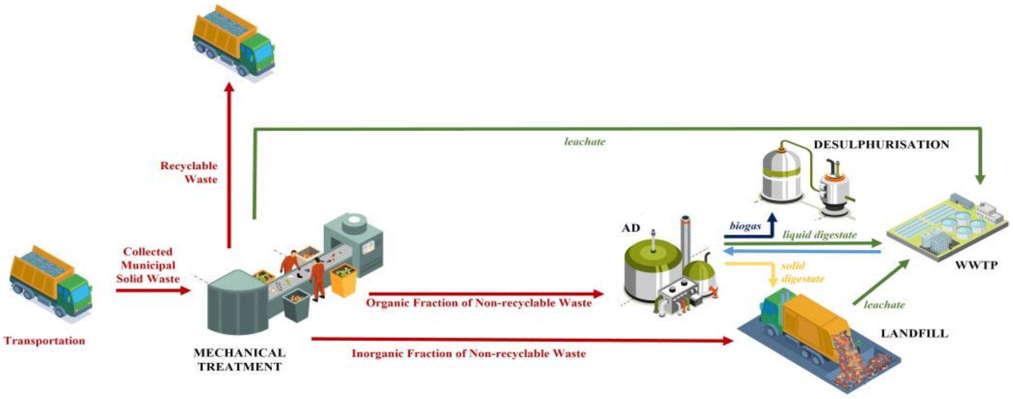


Figure 3.1 The study plant diagram.

Then, the BATs that could be applicable to this plant were identified from the Waste Treatment BREF as BATs 25 and 34 (Table 3.1).

Table 3.1 BATs Identified for the Study Plant

BAT No	BAT	Relevant process unit in the study plant
25	In order to reduce emissions to air of dust, and of particulate-bound metals, PCDD/F and dioxin-like PCBs, BAT is to apply BAT 14d and use one or a combination of the techniques given below: a. Cyclone b. Fabric filter c. Wet scrubbing d. Water injection into the shredder	Mechanical treatment
34	In order to reduce channelled emissions to air of dust, organic compounds and odorous compounds, including H_2S and NH_3, BAT is to use one or a combination of the techniques given below: a. Adsorption b. Biofilter c. Fabric filter d. Thermal oxidation e. Wet scrubbing	Desulphurization

Following these, the effectiveness of these BATs was evaluated using the LCA approach in comparison to the current situation in the Study Plant, through various scenarios formed. The scenarios considered are presented in Sec 3.2.1.

During the study, the following LCA phases were adopted: goal and scope definition, inventory analysis, impact assessment, and interpretation. Simapro 9.3.0.3 Analyst software was used.

3.2 Goal and Scope Definition

This study aims to evaluate the BATs described in the Waste Treatment BREF for improving waste treatment performance of the selected closed integrated solid waste separation, processing, and retrofitting plant. The system boundary was selected as gate-to-gate (from sorting facility to final disposal) (Figure 3.2), in principle. However, for some unit components drawn from the database available in the Simapro (for example, for the electricity and tap water), a cradle-to-gate boundary was an inevitable concern. Nevertheless, it was thought that it would not be a problem since the evaluations were made on a comparison basis with the current situation in the Study Plant. In other words, these units drawn from the database were all the same for the scenarios studied.

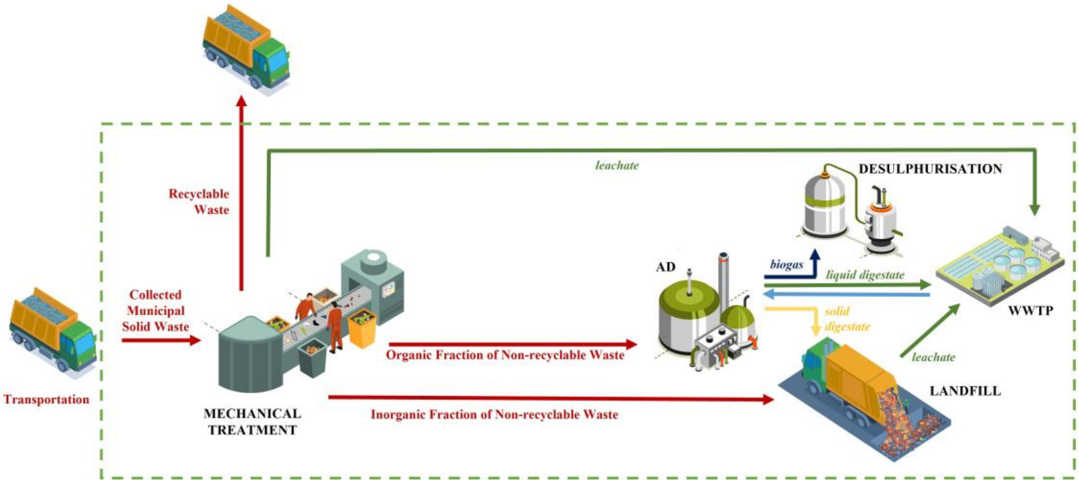


Figure 3.2 System boundary.

The FU of the study is described as 1 ton of municipal solid waste to be processed.

3.2.1 Scenarios

Scenarios including AD, landfill and composting units were identified and compared to manage the waste and identify the alternative with the lowest environmental impact.

In addition, different scenarios were identified to measure the environmental impacts of BAT25 for mechanical sorting and BAT34 for desulphurization, which are the best available techniques guided by the Waste Treatment BREF document. Scenarios and related processes are tabulated in Table 3.2.

Table 3.2 Developed Scenarios

Scenario No	Processes	Relevant BAT No*	The intended aim is to assess
Scenario 1 (baseline)	Mechanical treatment + AD + desulphurization (biofilter) + landfill	BAT 34.b	Existing situation. Also, the effect of using biofilter for desulphurization
Scenario 2.a	Mechanical treatment + AD + desulphurization (biofilter) + landfill + composting	- (good practice- BREF)	Effect of composting of the solid digestate of AD
Scenario 2.b	Mechanical treatment + AD + desulphurization (biofilter) + landfill + composting (with recirculated water)	- (good practice- BREF)	Effect of water recirculation in composting of solid digestate
Scenario 3.a	Mechanical treatment + AD + desulphurization (wet scrubbing) + landfill	BAT 34.e	Effect of using wet scrubber for desulphurization
Scenario 3.b	Mechanical treatment + AD + desulphurization (fabric filter) + landfill	BAT 34.c	Effect of using fabric filter for desulphurization

Table 3.2 Developed Scenarios (cont'd)

Scenario No	Processes	Relevant BAT No*	The intended aim is to assess
Scenario 3.c	Mechanical treatment + AD + desulphurization (thermal oxidation) + landfill	BAT 34.d	Effect of using thermal oxidation for desulphurization
Scenario 3.d	Mechanical treatment + AD + desulphurization (adsorption) + landfill	BAT 34.a	Effect of using adsorption for desulphurization
Scenario 4.a	Mechanical treatment (with cyclone separator) + AD + desulphurization (biofilter) + landfill	BAT 25.a (and BAT 34.b)	Effect of using a cyclone in mechanical treatment when biofilter is used for desulphurization
Scenario 4.b	Mechanical treatment (with fabric filter) + AD + desulphurization (biofilter) + landfill	BAT 25.b (and BAT 34.b)	Effect of using fabric filter in mechanical treatment when biofilter is used for desulphurization
Scenario 4.c	Mechanical treatment (with wet scrubbing) + AD + desulphurization (biofilter) + landfill	BAT 25c (and BAT 34.b)	Effect of using wet scrubber in mechanical treatment when biofilter is used for desulphurization

** As given in BAT Conclusions of Waste Treatment BREF (Pinasseau et al., 2018d)*

Descriptions of the scenarios are provided below:

Scenario 1 represents the current situation in the plant and includes mechanical treatment, AD, desulphurization, and landfill. The system boundary of this scenario is given in Figure 3.3. As shown in Figure 3.2, organic waste with 45% moisture content after mechanical treatment is sent to AD at first. As the outputs of the AD system, biogas, liquid and solid digestate are transferred to desulphurization, WWTP and landfill, respectively. Half of the liquid digester is recirculated into the AD system following treatment.

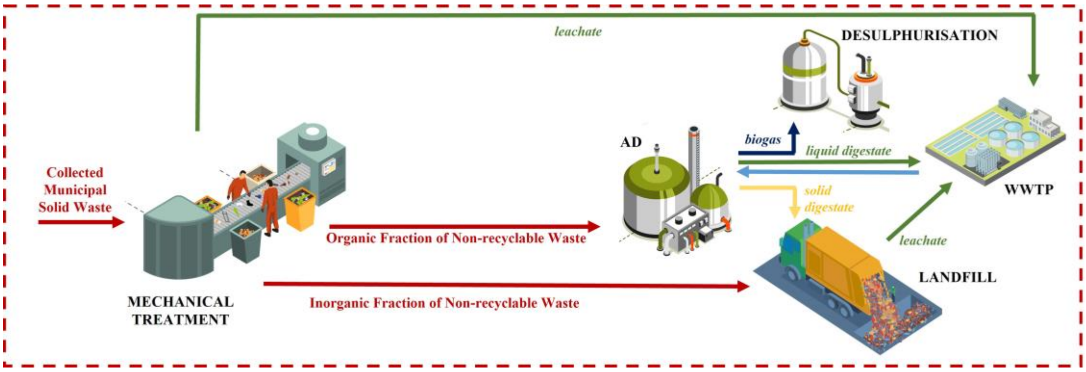


Figure 3.3 System boundary of Scenario 1.

Scenario 2 includes a combination of AD, compost, and landfill. The system boundaries of Scenarios 2.a and 2.b are shown in Figure 3.4. In this scenario, unlike the first scenario, solid digestate from the AD is sent to the composting unit rather than to the landfill. This scenario consists of two sub-scenarios: (I) Scenario 2a (Figure 3.4.a) and (ii) Scenario 2b (Figure 3.4.b). These scenarios are nearly identical; the difference between them is that a part of the treated effluent of WWTP where liquid digestate of AD and leachate of landfill and composting units are treated, is used for the water requirement of the composting unit in Scenario 2b.

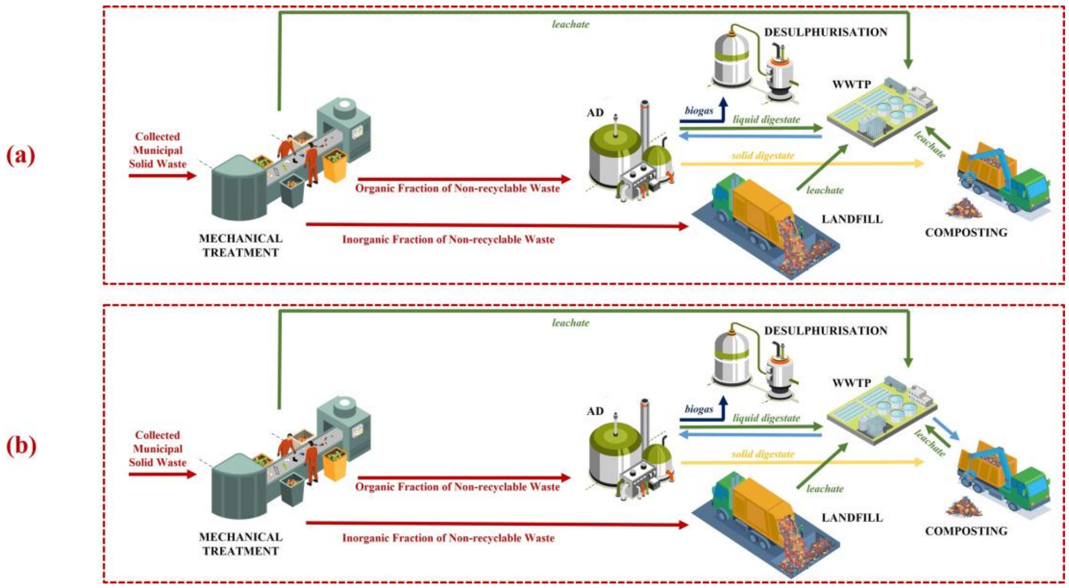


Figure 3.4 System boundary of a) Scenario 2a and b) Scenario 2b.

Scenario 3 is composed of four components. This scenario is based on the desulphurization techniques guided in BAT 34 of the Waste Treatment BREF. BAT 34 recommends using one or more of the techniques that are proposed to reduce the emissions of organic or odorous compounds, including H_2S and NH_3, to air. A biofilter is currently used at the plant (Scenario 1). In the subcomponents of Scenario 3, namely, 3a, 3b, 3c, and 3d), wet scrubbing, fabric filter, thermal oxidation and adsorption alternatives were evaluated, respectively. The system boundaries of Scenarios 3.a, 3.b, 3.c and 3.d are shown in

Figure 3.5.

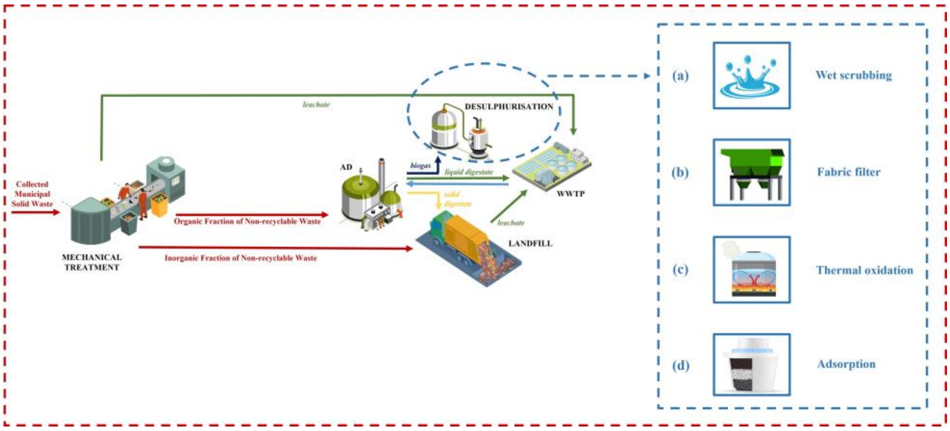


Figure 3.5 System boundary of a) Scenario 3a, b) Scenario 3b, c) Scenario 3c, d) Scenario 3d.

Similarly, Scenario 4 is related to the evaluation of BAT 25, which includes applying one or more of the proposed techniques to reduce airborne dust emissions. The techniques covered by the relevant BAT, namely, cyclone separator, fabric filter and wet brushing, constitute Scenario 4a, 4.b and 4.c sub-sections of Scenario 4, respectively. In fact, BAT 25 also proposes the injection of water into the shredder as an alternative to those mentioned above. However, it is stated that this technique is only feasible within the limitations imposed by regional circumstances (such as low temperatures and drought). Since the region where the studied facility is located does not meet the specified conditions, it was excluded from this technical study. The system boundaries of Scenarios 4.a, 4.b and 4.c are shown in Figure 3.6.

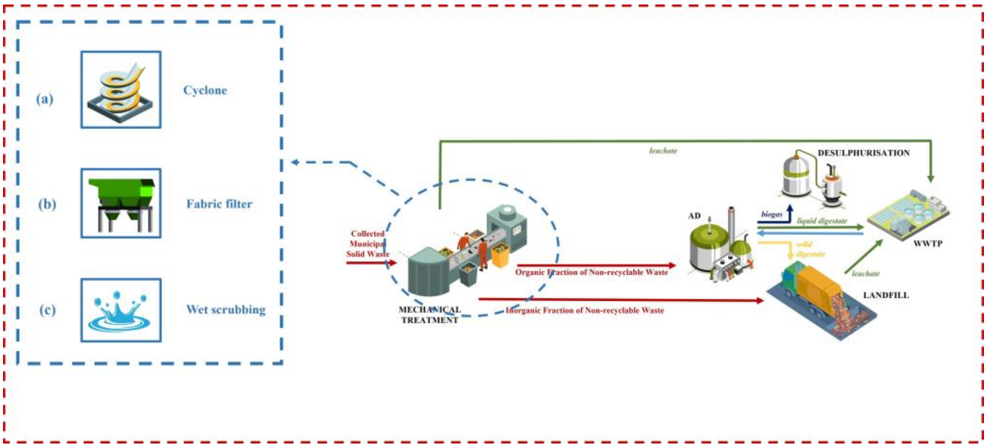


Figure 3.6 System boundary of a) Scenario 4a, b) 4b, c) Scenario 4c.

3.3 Life Cycle Inventory

3.3.1 Gathering of Data

Some LCI data were available in specifications, EIA report of the study plant, articles, and related studies. Other data on LCI steps were taken from the Study Plant. The sources of data used in this study are given in Table 3.3. The sources used are divided into three: (i) the plant, (ii) the EIA report of the study plant and (iii) literature represented based on the processes of the plant.

Some parameters, such as electricity, are modeled with the data defined for Turkey in the databases included in the Simapro software. Due to the lack of LCI data suitable for Turkey conditions, other globally authorized data were used for parameters such as heat, tap water and wastewater.

Table 3.3 Sources of Data Used

	Study Plant	EIA Report of the Study Plant	Literature
AD	✓ The amount of organic waste ✓ The amount of biogas ✓ The impurities of biogas	✓ The amount of solid digestate ✓ The amount of liquid digestate	✓ Electricity consumption (*Monson et al., 2007; Jungbluth et al., 2007)* ✓ Heat consumption (*Monson et al., 2007; Jungbluth et al., 2007)* ✓ Water demand (*Beneroso et al., 2014; Fernández-Rodríguez et al., 2013; Zeshan et al., 2012; Sajeena Beevi et al., 2015)* ✓ Calorific value of biogas (*Franz et. al., 2009)* ✓ Emissions to air *(Zaman et. al., 2010)*
Landfill	✓ Total amount of waste sent to the landfill ✓ The amount of biogas	✓ The amount of produced leachate	✓ Electricity consumption (*Hong et al., 2010)* ✓ Heat consumption (*Franz et al., 2009)* ✓ Diesel consumption (*Larsen et al., 2009)* ✓ Emissions to air *(Sivakumar et al., 2014; Mboowa et al., 2017; Samadder et al., 2017)* ✓ Emissions to soil

Table 3.3 Sources of Data Used (cont'd)

Study Plant	**EIA Report of the Study Plant**	**Literature**	**Study Plant**
Mechanical treatment	✓ Total amount of municipal solid waste entering the facility ✓ The amount of recyclable plastic ✓ The amount of recyclable glass ✓ The amount of recyclable mixed paper and cardboard ✓ The amount of organic waste ✓ The amount of non-recyclable inorganic waste	✓ The amount of produced leachate	✓ Electricity consumption of cyclone (*Chen & Wang, 2001)* ✓ Electricity consumption of fabric filter *(Xia et al., 2022)* ✓ Electricity consumption of wet scrubbing *(Hu et al., 2021)* ✓ Emissions to air (*Wei & Xin; 2015)*

Table 3.3 Sources of Data Used (cont’d)

Study Plant	EIA Report of the Study Plant	Literature	Study Plant
Composting	-	✓ The amount of solid digestate ✓ The amount of liquid digestate	✓ Electricity consumption *(Cadena et al., 2009)* ✓ Water demand *(Cadena et al., 2009)* ✓ The amount of produced fertilizer per feedstock *(van Haaren et al., 2010)* ✓ Diesel consumption *(Andersen et al., 2010)* ✓ Emissions to air *(World Resources Institute et al., 2019; Martínez-Blanco et al., 2010; Ng et al., 2021; Richard et al., 2021)* ✓ Emissions to soil *(Official Gazette, 2018)*
Desulphurization	✓ The amount of biogas sent to desulphurization ✓ The input/ output concentration of H_2S	-	✓ Electricity consumption of biofilter (*Cano et al., 2018)* ✓ Electricity consumption of wet scrubbing *(Alén, 2022; Beil & Beyrich, 2013)* ✓ Electricity consumption of fabric filter (*Huertas et al., 2020)* ✓ Electricity consumption of thermal oxidation *(Dong et al., n.d; Shah et al., 2017)*

3.3.2 Life Cycle Inventory for Anaerobic Digestion (AD)

In a single-stage dry thermophilic anaerobic digester with a volume of 4800 m^3, biogas, solid and liquid digestate are obtained from the biodegradation of organic wastes in an oxygen-free environment. As seen in the mass balance scheme of the anaerobic digestion process (Figure 3.7 and Figure 3.8), organic waste, electricity, water, and heat are primary inputs. Conversely, biogas, liquid, and solid digestate are the main outputs. The heat and electricity produced from the biogas generated are used to heat the digester, so they are classified as avoided products in the system. The data on the amount of organic waste fed to the system, the amount of biogas collected, the amount of liquid and solid digestate produced, and the impurities of the biogas were supplied from the Study Plant as presented in Table 3.3. The biogas that has been gathered consists mainly of methane, carbon dioxide, and hydrogen sulfide gases. These gases have added to the emissions to the air section of the system.

Depending on the scenarios considered, the inventory for the AD system showed some variation in terms of the fate of solid and liquid digestates. In contrast to the remaining scenarios, the solid waste is subjected to a process of composting in Scenarios 2.a and 2.b.

Consequently, considering all the circumstances, two distinct AD systems were implemented. In opposition to AD System 1, AD System 2 also meets the water demand for composting by utilizing the WWTP output. In this case, the quantity of tap water utilized as a substitute product in the second AD system surpasses that of the first AD system.

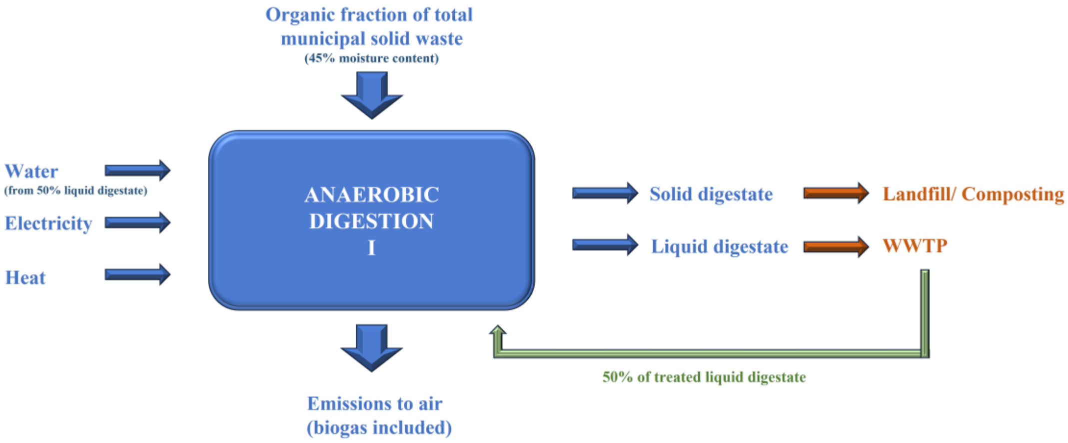


Figure 3.7 Mass balance of AD System 1 (for Scenarios 1, 3 and 4).

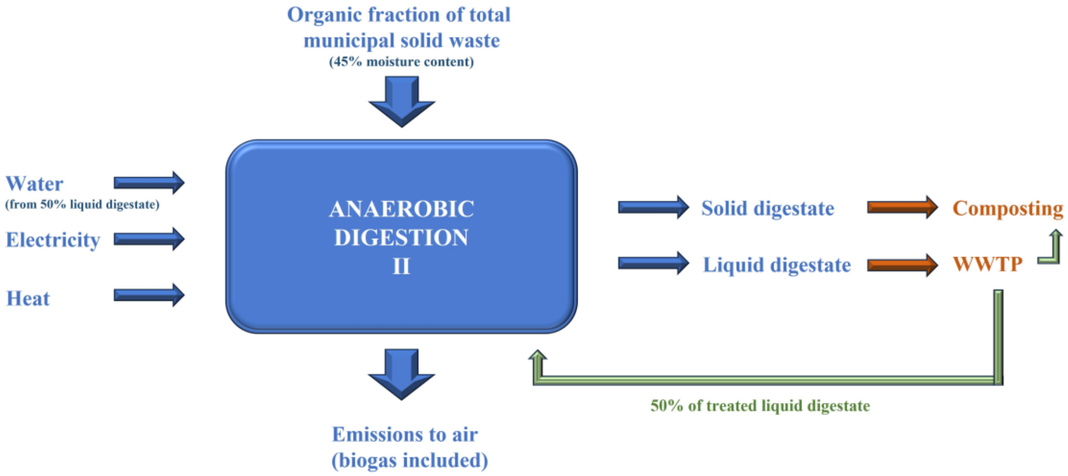


Figure 3.8 Mass balance of AD System 2 (for Scenario 2).

The inputs and outputs for both AD systems are presented in Table 3.4.

Table 3.4 The Inputs and Outputs of AD Systems (for 1 ton of municipal solid waste)

	AD System 1	**AD System 2**	**Source**
Inputs			
Electricity	46 kWh	46 kWh	*Monson et al. (2007); Jungbluth et al. (2007)*
Heat	460.8 MJ	460.8 MJ	*Monson et al. (2007); Jungbluth et al. (2007)*
Tap water [a]	1.57 ton	1.57 ton	*Beneroso et al. (2014); Fernández-Rodríguez et al. (2013); Zeshan et al. (2012);* *Sajeena Beevi et al. (2015)*
Outputs			
Wastewater	0.36 ton	0.36 ton	*From the study plant*
Digester sludge	0.28 ton	0.28 ton	*From the study plant*
Outputs (Avoided products)			
Electricity [b]	270 kWh	270 kWh	*Franz et. Al. (2009)*
Heat [b]	1001.25 MJ	1001.25 MJ	
Tap water [a]	0.18 ton	0.20 ton	*From the study plant*
Emissions to air			
Nitrogen oxides	0.004383 kg	0.004383 kg	*Zaman (2010)*
Sulfur oxide	6.92E-05 kg	6.92E-05 kg	
Hydrogen chloride	4.69E-07 kg	4.69E-07 kg	
Hydrogen fluoride	1.61E-07 kg	1.61E-07 kg	

Table 3.4 The Inputs and Outputs of AD Systems (for 1 ton of municipal solid waste) (cont'd)

	AD System 1	**AD System 2**	**Source**
Cadmium	2.32E-09 kg	2.32E-09 kg	*Zaman (2010)*
Nickel	7E-09 kg	7E-09 kg	
Arsenic	1.16E-08 kg	1.16E-08 kg	
Mercury	1.39E-08 kg	1.39E-08 kg	
Carbon dioxide	198 kg	198 kg	*From the study plant*
Methane	144 kg	144 kg	
Hydrogen sulphide	0.0041 kg	0.0041 kg	

(a) This data was calculated in line with the information obtained from the sources given in the reference column. This calculation is given in detail in the following section of the chapter.

(b) This data was obtained by multiplying the amount of biogas by the coefficient obtained from the sources given in the reference column.

The heat, water, and electrical demands of the system were determined using data sourced from the literature on the subject. The calculations were conducted using a FU of 1 ton of MSW processed. Given that the current digester utilized in the facility is of the single stage dry thermophilic type, relevant information pertaining to this specific category of digester was sourced from the literature. Based on the data acquired from the plant, the biogas yield per metric ton was multiplied by the coefficients sourced from relevant literature. Subsequently, the resulting values were utilized to estimate the quantity of heat and power that could be generated. These quantities were then stated as avoided products inside the system.

Based on the findings of Franz et al. (2009), it has been determined that the mean calorific value of biogas falls within the range of 21 to 23.5 MJ/m^3 at standard temperature and pressure (STP). Conversely, the report of the International Energy Agency (IEA, 2020) presents a broader spectrum of 16-28 MJ/m^3 for biogas. The acknowledged average calorific value of biogas is 22 MJ/m^3 at STP. The quantity of biogas produced per metric ton is 45 cubic meters. This value is then multiplied by 22 megajoules per cubic meter to get the amount of heat that may be gained from combustion of biogas, which is calculated to be 1001.25 megajoules. In line with the findings of Franz et al. (2009), Deviren et al. (2017), Zăbavă et al. (2019), and Muh et al. (2018), it has been established that a cubic meter of biogas, with methane content ranging from 45% to 60%, is associated with an average electrical energy output of 6 kWh. The calculation of electricity generation in this context involves multiplying the volume of biogas per ton, which is 45 m^3, by the energy conversion factor of 6 kWh. This results in an estimated power generation of 270 kWh.

Beneroso et al. (2014) reported that the moisture content of the organic waste supplied to the system was 45%. Furthermore, based on the studies conducted by Fernández-Rodríguez et al. (2013), Zeshan et al. (2012), and Sajeena Beevi et al. (2015), it was determined that the acceptable concentration of total solids (TS) in single-stage dry thermophilic anaerobic digesters is 20%. The calculation was performed to establish the total water quantity required in relation to the feed's total solids concentration, which was measured at 0.55 tons. The resulting value was found to be 2.2 tons. Additionally, by subtracting the moisture content, it was determined that 1.57 tons of tap water needed to be added.

3.3.3 Life Cycle Inventory for Landfill

The solid digestate derived from the anaerobic digester, along with inorganic non-recyclable waste, is stored within the designated landfill site. The entirety of the biogas produced during the fermentation process within the landfill gas and biomethanization facility is combusted and afterward channeled into gas engines for the purpose of generating electricity and heat. The mass balance of the landfill process in the facility is illustrated in Figure 3.9. As depicted in Figure 3.9, the main inputs consist of inorganic fractions of total municipal solid waste, solid digestate, and diesel fuel. Conversely, the outputs include produced leachate and stored gas. The emission-to-water values have been eliminated under the assumption that the leachate from the landfill unit is directed to the wastewater treatment plant (WWTP). The collected biogas mostly comprises methane, carbon dioxide, and hydrogen sulfide gases. These gases have contributed to the emissions into the air component of the system.

This analysis incorporates two distinct possible scenarios for landfill. The present circumstances are acknowledged as Scenario 1. In the second case, solely non-recyclable inorganic waste is utilized as the input for processing. In contrast, it is commonly accepted that in the second scenario, solid digestate wastes are sent to the compost unit, which comprises two distinct subparts, namely Scenarios 2.a and 2.b. In these scenarios, unlike the other cases, the system exclusively utilizes inorganic non-recyclable wastes. For this reason, the solid digestate input is represented with a light blue color in contrast to the remaining inputs.

One of the system inputs is the quantity of diesel fuel consumed by the trucks during the transportation of waste to the disposal site. Larsen et al. (2009) state that the quantity of diesel utilized per metric ton of waste has a range of from 1.4 to 10.1 L. The average diesel consumption per ton of municipal waste was directly utilized by calculating the mean of this metric.

The methodology for determining the quantity of electricity and heat derived from the accumulated storage gas is identical to that employed in the calculation process for the AD system. The previously described procedure is elaborated upon fully in the preceding section.

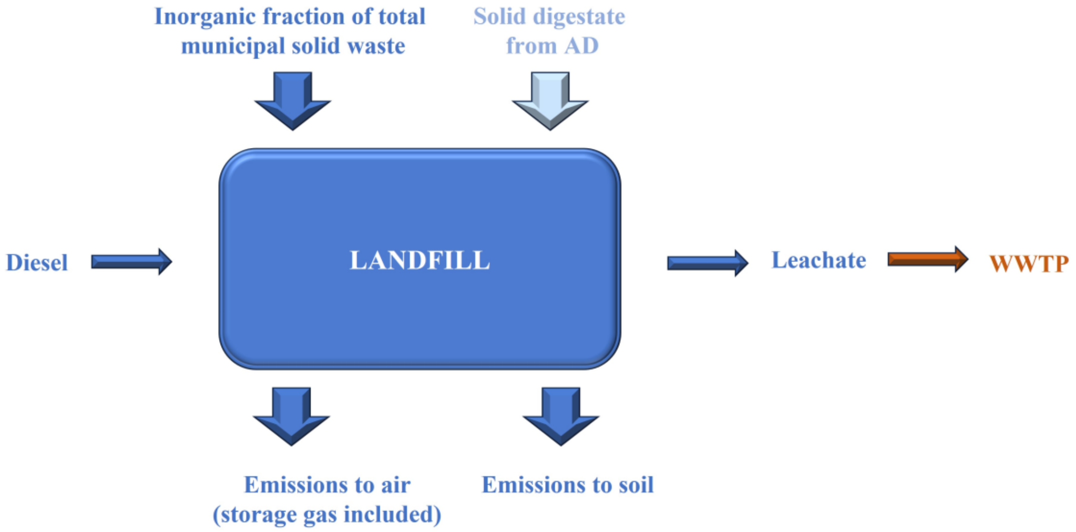


Figure 3.9 Mass balance of landfill system.

The inputs and outputs for landfill are presented in Table 3.5.

Table 3.5 The Inputs and Outputs of Landfill System (for 1 ton of municipal solid waste)

		Source
Inputs		
Electricity	0.42 kWh	*Hong et al. (2010)*
Diesel [b]	1.15 kg	*Larsen et al. (2009)*
Outputs		
Wastewater [a]	0.61 ton	*EIA report of the study plant*
Outputs (Avoided products)		
Electricity [b]	25.15 kWh	*Monson et al. (2007); Jungbluth et al. (2007)* *Monson et al. (2007); Jungbluth et al. (2007)*
Heat [b]	98.27 MJ	*Franz et. Al. (2009)*

Table 3.5 The Inputs and Outputs of Landfill System (for 1 ton of municipal solid waste)(cont'd)

		Source
Emissions to soil		
Nitrogen oxides	0.0014 kg	
Particulates	2.33E-5 kg	*Sivakumar et al. (2014);*
Hydrocarbons	0.39 kg	*Mboowa et al. (2017);*
Carbon monoxide	0.003 kg	*Samadder et al. (2017)*
Emissions to air		
Carbon dioxide	18.4 kg	
Methane	13.4 kg	*From the study plant*
Hydrogen sulfide	0.37 kg	

(a) This data was calculated in line with the information obtained from the sources given in the reference column. This calculation is given in detail in the following section of the chapter.

(b) This data was obtained by multiplying the amount of biogas by the coefficient obtained from the sources given in the reference column.

3.3.4 Life Cycle Inventory for Composting

Despite the absence of a composting unit at present, the facility was assessed in Scenarios 2.a and 2.b as a potential option for the management of solid digestate. In Scenario 2.b, the solid digestate that is currently disposed of in landfills is redirected to composting facilities, while the liquid fermented waste is directed to wastewater treatment plant (WWTP). In contrast, in Scenario 2.b, as opposed to Scenario 2.a, a portion of the liquid ferment is substituted for the requisite fresh water in the composting process following WWTP operations.

The mass balance of the composting unit is illustrated in Figure 3.10. The diagram illustrates that the primary inputs for the unit are energy, water, and diesel. Conversely, compost, which is a significant output of the system, can be utilized as fertilizer in accordance with suitable requirements. Consequently, fertilizer is regarded as a product that is intentionally not used.

Based on the data obtained from the plant, it has been determined that the quantity of liquid digestate is equivalent to 0.18 tons when divided by two. Based on the computation pertaining to the requisite water quantity for the composting unit, it is determined that the unit necessitates a little 10% of the liquid digestate volume. Hence, in Scenario 2.b, the entirety of the water demand is met through the utilization of the treated liquid digestate.

Furthermore, Andersen et al. (2010) state that the quantity of diesel utilized in the composting process is reported to be 1.54 Liters per metric ton (Mg). Consequently, the quantity of fuel, regarded as one of the input variables, was determined through the multiplication of the total mass of solid digestate, measured in metric tons.

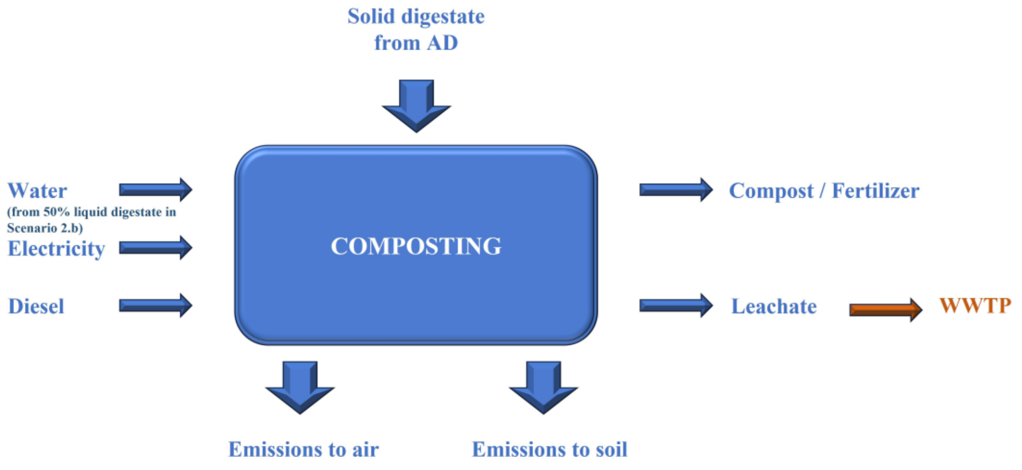


Figure 3.10 Mass balance of the composting system.

The inputs and outputs for composting are presented in Table 3.6.

Table 3.6 Inputs and Outputs for Composting System (for 1 ton of municipal solid waste)

		Source
Inputs		
Tap water ^{b}	0.02 ton	*Cadena et al. (2009)*
Electricity	65.5 kWh	*Cadena et al. (2009)*
Diesel	10.6 kWh	*Andersen et al. (2010)*
Outputs		
Compost ^{b}	5.4 kg	*van Haaren et al. (2010)*
Wastewater ^{b}	0.23 ton	*Environmental Protection Agency (EPA) (2002)*
Outputs (Avoided products)		
Fertiliser (N)	3.5 kg	*van Haaren et al. (2010)*
Fertiliser (P)	0.5 kg	
Fertiliser (K)	1.4 kg	
Emissions to air		
Methane	4 kg	*World Resources Institute et al. (2019)*
Nitrous oxide	0.24 kg	
Ammonia	0.84 kg	*Martínez-Blanco et al. (2010)*
Nitric oxide	0.25 kg	*Ng et al. (2021)*
VOCs	0.56 kg	*Martínez-Blanco et al. (2010)*
Carbon monoxide	0.069 kg	*Ng et al. (2021)*

Table 3.6 Inputs and Outputs for Composting System (for 1 ton of municipal solid waste) (cont'd)

		Source
Hydrogen sulfide	0.17 kg	*Richard et al. (2021)*
Emissions to soil		
Cadmium	3 g	*Official Gazette (2018)*
Copper	450 g	
Nickel	120 g	
Lead	150 g	
Zinc	1100 g	
Mercury	5 g	
Chromium	350 g	
Tin	10 g	

(a) This data was calculated in line with the information obtained from the sources given in the reference column. This calculation is given in detail in the following section of the chapter.

(b) This data was obtained by multiplying the amount of biogas by the coefficient obtained from the sources given in the reference column.

The formation of leachate per feedstock can vary between 10% and 30% of the starting weight. Nevertheless, this range may fluctuate based on factors such as the moisture content of the feedstock, the management of aeration and moisture throughout the composting procedure, and various other variables. Hence, in the context of accepting an average value, it was estimated that the leachate generated from the composting process was 20% of the initial feedstock.

3.3.5 Life Cycle Inventory for Mechanical Treatment

Mechanical Treatment Plant performs separation, size reduction/shredding, and screening procedures. Within this module, the municipal solid wastes that are delivered to the facility undergo a process of segregation, wherein they are categorized into several groups based on their recyclability and composition, specifically distinguishing between organic and inorganic components. Approximately 55% of the incoming waste can be classified as non-recyclable, with approximately 30% of this proportion consisting of organic waste. The remaining 45% is allocated to the appropriate recycling facilities. The study does not encompass waste that is directed to recycling facilities. The monitoring of electricity use in the plant is conducted by means of invoices. The mass balance of the mechanical treatment unit is depicted in Figure 3.10. According to the data presented in Figure 3.11, energy serves as the predominant input for the mechanical treatment of 1 ton of municipal waste. Conversely, the principal outputs consist of mixed plastics, recyclable paper, packaging glass, metals, organic non-recyclables, inorganic non-recyclables, and leachate.

The quantity of power, which serves as the primary input of the system, is determined through the utilization of established assumptions. Given that the specific electricity consumption per metric ton of MSW is the only available information, the electricity consumption for AD and desulphurization processes is obtained from existing literature sources. It should be noted here that the specific electricity consumption includes the use of electricity in non-operational sites of the facility (i.e., offices, cafeterias etc.). Therefore, this portion of the electricity used was estimated using the electricity consumption figure given for residential areas by TEIAS (Table 3.9). Consequently, the electricity consumption of the mechanical treatment unit was determined by deducting the calculated values for anaerobic digestion, desulphurization, and residential consumption in non-operational sites from the overall consumption.

The segregated waste materials are transported to the respective facilities, while the wastewater known as leachate, is directed to WWTP. During the process, emissions to the atmosphere and dust particles are occurrences. The evaluation of proposed alternatives in the existing BAT 25, as outlined in the waste treatment BREF, was conducted to address the reduction of dust emissions in the relevant unit. Subsequently, suitable scenarios were developed based on these alternatives.

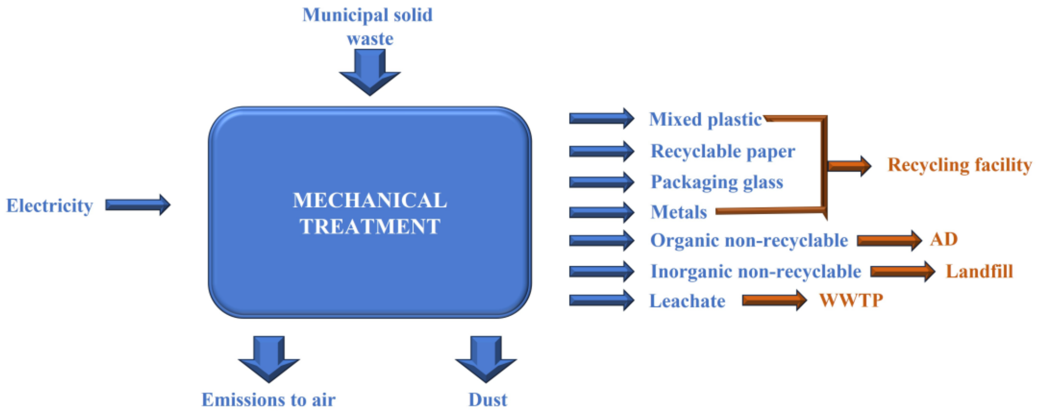


Figure 3.11 Mass balance of mechanical treatment system (for Scenario 1, 2 and 4).

As previously stated, Scenario 4.a employs a cyclone separator, whereas Scenario 4.b utilizes a fabric filter, both of which are employed to mitigate dust emissions. The mass balance for each of the scenarios is presented in Figure 3.12. Figure 3.12 displays alterations solely in the electricity and dust emissions, depicted in the color green, for the two scenarios. Based on the findings of Chen and Wang (2001), the yearly electrical consumption in the mechanical treatment including a cyclone separator amounts to 80,178 kWh. The electricity consumption for the cyclone is determined by the quantity of MSW processed on a yearly basis. In contrast, Xia et al. (2022) assert that the utilization of a fabric filter in mechanical treatment results in an electrical demand of 0.064 kWh per metric ton of waste. Furthermore, the values for dust emission reduction in Scenarios 4.a and 4.b were obtained from existing literature, and the dust emissions where the dust emissions were computed. Based on the research conducted by Taiwo and Mokwa (2016), it subsequently has been determined that the dust removal efficiency in cyclones surpasses 98% for particles with a size above 5 microns, while consistently achieving over 90% efficiency for particles larger than 15-20 microns.

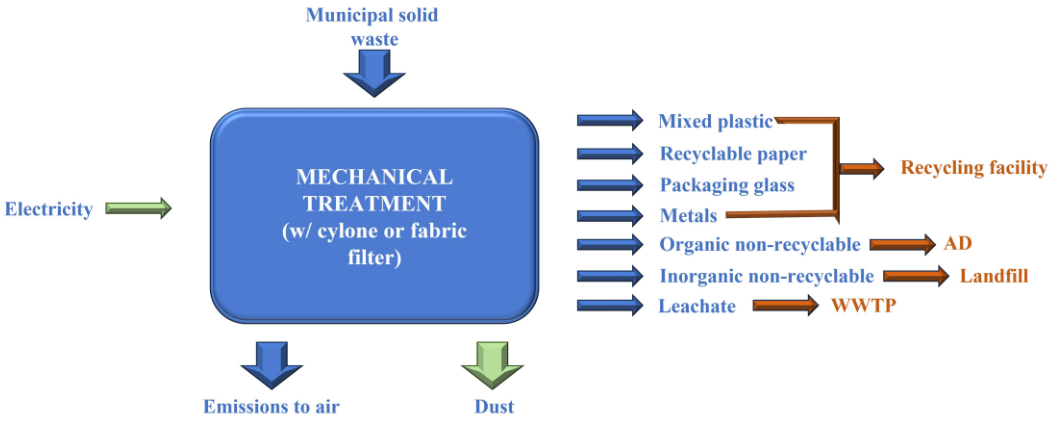


Figure 3.12 Mass balance of mechanical treatment with cyclone or fabric filter.

The mass balance for Scenario 4.c is depicted in Figure 3.13. In contrast to Scenarios 1, 4.a, and 4.b, Scenario 4.c include the introduction of water. Hu et al. (2021) reported that a wet scrubber exhibits optimal dust removal efficiency when subjected to a water input rate of 1.35 m3/hour. According to this investigation, the system's dust removal performance ranges from 96.81% to 95.59%. Consequently, the calculated value for dust output was determined.

Furthermore, as stated by Pozzo and Cozzani (2021), the quantity of wastewater generated in wet scrubber systems is around 87% of the initial water intake. Hence, in the present situation, there is a variation in the quantity of leachate in comparison to the reference example (Scenario 1), which is visually represented by the green color in Figure 3.13, together with the electricity input and dust output. The quantity of wastewater determined using the specified rate is combined with the leachate in Scenario 1. Furthermore, according to the United States Environmental Protection Agency (EPA, 2016), wet scrubbers exhibit considerable power consumption, with a range of 4 to 10 kilowatts (kW) per 1000 actual cubic feet per minute (acfm) or 0.004 kWh/m3.

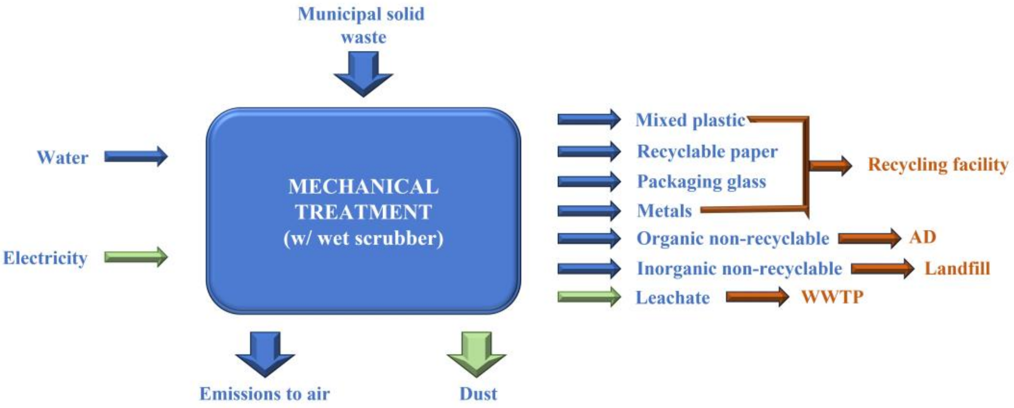


Figure 3.13 Mass balance of mechanical treatment with a wet scrubber.

In the context of Scenario 3, it is assumed that the pertinent approaches will be incorporated into the pre-existing system for all sub-scenarios. Hence, the power consumption numbers derived from calculations or obtained from relevant literature sources were incorporated into the pre-existing electricity consumption statistics of the mechanical treatment unit and subsequently integrated into the system.

The inputs and outputs of mechanical treatment alternatives given in Scenarios 1, 4.a, 4.b and 4.c are given in Table 3.7.

Table 3.7 Inputs and Outputs of Mechanical Treatment Alternatives (for 1 ton of municipal solid waste)

	Mechanical treatment	**Source**	**Mechanical treatment w/ cyclone**	**Source**	**Mechanical treatment w/ fabric filter**	**Source**	**Mechanical treatment w/ wet scrubbing**	**Source**
Inputs								
Electricity	3.87 kWh [a]	*From the plant*	4.71 kWh	*Chen & Wang (2001)*	3.9330 kWh	*Xia et al. (2022)*	7.02 kWh	*Hu et al. (2021)*
Tap water	-		-		-		0.037 ton	*Hu et al. (2021)*
Outputs								
Mixed plastics	0.13 ton	*From the plant*	0.13 ton	*From the plant*	0.13 ton	*From the plant*	0.13 ton	*From the plant*
Waste glass	0.09 ton		0.09 ton		0.09 ton		0.09 ton	
Wastepaper	0.08 ton		0.08 ton		0.08 ton		0.08 ton	
Biowaste	0.17 ton		0.17 ton		0.17 ton		0.17 ton	
Wastewater	0.05 ton		0.05 ton		0.05 ton		0.082 ton	

Table 3.7 Inputs and Outputs of Mechanical Treatment Alternatives (for 1 ton of municipal solid waste)(cont'd)

	Mechanical treatment	**Source**	**Mechanical treatment w/ cyclone**	**Source**	**Mechanical treatment w/ fabric filter**	**Source**	**Mechanical treatment w/ wet scrubbing**	**Source**
Metal wastes	0.13 ton		0.13 ton		0.13 ton		0.13 ton	
Inorganic fraction	0.4 ton		0.4 ton		0.4 ton		0.4 ton	
Emissions to air								
Carbon dioxide	1,524 kg	*Wei & Xin (2015)*	1,524 kg	*Wei & Xin (2015)*	1,524 kg	*Wei & Xin (2015)*	1,524 kg	*Wei & Xin (2015)*
Sulfur dioxide	0.0087 kg		0.0087 kg		0.0087 kg		0.0087 kg	
Nitric oxide	0.0091 kg		0.0091 kg		0.0091 kg		0.0091 kg	
Carbon monoxide	0.00023 kg		0.00023kg		0.00023 kg		0.00023 kg	
Methane	0.0 012 kg		0.0 012 kg		0.0 012 kg		0.0 012 kg	
Ammonia	0.0052 kg		0.0052 kg		0.0052 kg		0.0052 kg	

Table 3.7 Inputs and Outputs of Mechanical Treatment Alternatives (for 1 ton of municipal solid waste)(cont'd)

	Mechanical treatment	**Source**	**Mechanical treatment w/ cyclone**	**Source**	**Mechanical treatment w/ fabric filter**	**Source**	**Mechanical treatment w/ wet scrubbing**	**Source**
Hydrogen sulfur	0.0064 kg		0.0064 kg		0.0064 kg		0.0064 kg	
Flow								
Dust	0.0063 kg	*Wei & Xin (2015)*	0.00378 kg	*Taiwo & Mokwa (2016)*	0.00019 kg	*Xia et al. (2022)*	0.0024 kg	*Hu et al. (2021)*

(a) This data was calculated in line with the information obtained from the sources given in the reference column. This calculation is given in detail in the following section of the chapter.

3.3.6 Life Cycle Inventory for Desulphurization

Given the corrosive nature of H_2S, which is found in small quantities within the composition of biogas, it is imperative to employ suitable protocols for the extraction of biogas from the system prior to its utilization in cogeneration units. As previously stated, the desulphurization techniques outlined in BAT34, as directed by the waste treatment BREF document, encompass physical, biological, and chemical methods that can be employed either individually or in conjunction with one another for the purpose of desulphurization. The utilization of a biological desulphurization filter in the plant is a very appropriate method given the prevailing process operating parameters. The utilization of a biofilter is employed in Scenario 1, which serves as the foundational scenario. Based on the data obtained from the plant, it has been determined that the biogas composition at the system inlet consists of 55% methane, 40% carbon monoxide, and 3000 parts per million (ppm) of hydrogen sulfide. Presently, the content of hydrogen sulfide has been diminished to 250 ppm with the use of a biofilter. Figure 3.14 represents the mass balance of Scenario 1.

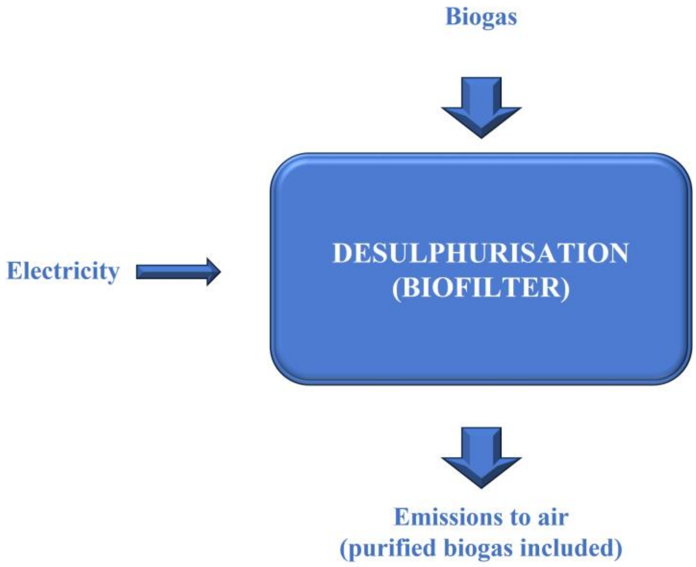


Figure 3.14 Mass balance of desulphurization using biofilter.

BAT 34, which is recommended in the Waste Treatment BREF document to reduce the channeled emissions of dust, organic compounds, and odorous compounds to the air, including H_2S and NH_3, includes methods such as biofilter, adsorption, thermal oxidation, fabric filter and wet scrubbing. At the same time, forming the scenarios matched with the alternative desulphurization methods the required data were taken in the literature.

Firstly, a wet scrubber, one of the methods used to reduce H_2S concentration, was used in the first sub-scenario of Scenario 4. This system's electricity and water are inputs, as seen in the figure below. According to (Beil & Beyrich, 2013) research, the water consumption of a wet scrubbing system for biogas purification is 1-3 m^3/d biogas. Thus, the annual water consumption amount was calculated using the given coefficient and the ratio per ton of waste was calculated. The same study and another study (Alén, 2022) on a similar subject state that electricity demand is 0.2 to 0.3 kWh/m^3 biogas. The average of this range was used as a coefficient in this study. According to research, the amount of wastewater produced by wet scrubber systems corresponds to about 87% of the input water volume (Pozzo & Cozzani, 2021). The leachate formation was calculated with this percentage. Also, Beil & Beyrich (2013) state that the H_2S removal efficiency of wet scrubber is 98-99.5%. For this reason, this efficiency is accepted as 98.75% as an average, and the output H_2S concentration is calculated with this coefficient.

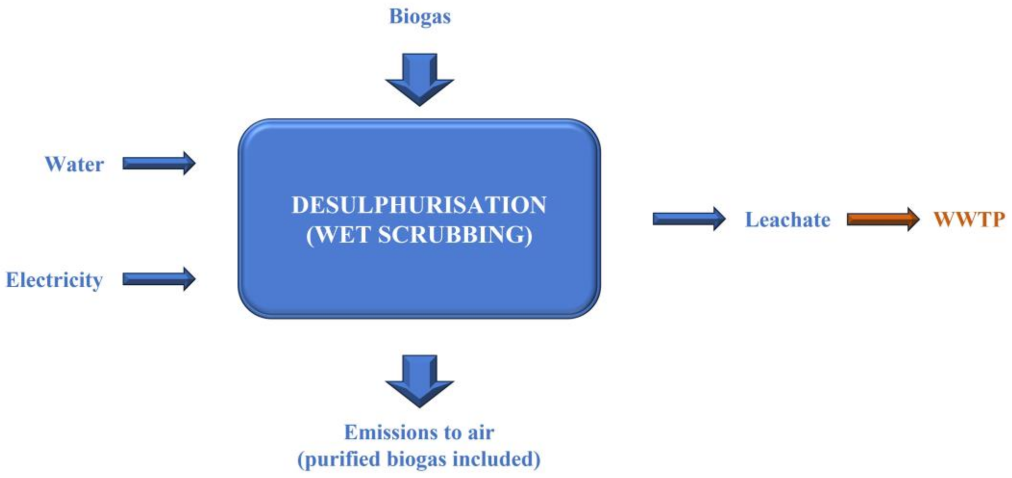


Figure 3.15 Mass balance of desulphurization using a wet scrubber.

In Scenario 4.a, a wet scrubber, which is a commonly employed technique for mitigating H2S levels, was utilized. The system receives electricity and water as its inputs, as depicted in Figure 3.15. Based on the findings of Beil and Beyrich (2013), the water consumption associated with the wet scrubbing system utilized for biogas treatment ranges from 1 to 3 m^3 per day of biogas. The calculation of the ratio of water to biogas entering the desulphurization unit was performed based on the functional unit. According to Alén (2022) and another study conducted on a related subject, it has been determined that the electricity demand associated with biogas is estimated to range between 0.2 and 0.3 kWh/m^3. The calculation of electricity consumption was derived from the aggregate quantity of biogas, employing an assumed average of 0.25 kilowatt-hours per cubic meter.

Pozzo and Cozzani (2021) reported that the quantity of wastewater generated by wet scrubber systems is equivalent to approximately 87% of the incoming water volume. The quantity of wastewater, namely in the form of leachate, was determined by utilizing the ratio. Furthermore, according to Beil and Beyrich (2013), the wet scrubber exhibits an H_2S removal effectiveness ranging from 98% to 99.5%. Consequently, the average efficiency was deemed to be 98.75%, and the concentration of H_2S at the exit was determined using this ratio.

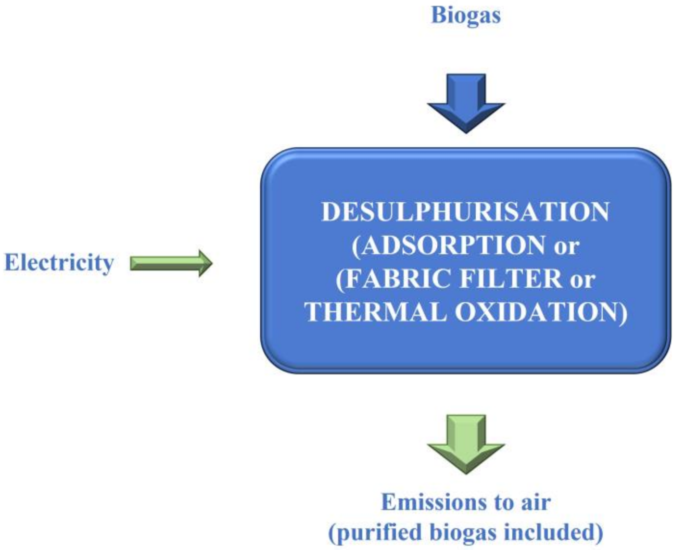


Figure 3.16 Mass balance of desulphurization using the other options (Adsorption, Fabric Filter, and Thermal Oxidation).

Figure 3.16illustrates the mass balance pertaining to Scenarios 3.b, 3.c, and 3.d. As depicted in Figure 3.16, the depicted alternatives exhibit variations in the input of power consumption and the output of emissions to air, as denoted by the green color. According to Beil and Beyrich (2013), the efficacy of H_2S removal using adsorption ranges from 90% to 98%. In line with the findings of Huertas et al. (2020), the fabric filter demonstrates a removal efficiency ranging from 91.5% to 99.8%. Additionally, Dong et al. (n.d.) and Shah et al. (2017) report a removal efficiency of 99.5% for thermal oxidation. Apart from Scenario 3.c, the concentrations of H_2S at the outlet for both scenarios were determined by taking the average of these ranges. In Scenario 3.c, the ratio was employed in a direct manner.

The inputs and outputs of desulphurization alternatives given in Scenarios 1, 3.a, 3.b, 3.c and 3.d are given in Table 3.8.

Table 3.8 Inputs and Outputs of Desulphurization Alternatives (for 1 ton of municipal solid waste)

	Desulphurization (via biofilter)	**Source**	**Desulphurization (via wet scrubbing)**	**Source**	**Desulphurization (via fabric filter)**	**Source**	**Desulphurization (via thermal oxidation)**	**Source**	**Desulphurization (via adsorption)**	**Source**
Inputs										
Electricity[a]	7.02 kWh	*Cano et al. (2018)*	3.9 kWh	*Alén (2022);* *(Beil & Beyrich (2013)*	0.064 kWh	*Huertas et al. (2020)*	2212.5 kWh	*Dong et al. (n.d.);* *Shah et al. (2017)*	3.98 kWh	*Beil & Beyrich (2013)*
Tap water [a]	-		0.0042 ton	*Beil & Beyrich (2013)*		-	-		-	
Outputs										
Wastewater [a]	-		0.037 ton	*Pozzo &Cozzani(2021)*		-	-		-	

Table 3.8 Inputs and Outputs of Desulphurization Alternatives (for 1 ton of municipal solid waste) (cont'd)

	Desulphurization (via biofilter)	**Source**	**Desulphurization (via wet scrubbing)**	**Source**	**Desulphurization (via fabric filter)**	**Source**	**Desulphurization (via thermal oxidation)**	**Source**	**Desulphurization (via adsorption)**	**Source**
Emissions to air										
Methane	550 kg	*From the plant*	550 kg	*From the plant*	550 kg	*From the plant*	550 kg	*From the plant*	550 kg	*From the plant*
Carbon dioxide	400 kg		400 kg		400 kg		400 kg		400 kg	
Hydrogen sulphide [b]	0.03 kg		0.005 kg	*Beil & Beyrich (2013)*	0.016 kg	*Huertas et al. (2020)*	0.0019 kg	*Dong et al. (n.d.);* *Shah et al. (2017)*	0.02 kg	*Beil & Beyrich (2013)*

(a) This data was calculated in line with the information obtained from the sources given in the reference column. This calculation is given in detail in the following section of the chapter.

(b) This data was obtained by multiplying the amount of hydrogen sulfide by the removal efficiency (%) obtained from the sources given in the reference column.

3.3.7 Assumptions

Several assumptions were made during the study. These assumptions are tabulated in Table 3.9. As seen from Table 3.9, in addition to the general assumptions, unit-based assumptions are categorized, and information on the references used is provided.

Table 3.9 Assumptions Considered in This Study

Assumptions	**Reference**
All parts of the plant	
The plant is assumed to operate 300 working days and 8 hours daily.	The EIA Report of Study Plant
Residential electricity consumption per capita in Turkey is 3,142 kWh for 2021, the year the data is used in this study.	TEDAS (2022)
There are 20 employees in the study plant.	
Medium voltage generation is for industry, so medium-voltage electricity is used in factories and industrial processes. In this study, all electrical data were chosen as medium voltage.	Inventory of Country Specific Electricity in LCA - Consequential Scenarios. Ecoinvent Version 3.0 (n.d.)
Anaerobic Digestion	
The moisture content of municipal organic waste is 45% on average.	Beneroso et al. (2014)

Table 3.9 Assumptions Considered in This Study (cont'd)

Assumptions	**Reference**
A dry anaerobic digester's total solid concentration (TS) is 20%.	Fernández-Rodríguez et al. (2013); Zeshan et al. (2012); Sajeena Beevi et al. (2015)
It was assumed that the gas motors work with %100 efficiency.	
Biogas with a 45-60% methane content produces an average of 6 kWh of electricity per m^3.	Deviren et al. (2017); Zăbavă et al. (2019); Muh et al. (2018); Franz et al. (2009)
Biogas has an average calorific value of 21-23.5 MJ/m^3 at STP.	Franz et al. (2009); IEA (2020)
Landfill	
The characterization of input waste sent to a landfill does not affect the efficiency of the produced biogas.	
It was assumed that the gas motors work with %100 efficiency.	
The total storage gas produced in the landfill site was transformed into a biogas collection system, and there was no leakage.	

Table 3.9 Assumptions Considered in This Study (cont’d)

Assumptions	**Reference**
The data revealed a significant variance between different collecting strategies, ranging from 1.4 to 10.1 L diesel per one of waste.	Larsen et al. (2009)
Biogas with a 45-60% methane content produces an average of 6 kWh of electricity per m^3.	Deviren et al. (2017); Zăbavă et al. (2019); Muh et al. (2018); Franz et al. (2009)
Biogas has an average calorific value of 22 MJ/m^3 at STP.	Franz et al. (2009)
Composting	
CCW (composting in confined windrows) method, a completely open system that does not require pre-treatment, was selected as the composting process.	Colón et al. (2012)
Composting requires 1.54 L of diesel per Mg of waste, including consumption such as turning (front loader) and dredging mature compost.	Andersen et al. (2010)
Compost tunnel (CT) plant consumes more electricity than the Composting in Confined Windrow (CCW) plant (95 kWh/t OFMSW in opposition to 65.5 kWh/t OFMSW).	Cadena et al. (2009)
The output of composting is used as fertilizer.	Pinasseau et al. (2018b)

Table 3.9 Assumptions Considered in This Study (cont'd)

Assumptions	**Reference**
The leachate originating from the composting is sent to the WWTP.	
Mechanical Treatment	
There is no water consumption in the existing mechanical treatment unit.	
The dust removal efficiency of the fabric filter is 99.7%	Xia et al. (2022)
The electricity demand of the wet scrubber to reduce dust emissions is 0.04 kWh/ m^3, which requires water.	Hu et al. (2021)
The annual water demand of the wet scrubber to reduce dust emissions is 1.35 m^3.	Hu et al. (2021)
When wet scrubbing methods are utilized, wastewater generation corresponds to about 87% of the input water quantity.	Pozzo & Cozzani (2021)
The wet scrubber's dust removal efficiency is 96.20%	Hu et al. (2021)
The dust removal efficiency of the cyclone separator is 94.0%	Taiwo & Mokwa (2016)

Table 3.9 Assumptions Considered in This Study (cont'd)

Assumptions	**Reference**
Desulphurization	
Loss of methane is negligible and set to zero when comparing desulphurization alternatives.	
Electricity demand for biofilter application in the plant is 20.4 kWh per ton of H_2S removed.	Cano et al. (2018)
The H_2S concentration removal efficiency of the wet scrubber is 98.75%.	Beil & Beyrich (2013)
The water demand of a wet scrubbing system is 2 m^3 water/d.	Beil & Beyrich (2013)
Wastewater formation represents approximately 87% of the input water when wet scrubbing techniques are used.	Pozzo & Cozzani (2021)
The energy demand of a water scrubbing system is 0.25 kWh/ m^3 of biogas.	Alén (2022); Beil & Beyrich (2013)
The H_2S concentration removal efficiency of the adsorption system is 94.25%.	Beil & Beyrich (2013)
The energy demand of the adsorption for desulphurization is 0.255 kWh/ m^3 biogas.	Beil & Beyrich (2013)

Table 3.9 Assumptions Considered in This Study (cont'd)

Assumptions	Reference
The H_2S concentration removal efficiency of the fabric filter is 95.65%.	Huertas et al. (2020)
The electricity requirement is 0.064 kWh/ m^3 using a fabric filter to reduce the H_2S concentration of biogas.	Huertas et al. (2020)
The thermal oxidation system consumes 17.7 MW of electricity per day.	Tomatis et al. (2019)
Thermal oxidation is an exothermic reaction; therefore, no heat is needed.	
The H_2S concentration removal efficiency of the thermal oxidation is 99.5%.	Dong et al. (n.d.); Shah et al. (2017)
The generated leachate from wet scrubbing is sent to WWTP.	

3.4 Life Cycle Impact Assessment (LCIA)

LCIA refers to the evaluation of the environmental consequences associated with a product's life cycle both qualitatively and quantitatively. This assessment is conducted by analyzing data on resource utilization, energy consumption, and emissions, which are obtained by inventory analysis. These indicators quantify the magnitude of the contribution of impact categories to the overall environmental burden.

There are several alternative LCIA methods as described in Sec. 2.1.3. The outcomes can differ based on the selected method, even while utilizing identical inventory. In this study, the ReCiPe framework was employed as it offers several advantages compared to the others. First of all, it is of global scale, and it considers the most comprehensive range of midpoint impact categories. Also, in contrast to alternative methodologies such as CML, IMPACT World+, ReciPe 2016, TRACI 2.1, LC-Impact, IPPC 2021, and USEtox 2, it does not incorporate prospective effects stemming from forthcoming extractions inside the impact assessment. Instead, it assumes that these potential consequences have already been accounted for in the inventory analysis. Further, it has an ability to provide an overview of the present circumstances without making any presumptions on future consequences (Huijregts et al., 2017). As previously stated (Sec 2.1.3.1), the hierarchist approach, which is widely acknowledged as the default, was preferred.

3.5 Interpretation

In the last stage of the LCA study, the outcomes of the impact assessment were thoroughly examined and comprehensively interpreted.

During this stage, the results of LCA conducted for three primary waste treatment scenarios, four distinct desulphurization scenarios, and three mechanical treatment scenarios were evaluated and interpreted. The evaluation process involved assessing the normalized midpoint and end-point outcomes, as well as the single-score findings, for each scenario. The details are given in Section 4.

CHAPTER 4

RESULTS & DISCUSSION

This section includes LCA findings and analysis for three waste treatment scenarios, five desulphurization scenarios, and four mechanical treatment scenarios.

The environmental impacts of all twelve scenarios at both endpoint and midpoint levels were summarized below, while details were provided in the Appendix part.

4.1 Environmental Impact Analysis

4.1.1 Environmental Impact of Waste Treatment Scenarios

The LCIA results of two different scenarios (Scenario 2.1 and 2.2 in Table 3.2) for waste treatment are compared with the baseline scenario (Scenario 1 in Table 3.2) to assess the effects of integrating a composting unit into the system with two possible implementations for the treatment of AD solid digestate which would otherwise go to the landfilling. Indeed, composting is not indicated among the BAT conclusions of the Waste Treatment BREF (Pinasseau et al., 2018a), but it is mentioned as a good practice to be used to upgrade the solid digestate for use as fertilizer (Pinasseau et al., 2018b). Therefore, these two scenarios were considered worthy of evaluation for the Study Plant.

The process units used in the LCA model constructed for the waste treatment scenarios are provided as screenshots in Appendix Part A where all entries are indicated. Furthermore, the characterization and normalization results are also provided in Appendix Part B. The results obtained from the normalization and characterization analyses indicate that the human health category and the human health related GWHH mid-point impact category exhibit the highest impact value. Furthermore, it should be noted that Scenario (baseline scenario), has the least significant influence. The findings align with those derived from the single score outcomes.

Figure 4.1 shows the impact assessment single-score results initially assessed on the endpoint basis. The characterization and normalization results are also given in Appendices Part B. While the overall impact is greater, though slightly, in Scenario 2.a and 2.b when compared to the baseline scenario, it is evident that the total impacts of these two scenarios are equivalent. Normally, one should expect a more pronounced difference (i.e., a much greater difference) between Scenario 1 and Scenario 2a/b due to the additional energy consumption arising from the use of electricity and diesel in composting units. However, when the fertilizer value of the compost produced in the composting unit (entered as an avoided product) is taken into consideration, it would be deemed that this effect is neutralized to a great extent. Regarding the comparison between Scenario 2a and 2b, it was expected to have a lower impact in Scenario 2b than 2a; however, this was not noticed in the single score values provided in Figure 4.1. Indeed, as can be seen from this figure, a very slight improvement noticeable in the 4-digit level is present in Scenario 2b as compared to Scenario 2a (93.8939 vs 93.8943 pts in the "Human Health" category).

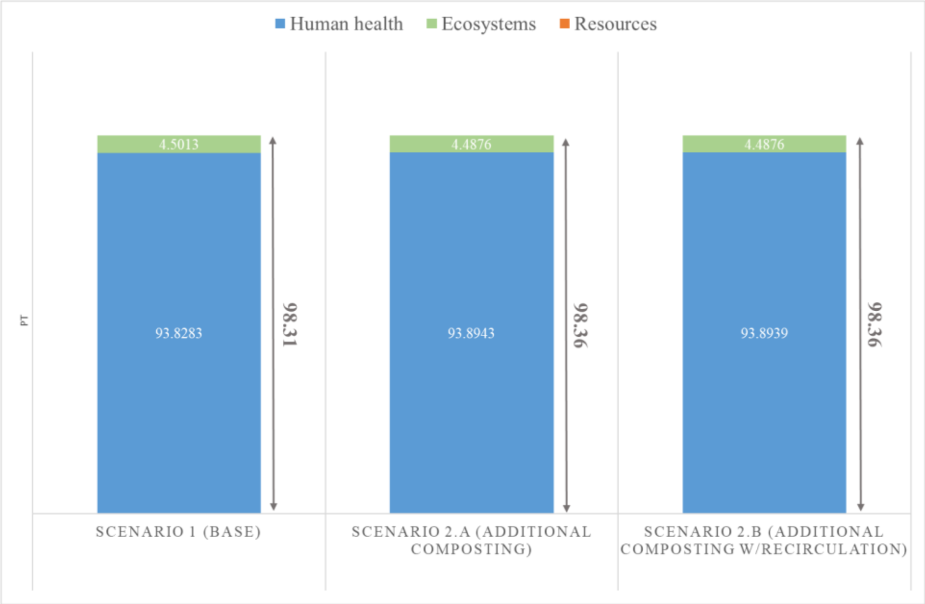


Figure 4.1 Comparative end-point single score results for waste treatment scenarios.

To conduct a more comprehensive evaluation, the findings of the single-score comparison for mid-point impact categories were assessed and are presented in Figure 4.2. Given that the primary impact of the baseline and two composting scenarios is depicted in the "Human Health" category in Figure 4.1, it is expected that the midpoint categories related to human health will present higher impacts in Figure 4.2. The midpoint single score results confirm that human health is the category with the most significant impact. Also, Figure 4.2indicates that "Global Warming, Human Health (GWHH)" has the highest value in this category across all three scenarios. Followingly, the second highest impact was observed in the "Human Non- Carcinogenic Toxicity (HNCT)" category. This is consistent with the findings of Hong et al., (2010). HHGW and HNCT impact categories were the highest in Hong et al. (2010) study like for this study. Even though there is a small difference in impact in all three scenarios, it is observed that the "Water consumption, Aquatic ecosystems (WCAE)" impact has reduced from 1.02E-03 pts to 1E-03 pts when switched from Scenario 2.a to Scenario 2.b as a result of water recirculation.

Despite being the second highest category, HCNT was deemed insufficient in size for sufficient adjustment of the impact results. Consequently, further analysis was exclusively conducted for the individual GWHH impact category.

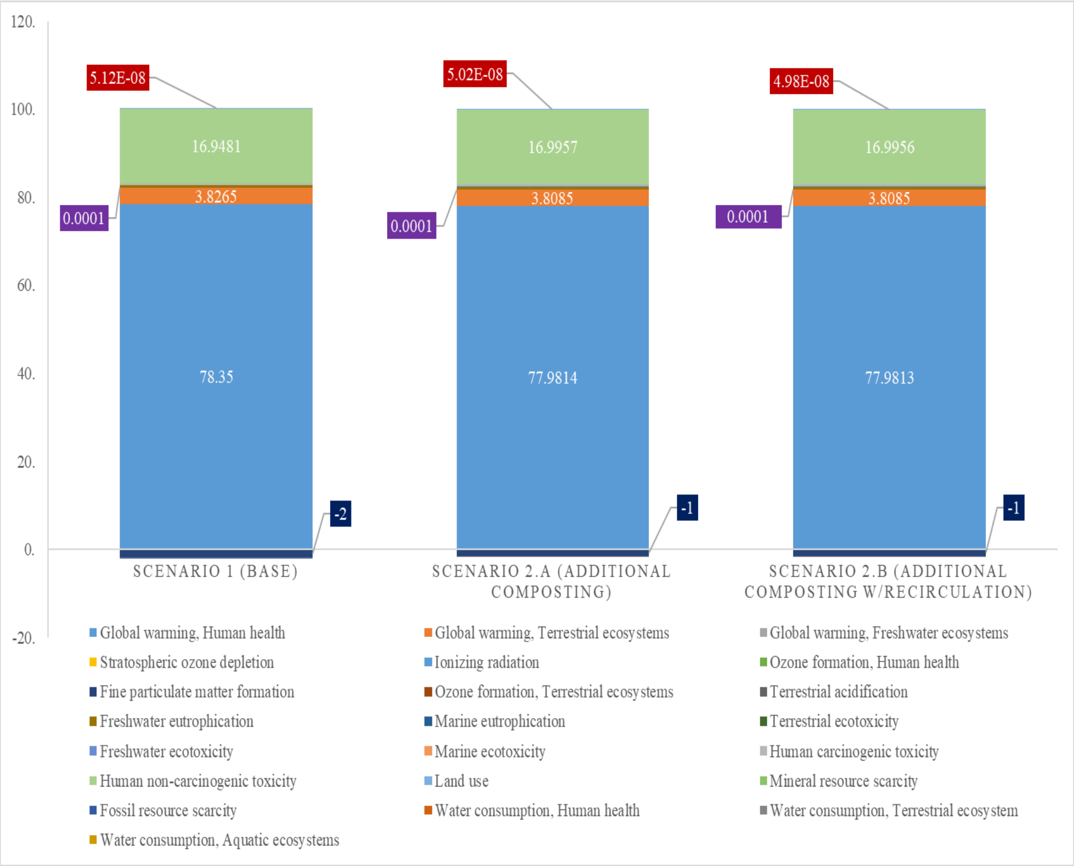


Figure 4.2 Mid-point single score results for waste treatment scenarios.

Figure 4.2 shows that the impact on the GWHH midpoint category is lower in Scenarios 2.a and 2.b compared to the baseline scenario, while the impact is almost the same for these two scenarios. As stated above, for the Human Health endpoint category, this difference would be due to the composting unit, as the baseline scenario does not include a composting unit. It should be noted here that the discrepancies in the impacts are marginal among the scenarios. So, it should be considered normal, as evidenced by Figure 4.3, which illustrates the process contributions to the impact on the GWHH. As seen in this figure, the input and output parameters of the desulphurization unit contribute the most to this category. This contribution is followed by AD, mechanical treatment, landfill and composting units, in the decreasing order.

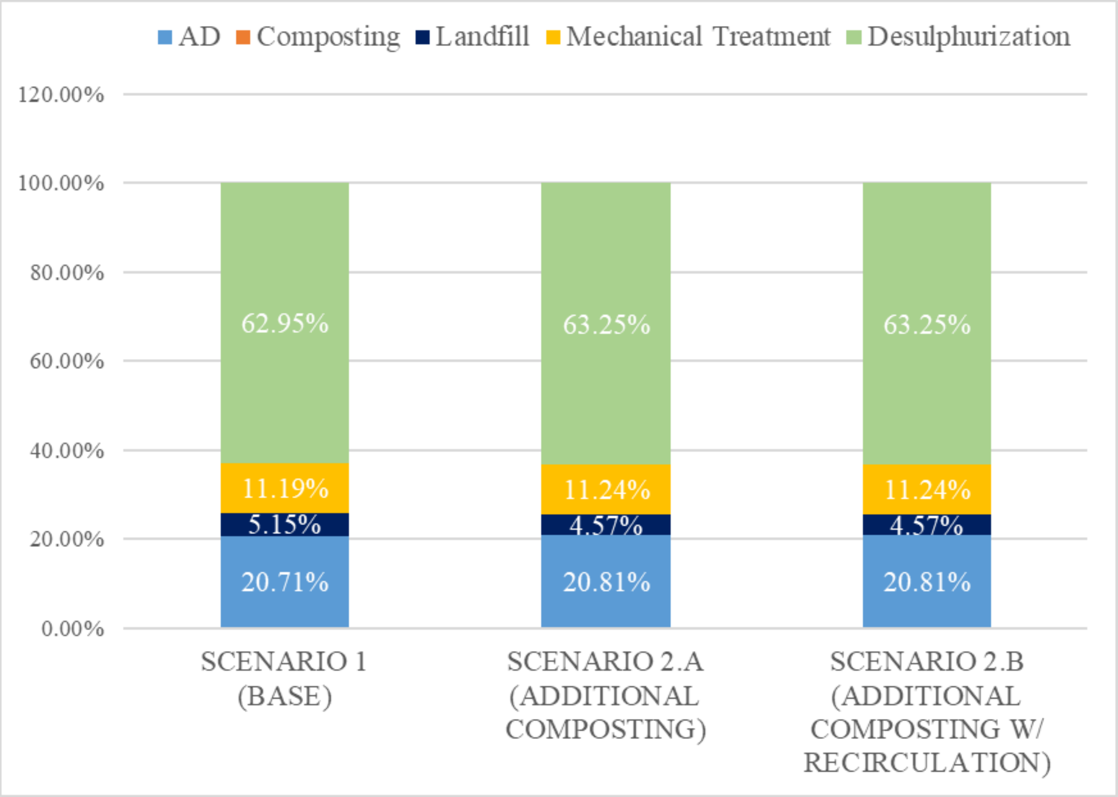


Figure 4.3 Unit- based contribution analysis of waste treatment scenarios based on GWHH.

In order to facilitate a broader review, Figure 4.4 shows the influencing input and output parameter analysis of waste treatment scenarios based on GWHH. In Figure 4.4, the highest influencing parameter is the electricity input of the desulfurization unit. This parameter is followed by the electricity input of AD, total municipal waste amount entering, and electricity consumed in the mechanical treatment unit, respectively. Furthermore, Figure 4.4 shows the contribution of the electricity input of the composting unit (the values also given in Table B.6 in the Appendix) in Scenarios 2.a and 2.b, which is different from the baseline scenario.

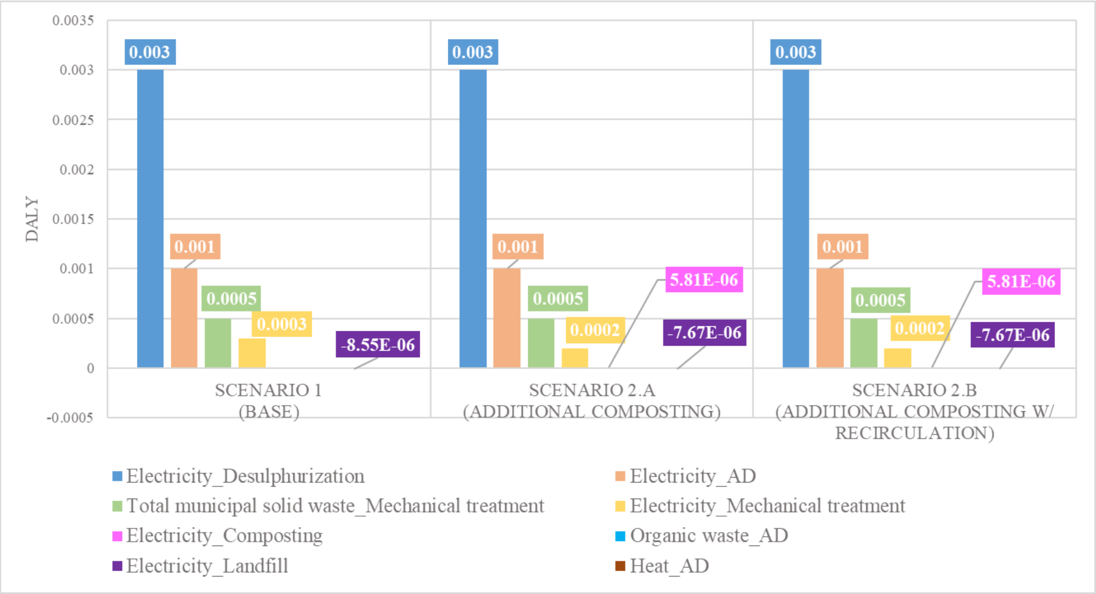


Figure 4.4 Influencing input parameter analysis of waste treatment scenarios based on GWHH.

As stated above, considering the total impact, the highest impact in the GWHH category among the 3 scenarios was observed in the baseline scenario (Scenario 1). This finding is consistent with the outcomes of the LCA study conducted by Liikanen et al. (2018) who assessed the environmental impacts of different management alternatives for MSW in São Paulo. This analysis highlights that the only landfill option has a greater impact in the category of greenhouse gas emissions compared to the alternative of composting and landfilling.

4.1.2 Environmental Impact of Desulphurization Scenarios

As stated in Sec 3.1, in the Study Plant, desulphurization process is applied in order to remove the gaseous impurities, particularly H_2S, from the biogas produced in the AD unit. Regarding the control of these impurities, there are five different techniques defined in BAT 34 of BREF BAT Conclusions, namely, BAT 34.a - biofilter (Scenario 1), BAT 34.e - wet scrubbing (Scenario 3.a), BAT 34.c - fabric filter (Scenario 3.b), BAT 34.d - thermal oxidation (Scenario 3.c), BAT 34.a - adsorption (Scenario 3.d), (Table 3.2). These BATs have been compared in terms of their environmental impacts that would be used in selecting the more appropriate BAT.

In Appendix Part A, screenshots of the process units utilized in the LCA model developed for the desulfurization scenarios are presented; each entry is clearly indicated. The characterization and normalization results are also provided in Appendix Part C. Based on the findings from the normalization and characterization analyses, the human health category, and the human health related GWHH mid-point impact category show the highest impact values. Moreover, Scenario 3.c (thermal oxidation) has the highest environmental impact. This has a resemblance to the outcomes derived from a single score results.

In this regard, the impact analysis for the above-mentioned scenarios was carried out comparatively firstly on an end-point basis. Figure 4.5displays the end-point single score results. It is clear from Figure 4.5that the "Human Health" end-point impact category is where all five of the desulphurization scenarios have the most significant influence. However, this impact was much more remarkable in Scenario 3.c where thermal oxidation is implemented. The second highest impact was on “Ecosystem” with almost same value in all scenarios, though slightly higher in Scenario 3.c. It was also observed that Scenario 3.b (fabric filter) had the lowest impact with a small difference. This finding is in line with the outputs of Ardolino et al. (2020) who similarly evaluated membrane separation, wet injection, absorption, and adsorption technologies for biogas upgrading by LCA. Accordingly, the highest impacts in the mid-point categories are expected to be seen in the categories related to “Human Health”. Figure 4.6 presents the single score results for the desulphurization scenarios based on the midpoint impact categories for a more detailed examination.

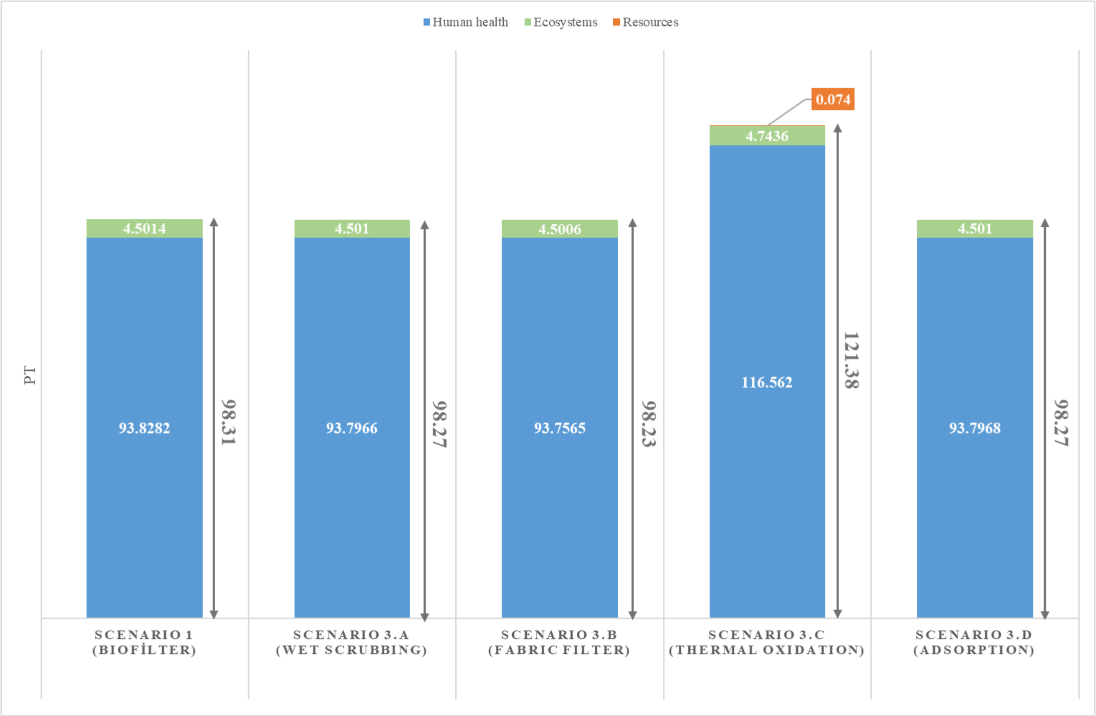


Figure 4.5 Comparative end-point single score results for desulphurization scenarios.

As expected, there were greater effects identified in the mid-point categories pertaining to the Human Health category. It is consistent with the findings presented in Figure 4.5. The highest contribution for each scenario is in the category GWHH, as can be depicted in Figure 4.6. This category is followed by the HNCT for all scenarios, though slightly higher in Scenario 3.c. Furthermore, another important finding is that the impact on the "Fine Particulate Matter Formation (FMFP)" category is noticeably different in Scenario 3.c (thermal oxidation) compared to the other scenarios. The observed phenomenon is believed to be attributable to the higher electricity input during the desulphurization procedure in Scenario 3.c in comparison to the remaining scenarios. The subsequent sections of this chapter and the data shown in Table C.6 in the Appendix part provide further evidence to support this assertion.

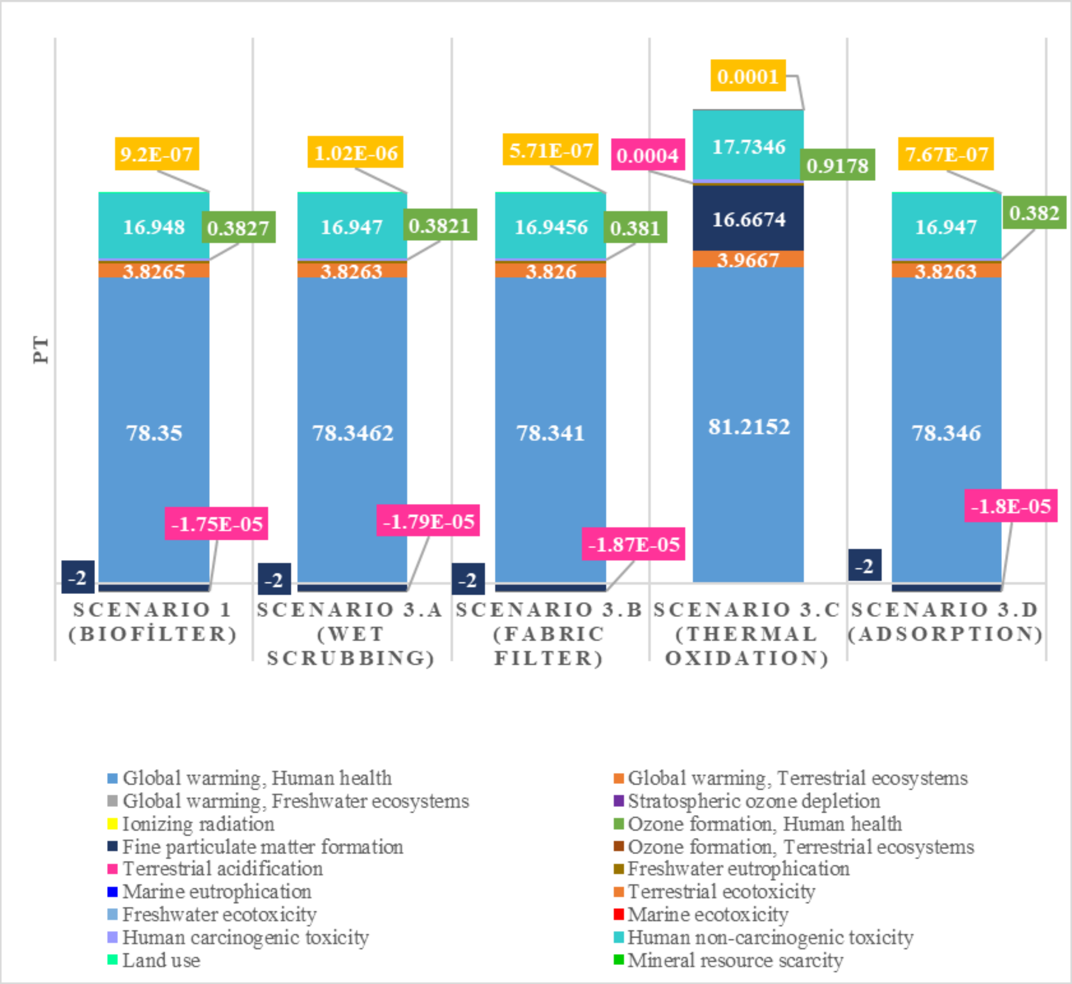


Figure 4.6 Mid-point single score results for desulphurization scenarios.

As shown in Figure 4.6, the highest impact in all five scenarios was observed in the GWHH and HNCT impact categories. Although it is the second highest category, the size of HCNT was considered inadequate for adequately adjusting the impact findings. As a result, additional examination was solely carried out for the specific impact category of GWHH for all five desulphurization scenarios.

As seen in Figure 4.6, the highest impact in the GWHH category is observed in Scenario 3.c (thermal oxidation). The difference arises from the substantially higher electricity consumption observed in this scenario in comparison to the remaining four scenarios. Figure 4.7 illustrates which unit's input and output parameters have the highest contribution to the GWHH impact value. In all desulphurization scenarios, the input and output parameters of the desulphurization unit are the primary contributors to the GWHH impact category. Also, it is seen that the contribution of these parameters has more impact in Scenario 3.c which is also the highest for GWHH category. The disparity is related to the elevated energy consumption of the desulphurization units in this scenario (Scenario 3.c). The influencing input parameter analysis of desulphurization scenarios based on GWHH is presented in Figure 4.8 for detailed examination.

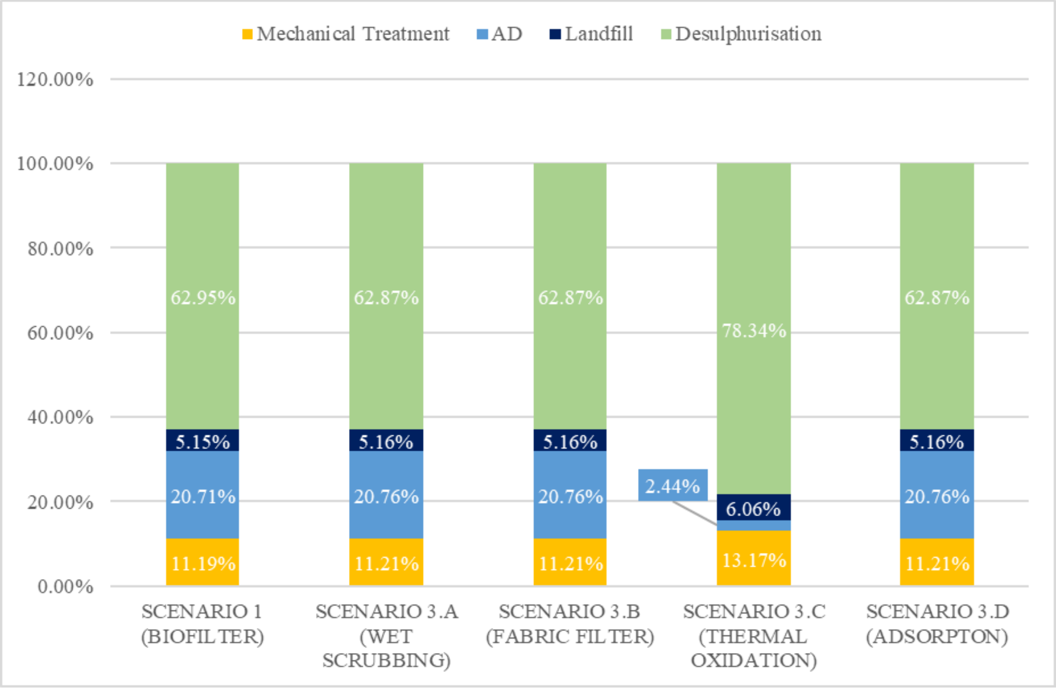


Figure 4.7 Unit- based contribution analysis of desulphurization scenarios based on GWHH.

As shown in Figure 4.8, the electricity input of the desulphurization unit is the most significant contributor for all five desulphurization scenarios. This is consistent with the outputs of Figure 4.7. Although the electricity input of the AD unit has a relatively high contribution, its contribution is the same for all scenarios.

On the other hand, Figure 4.8 indicates that the electricity inputs of the landfill and mechanical treatment units and heat inputs of AD units reduce the total GWHH impact for all scenarios except Scenario 3.c (the numerical values are also given in Table C.6 in Appendix). Therefore, the total impact value of Scenario 3.c in GWHH category is higher than the other scenarios (Table C.2 in Appendix).

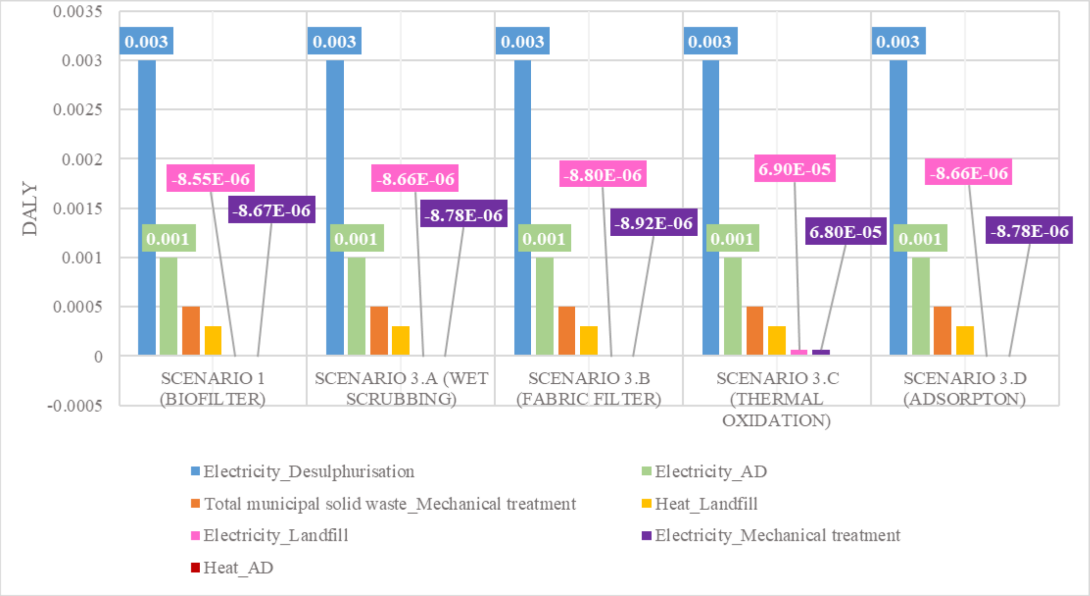


Figure 4.8 Influencing input parameter analysis of desulphurization scenarios based on GWHH.

4.1.3 Environmental Impact of Mechanical Treatment Scenarios

In the Study Plant, mechanical treatment is applied in order to reduce the dust and particulate-bound metals, PCDD/F and dioxin-like PCBs likely to be emitted from the municipal solid waste sorted in the mechanical treatment unit (Sec 3.1). Regarding the control of these emissions, there are four different techniques defined in BAT 25 of BREF BAT Conclusions, namely, BAT 25.a – cyclone separator (Scenario 4.a), BAT 25.b – fabric filter (Scenario 4.b), BAT 25.c – wet scrubbing (Scenario 4.c), BAT 25.d – water injection into the shredder), (Table 3.1 and Table 3.2). As can be inferred from Table 3.3, the latter BAT (i.e., BAT 25.d) was not included in the scenarios considered. The reason for this exclusion is that this BAT is remarked in the Waste Treatment BREF as “only applicable within the constraints associated with local conditions (e.g., low temperature, drought)”. Further, it requires the waste gas that contains residual dust to be directed to a cyclone and/or a wet scrubber. Therefore, it was deemed as not appropriate for the Study Plant. So, only the first three BATs were taken into consideration while assessing their environmental impacts that would be used in selecting the more appropriate BAT for the mechanical treatment unit. Here, it should be noted that the relevant scenarios include the use of biofilter in desulphurization which represents the existing implementation in the Study Plant. Therefore, the results obtained will also serve to understand the combined effects of each scenario with BAT 34.b.

The screenshots of the process units employed in the LCA model created for the desulfurization scenarios are displayed in Appendix Part A; each entry is clearly marked. The appendix Part D includes the results for characterization and normalization. The findings from the normalization and characterization analyses indicate that the human health category and the human health related GWHH mid-point impact category exhibit the most significant impact value. The compared scenarios exhibit small disparities. The conclusions coincide with those uncovered by the single score outcomes.

Comparative end-point basis single score results for baseline and all three mechanical treatment scenarios are given in Figure 4.9. While the variations among all scenarios are not significant, it is notable that the Human Health category receives the most significant impact across all of them. The magnitude of this impact is more remarkable (93.8791 pt) in Scenario 4.a (with cyclone) compared to the other scenarios. The present results are deemed to be associated with the rise in energy consumption resulting from the utilization of cyclone separators. This observation is further supported by the subsequent findings presented in this section, as well as the data provided in Table D.6 in the Appendix part. For a more comprehensive analysis, the single score mid-point results for the mechanical treatment scenarios are given in Figure 4.10.

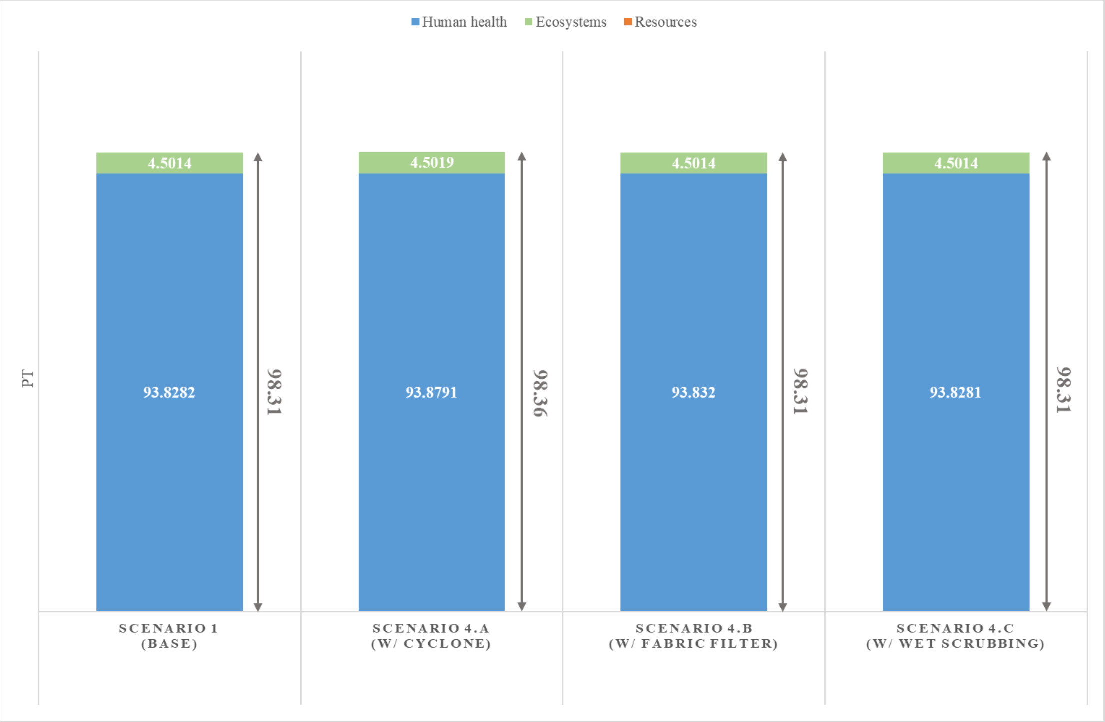


Figure 4.9 Comparative end-point single score results for mechanical treatment scenarios.

As observed in Figure 4.10, the results for the baseline and all three mechanical treatment scenarios are very close to each other. The highest impact is observed in the GWHH which is associated with the human health category, and HNCT categories, respectively. This is consistent with the findings of Figure 4.9.

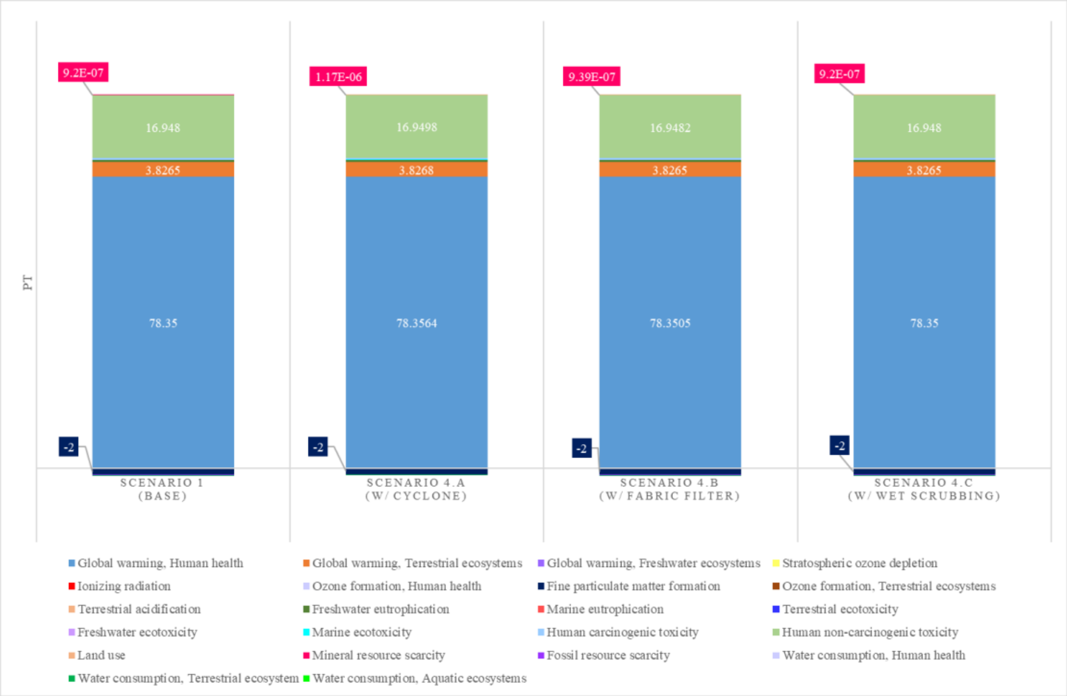


Figure 4.10 Mid-point single score results for mechanical treatment scenarios.

Despite the proximity of the impact values for the GWHH category in mechanical treatment scenarios, Scenario 4.a exhibits higher values for both impact categories compared to the other scenarios (Table D.2 in Appendix). Despite being the second highest category, the magnitude of HCNT was deemed insufficient to mitigate the negative results effectively. GWHH impact category has been focused on making analyses for baseline and all three scenarios.

Figure 4.11 depicts the analysis of the contribution in mechanical treatment scenarios based on units. The influence originated from the parameters of all units, which are seen to be identical. While desulphurization input and output parameters have the highest impact, the parameters of landfill have the lowest impact. The input and output parameters analysis are presented in Figure 4.12.

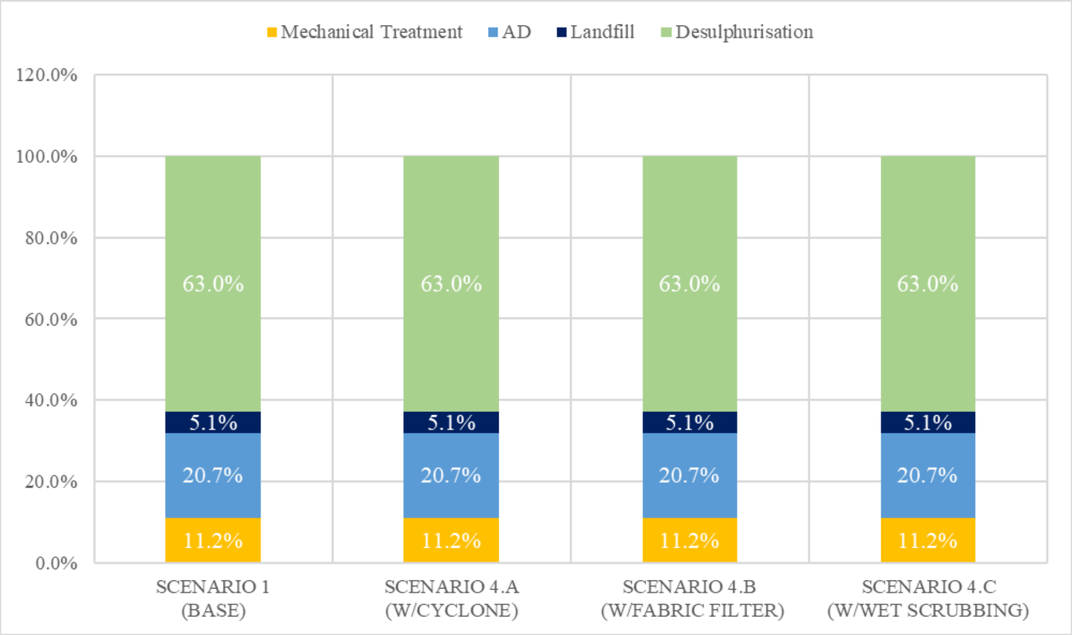


Figure 4.11 Unit- based contribution analysis of mechanical treatment scenarios based on GWHH.

As can be seen in Figure 4.12, the contribution analysis of the input and output parameters of the units of the study plant are almost the same for the baseline scenario and all three mechanical treatment scenarios. Although only the electricity input of the landfill unit and the heat input of the AD unit create small differences between the scenarios, these differences are quite negligible when the total impact is evaluated. Similarly, the electricity input of the mechanical treatment unit also creates differences between the scenarios. The observed disparities can be attributed to variations in the electrical inputs (Table D.6 in Appendix part) utilized by the procedures led by BAT25. Nevertheless, the electrical consumption of the mechanical treatment unit exhibits a minimal influence on the GWHH effect category. Hence, the disparities among the scenarios generated by various approaches are inconsequential.

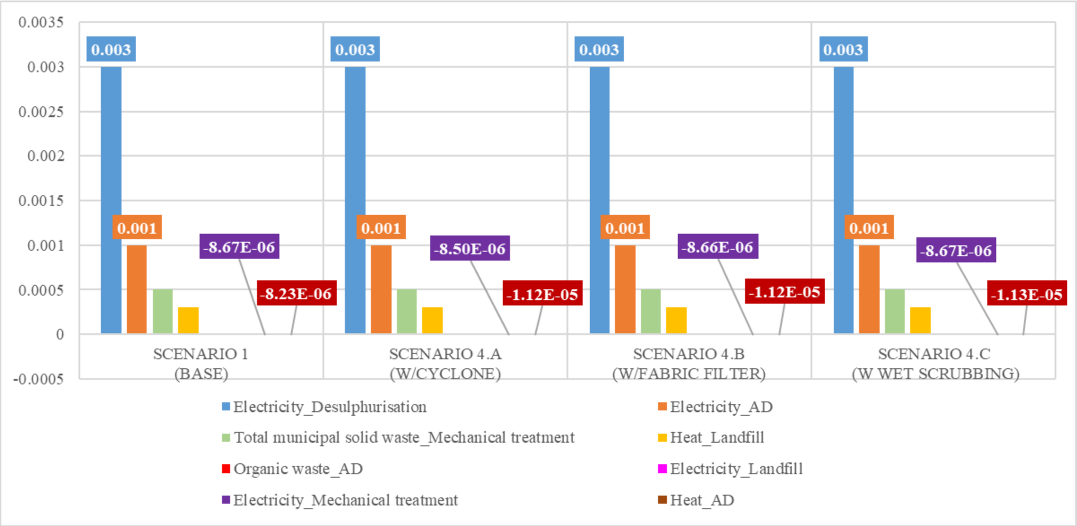


Figure 4.12 Influencing input parameter analysis of mechanical treatment scenarios based on GWHH.

4.2 Sensitivity Analysis

The inclusion of sensitivity analysis has significant importance in the ultimate interpretation. The ISO standards pertaining to LCA studies recognize the significance of sensitivity analysis. However, they do not offer explicit guidance or suggestions on the specific technique or criteria to be employed in performing or selecting an appropriate sensitivity analysis. A crucial parameter to be selected exhibits a high sensitivity, meaning that even a slight change in its value would have a substantial impact on the outcome or considerably contribute to the variability of the output. The purpose of doing a sensitivity analysis in this study is to assess the extent to which variations in the indicated parameters influence the outcomes, and to compare these variations with the baseline scenario.

4.2.1 Effect of Variation in the Electricity Type

In this study, “the electricity grid mix for Turkey” was used as electricity data in the Ecoinvent database. When the results presented in Sec. 4.1 are analyzed, it is observed that the GWHH impact is the highest in all scenarios. It is also clear that the parameter that contributes the most to the GWHH impact category is the electricity input of the desulphurization unit. For this reason, the results were compared by selecting different electricity-type modules from the Ecoinvent database. For this purpose, three different electricity type modules were selected from the Ecoinvent database:

- Module 1: Electricity, medium voltage {TR}| market for | Conseq, U (Electricity grid mix for Turkey): electricity grid mix for Turkey; used as default in the LCA runs in this study.
- Module 2: Electricity grid mix 1kV-60kV, AC, consumption mix, at consumer, 1kV - 60kV EU-27 S System - Copied from ELCD: electricity grid mix for Europe; selected based on its use in readily available process modules in the Ecoinvent Database.
- Module 3: Electricity from wind power, AC, production mix, at wind turbine, < 1kV RER S System - Copied from ELCD: The electricity from wind farms; selected as to represent renewable energy source.

This sensitivity analysis was conducted only for Scenario 3.c, which has the highest total impact value among all scenarios studied. The end- point single score results for variation of the electricity type are provided in Figure 4.13 (the numerical values also given in Table E.1 in Appendix). As seen in this figure, the impact has a decreasing trend in all three end- point categories (Human Health, Ecosystems, and Resources) from Scenario 3.c with Module 1 to with Module 3. Comparison between Scenario 3.c (Module 1) and Scenario 3.c (Module 2) revealed that the declines for three end-point impact categories are 13%, 0.79% and %38, respectively. Similarly, the fall between Scenario 3.c (Module 1) and Scenario 3.c (Module 3) for three end- point categories are 17%, 4.46% and 107%, respectively. The highest difference in both comparisons is observed in the Resources impact category. As a result, the total environmental impact in Scenario 3.c (Module 1) is 53% less than in Scenario 3.c (Module 2), when the total impact is reduced by 128% in Scenario 3.c (Module 3) to Scenario 3.c (Module 1). So, the selection of electricity type influences the overall results remarkably.

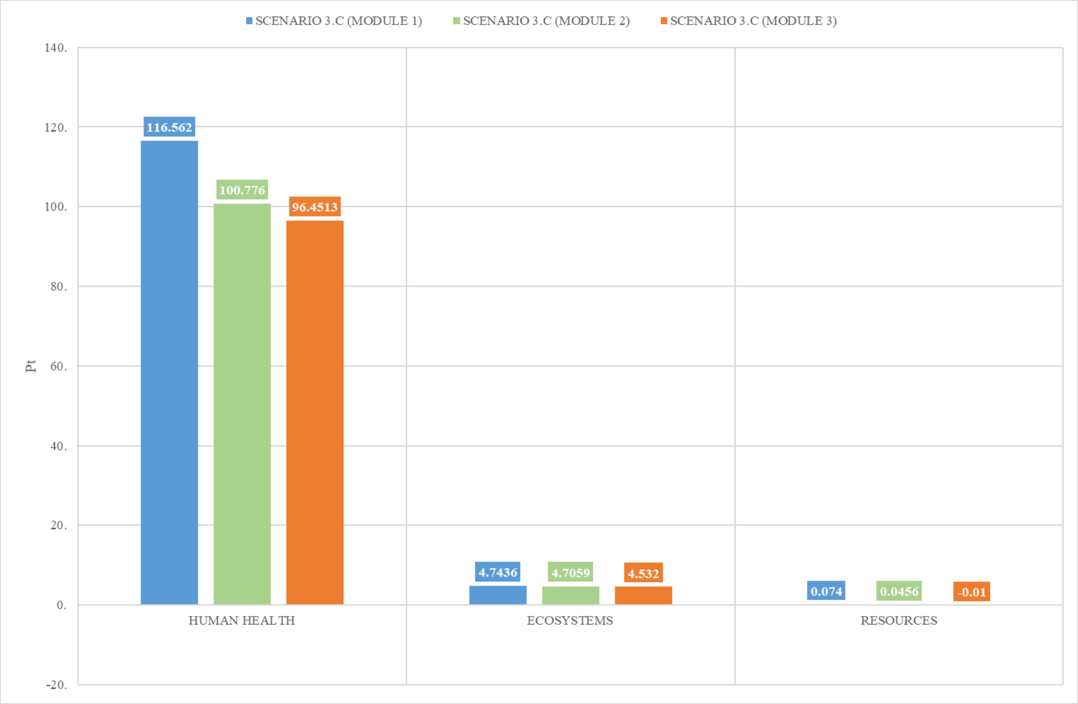


Figure 4.13 Comparative end-point single- score results with different electricity type.

4.2.2 Effect of Bulking Agent Using in Composting Unit

As mentioned in Section 3.1, the components required for composting are assumed to be implemented for the solid digestate. In other words, only water, electricity and diesel were accepted as system inputs. During the sensitivity analysis, since bulking agents were indicated as an input in some studies (Adhikari et al., 2009; Keng et al., 2020), the bulking agent was also included in the input parameters and compared. Therefore, it was deemed worth considering this assumed input parameter during the sensitivity analysis. This sensitivity analysis was performed only for Scenario 2.a, and the results of both scenarios were compared with the baseline Scenario 2.a. The required amount was calculated according to the ratio presented in the literature by Keng et al. (2020) and Adhikari et al. (2009) where bulking agents of miscanthus chopped and wood chips were added at a ratio of 5:1 and 4:1, respectively. Figure 4.14 (the numerical values also given in Table E.2 in Appendix) demonstrates the single score end- point results for the situation using bulking agent in composting.

As shown in Figure 4.14, the impact on the Human Health category increases from 93.8942 to 93.9195 when Scenario 2.a is changed to Scenario 2.a with added wood chips. In comparing Scenario 2.a and Scenario 2.a with added miscanthus chopped), the differences for three end-point impact categories revealed as -2.27%, 1.1% and %0.04, respectively (Table E.2 in Appendix). Similarly, the disparity between Scenario 2.a and Scenario 2.a with added wood chips for three end- point categories were observed to be 2.5%, -3.2% and 3.7%, respectively. The total difference between Scenario 2.a with chopped Miscanthus and Scenario 2.a is 1.13%, while the total effect in Scenario 2.a with added wood chips increased by 3.03% compared to Scenario 2.a. Thus, using bulking agent does not affect the overall results in this study.

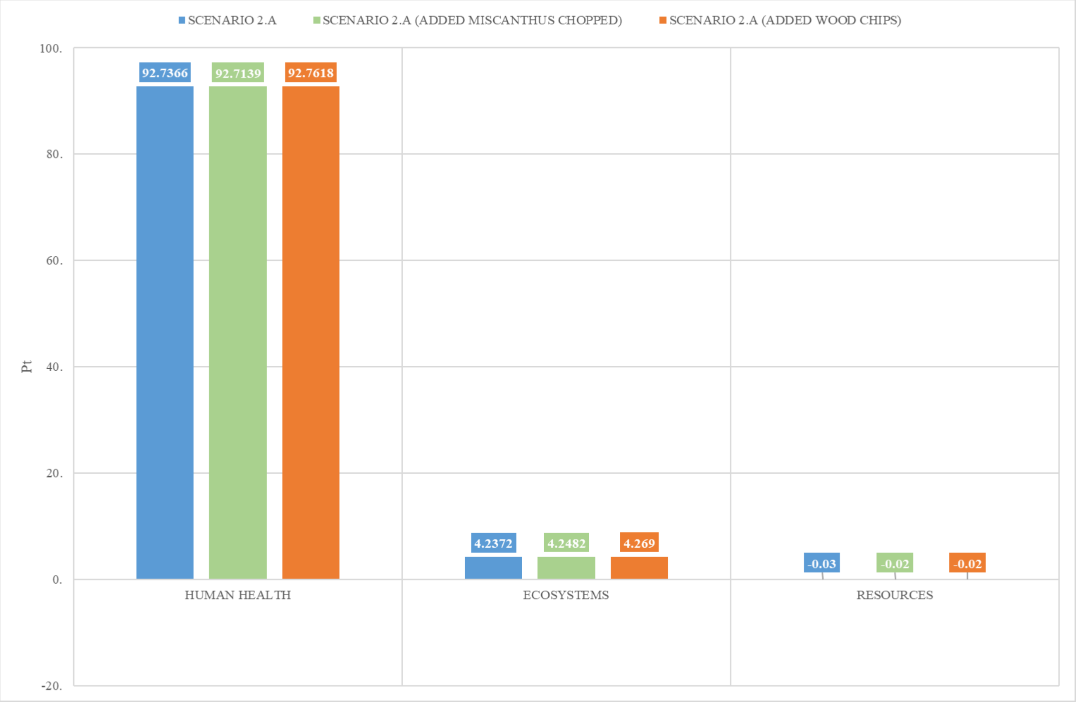


Figure 4.14 Comparative end-point single- score results for using bulking agent in composting.

4.2.3 Effect of Emissions Level to Soil in Composting Unit

The values of emissions to soil were taken from the Official Gazette (2018). A sensitivity assessment was performed by entering 5%, 10% and 15% more of these values into the system. It is because these values are given as minimum limits as required by the regulation. As in the case presented in Sec. 4.2.2, this sensitivity analysis was performed for only Scenario 2.a, and the results of three scenarios were compared with baseline Scenario 2.a. Figure 4.15 shows the end-point single score results for varied values of emissions to soil. As shown in this figure (the numerical values are also given in Table E.3 in the Appendix), while the impact values remain the same in both Ecosystems and Resources categories for all four alternatives, the impact on Human Health category increases from Scenario 2.a to Scenario 2.a w/ 15% rise in emissions. The disparity between Scenario 2.a and the alternatives related to soil emissions level are 0.23%, 0.47% and 0.47%, respectively. Hence, the effect of variation in the emissions to soil level in the composting unit is found to be negligible for the overall results of this study.

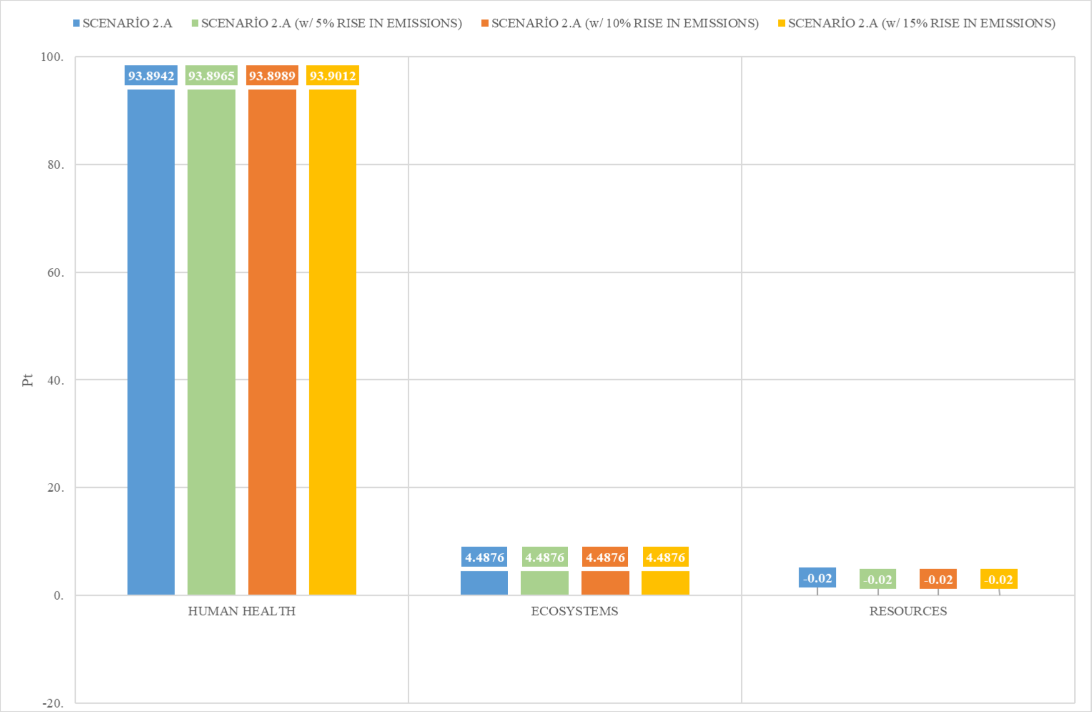


Figure 4.15 Comparative end-point single- score results for variation in emission levels to soil.

4.2.4 Effect of Loss of Methane in Desulphurization Unit

As previously indicated in Table 3.9, it is assumed that there is no methane loss when using the desulphurization techniques considered. According to Beil & Beyrich (2013), methane loss is 3.75% in adsorption and 1.25% in wet scrubbing. The ratio of methane loss is identical for both wet scrubbing and thermal oxidation based on the research by Moscato et al. (2020). The other quoted figures are 0.81% with fabric filters (Kvist & Aryal, 2019) and 0.5% with biofilters (Wechselberger et al., 2023). The sensitivity analysis was implemented in all five desulphurization scenarios studied, and the results were compared with baseline desulphurization scenarios (Table E.4 in Appendix). The end- point single score results belonging to the different levels of the methane loss during the desulphurization are presented in Figure 4.16.

As observed in Figure 4.16, even though the impact on the 'Resources' category is the same for both situations in all five scenarios, the impact on both the 'Human Health' and 'Ecosystems' categories declines with the exception in the 'Human Health' impact category for Scenario 1. The difference between baseline desulphurization scenarios (Scenario 1, Scenario 3.a, Scenario 3.b, Scenario 3.c, Scenario 3.d) and the optional scenarios (w/ methane loss) are found to be 0.26%, -0.65%, -0.43%, -0.52% and -1.97%, respectively in 'Human Health' impact category while -0.26%, -0.66%, -0.43%, -0.63% and -2%, respectively, in 'Ecosystems' impact category (Table E.4 in Appendix). As a result, total impact variation for this comparison is revealed to be -0.004%, -1.33%, -0.87%, -1.16% and -3.97%, respectively (Table E.4 in Appendix). So, it can be safely stated that the methane loss does not affect the overall results of this study.

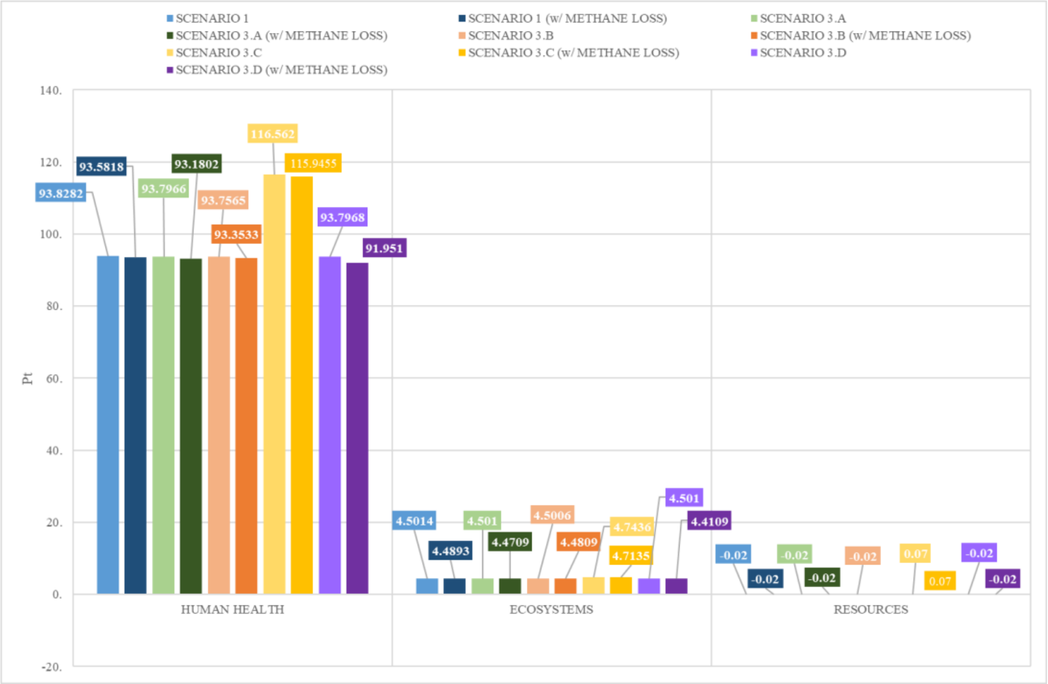


Figure 4.16 Comparative end-point single- score results in the situations for methane loss in desulphurization unit.

CHAPTER 5

CONCLUSION

The objective of this study is to assess the applicability of BATs (Best Available Techniques) as outlined in the European Waste Treatment BREF (BAT Reference Document) guidelines, with a specific emphasis on the impacts on the environment within a selected integrated solid waste facility. The environmental impacts of the waste treatment processes at the facility were assessed using LCA (Life Cycle Assessment) methodology. The evaluation encompassed the identification of BATs that were intended for the reduction of dust emissions in the mechanical treatment unit and hydrogen sulfide emissions in the desulphurization unit. The study also evaluated two good practices mentioned in the Waste Treatment BREF: (i) the environmental impact of implementing composting for handling solid digestate from AD (Anaerobic Digestion) and (ii) the influence of the water recirculation on the composting of the solid digestate.

The following conclusions were drawn from this study:

Related to the Integration of the Composting Unit

- The assessment of the solid digestate originating from AD revealed that the landfilling option has a lower environmental impact than the composting. The increased electrical input of the composting unit was addressed.
- The contribution of water input to environmental impact was considerably less than that of energy and the total amount of municipal waste inputs.
- Additionally, the impact assessment results did not indicate any significant variation in the overall environmental impact as a result of water recirculation in the composting process. Hence, the influence of avoided water on the environmental consequences of composting was negligible.

- Also, sensitivity analysis was conducted to examine the impact of both variations in emissions to soil and the utilization of bulking agent in the composting unit, showing that the overall impacts were not sensitive to these parameters.
- Considering the electricity input appeared as the primary contributing parameter, sensitivity analyses performed for different types of electricity mix modules revealed that the impact of the choice of electricity module should not be ignored.
- A noteworthy finding of this study is that the utilization of renewable energy (specifically 100% wind-generated electricity leads to a substantial decrease in the overall environmental impact in comparison to the grid mix type designed for Turkey.

Related to the Implementation of BAT 25

- There is an absence of significant disparities observed in the impact outcomes of the methods implementedin line with BAT25 considered with an emphasis on mitigating dust emissions in mechanical treatment.
- Hence, the utilization of wet scrubber, fabric filter, and cyclone separator in mechanical treatment has a minimal impact on the overall environmental impact.

Related to the Implementation of BAT 34

- Thermal oxidation has the highest environmental impact of all alternatives constructed in line with BAT34. This is due to the fact that the energy input is the main contributor to the GWHH impact category, which exhibited the highest impact in all scenarios.
- On the other hand, using a fabric filter to reduce H2S concentration in the desulphurization unit has the least environmental impact.
- The effect of methane losses for alternate methods employed in desulphurization showed that the overall impacts were not sensitive to this parameter.

Related to the Implementation of BAT 25 and BAT 34

- The impact assessment of reducing the dust emission and H_2S concentration via the methods mentioned in both BAT 25 and 34 consistently highlighted the significance of impacts in the Global Warming Human Health (GWHH) impact category. The key indicator responsible for this impact appeared to be the input of electricity.
- Although the Human Non-Carcinogenic Toxicity (HNCT) category demonstrated the second highest level of influence for each option, the observed impacts were not sufficiently large to make a further elaboration on the relevant responsible key indicator.

In conclusion, the options suggested in BAT34 offer a possibility to reduce the environmental impacts, though BAT25 does not significantly alter the environmental impacts.

5.1 Summary of Results

As a result of all these evaluations, the prominent findings of the study are summarized in Table 5.1.

Table 5.1 Summary of Results

Related Category	**Results**
Integration of Composting	The evaluation of the solid digestate derived from anaerobic digestion indicates that landfilling has a lesser environmental impact compared to composting. The heightened electrical input of the composting unit was resolved.
	The water input made a significantly smaller contribution to the overall environmental impact compared to the energy input and the entire volume of municipal trash inputs.
	An important discovery from this study is that the use of renewable energy, notably electricity generated entirely from wind power, results in a significant reduction in the total environmental effect when compared to the system mix established for Turkey.
Implementation of BAT 25	The use of wet scrubber, fabric filter, and cyclone separator in mechanical treatment has a negligible effect on the total environmental impact.
Implementation of BAT 34	Thermal oxidation exhibits the most significant environmental impact among all the alternatives developed in accordance with BAT 34 (BAT34). The primary reason for this is that energy intake is the key driver of the GWHH impact category, which consistently shows the greatest impact across all situations.
	Using a fabric filter to decrease the concentration of H2S in a desulphurization unit has the lowest environmental impact.
Implementation of BAT 25 and BAT 34	The evaluation of the effects of lowering dust emission and H2S concentration, as described in both BAT 25 and 34, repeatedly emphasized the importance of consequences in the Global Warming Human Health (GWHH) impact category. The primary factor that caused this effect was the introduction of electrical input.

CHAPTER 6

RECOMMENDATION

6.1 Recommendation for the Study Plant

One of the most important findings of this study is that the electricity generated from renewable energy (100% wind) from the electricity modules evaluated in the sensitivity analysis significantly reduces the total environmental impact compared to the grid mix created for Turkey. In this case, considering the geography and climatic conditions of the facility, it is recommended that the conditions are suitable for a wind power plant and that the facility should consider getting its energy entirely from renewable sources in the long term.

6.2 Recommendation for Future Work

The findings of this study indicate that the outcomes of impact assessments may differ based on many characteristics associated with the methodologies employed, including the factors related to damage, characterization, and normalization. Moreover, the accuracy of the findings of this study is likely to change in line with the assumptions made in this study.

The sensitivity analysis has revealed that the electricity input has emerged as a significant parameter. Therefore, variations in the composition of the electricity generation mix will have an impact on the outcomes. It is advisable to undertake a site-specific investigation to assess the influence of the local electricity generating mix on the study.

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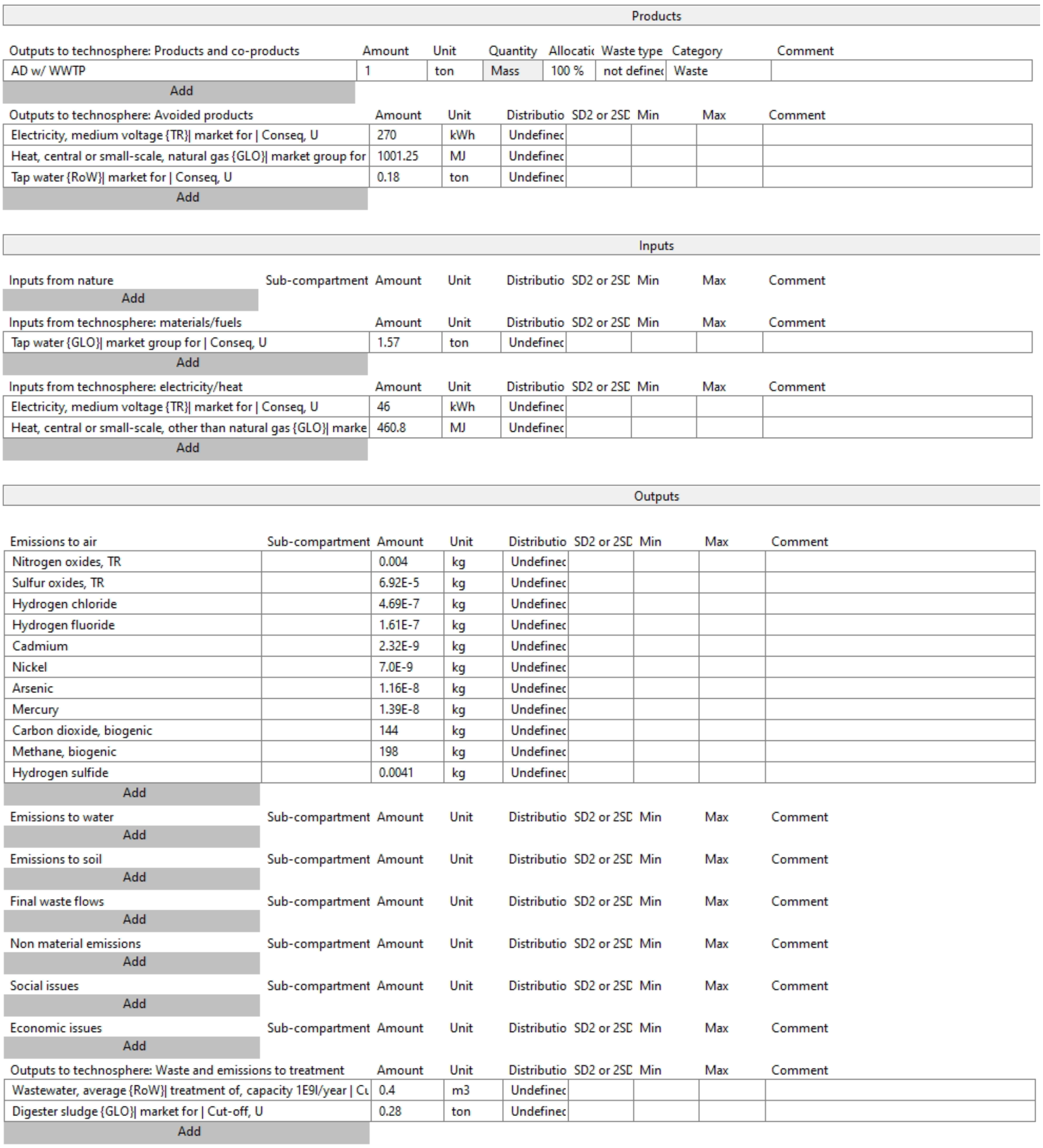
APPENDICES

A. Life Cycle Inventory Screenshots in Simapro

Anaerobic Digestion (AD w/ WWTP)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
AD w/ WWTP	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	270	kWh	Undefinec				
Heat, central or small-scale, natural gas {GLO}| market group for	1001.25	MJ	Undefinec				
Tap water {RoW}| market for | Conseq, U	0.18	ton	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {GLO}| market group for | Conseq, U	1.57	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	46	kWh	Undefinec				
Heat, central or small-scale, other than natural gas {GLO}| marke	460.8	MJ	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Nitrogen oxides, TR		0.004	kg	Undefinec				
Sulfur oxides, TR		6.92E-5	kg	Undefinec				
Hydrogen chloride		4.69E-7	kg	Undefinec				
Hydrogen fluoride		1.61E-7	kg	Undefinec				
Cadmium		2.32E-9	kg	Undefinec				
Nickel		7.0E-9	kg	Undefinec				
Arsenic		1.16E-8	kg	Undefinec				
Mercury		1.39E-8	kg	Undefinec				
Carbon dioxide, biogenic		144	kg	Undefinec				
Methane, biogenic		198	kg	Undefinec				
Hydrogen sulfide		0.0041	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

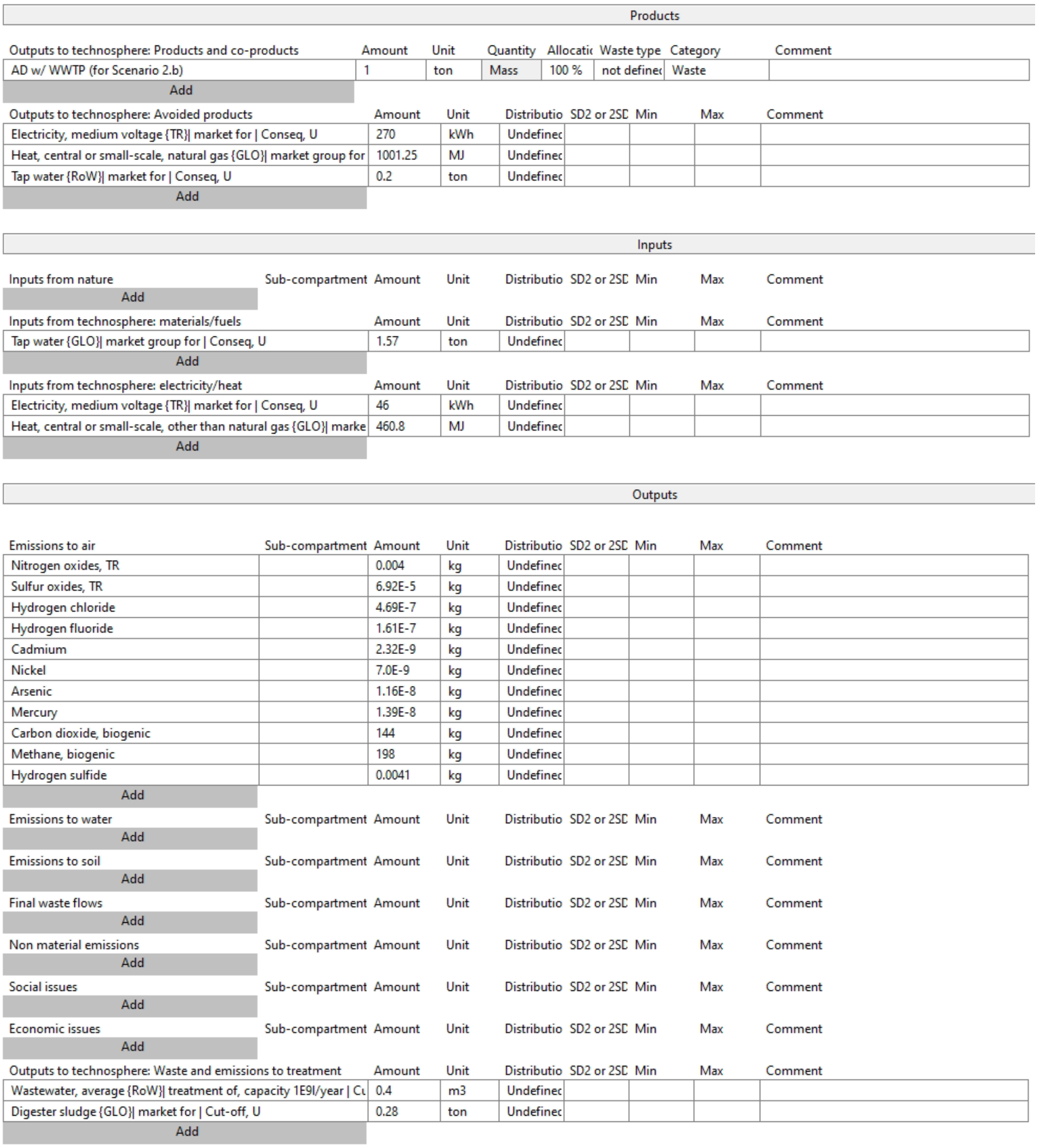
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.4	m3	Undefinec				
Digester sludge {GLO}| market for | Cut-off, U	0.28	ton	Undefinec				

Anaerobic Digestion (AD w/ WWTP for Scenario 2.b)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
AD w/ WWTP (for Scenario 2.b)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	270	kWh	Undefinec				
Heat, central or small-scale, natural gas {GLO}| market group for	1001.25	MJ	Undefinec				
Tap water {RoW}| market for | Conseq, U	0.2	ton	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {GLO}| market group for | Conseq, U	1.57	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	46	kWh	Undefinec				
Heat, central or small-scale, other than natural gas {GLO}| marke	460.8	MJ	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Nitrogen oxides, TR		0.004	kg	Undefinec				
Sulfur oxides, TR		6.92E-5	kg	Undefinec				
Hydrogen chloride		4.69E-7	kg	Undefinec				
Hydrogen fluoride		1.61E-7	kg	Undefinec				
Cadmium		2.32E-9	kg	Undefinec				
Nickel		7.0E-9	kg	Undefinec				
Arsenic		1.16E-8	kg	Undefinec				
Mercury		1.39E-8	kg	Undefinec				
Carbon dioxide, biogenic		144	kg	Undefinec				
Methane, biogenic		198	kg	Undefinec				
Hydrogen sulfide		0.0041	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

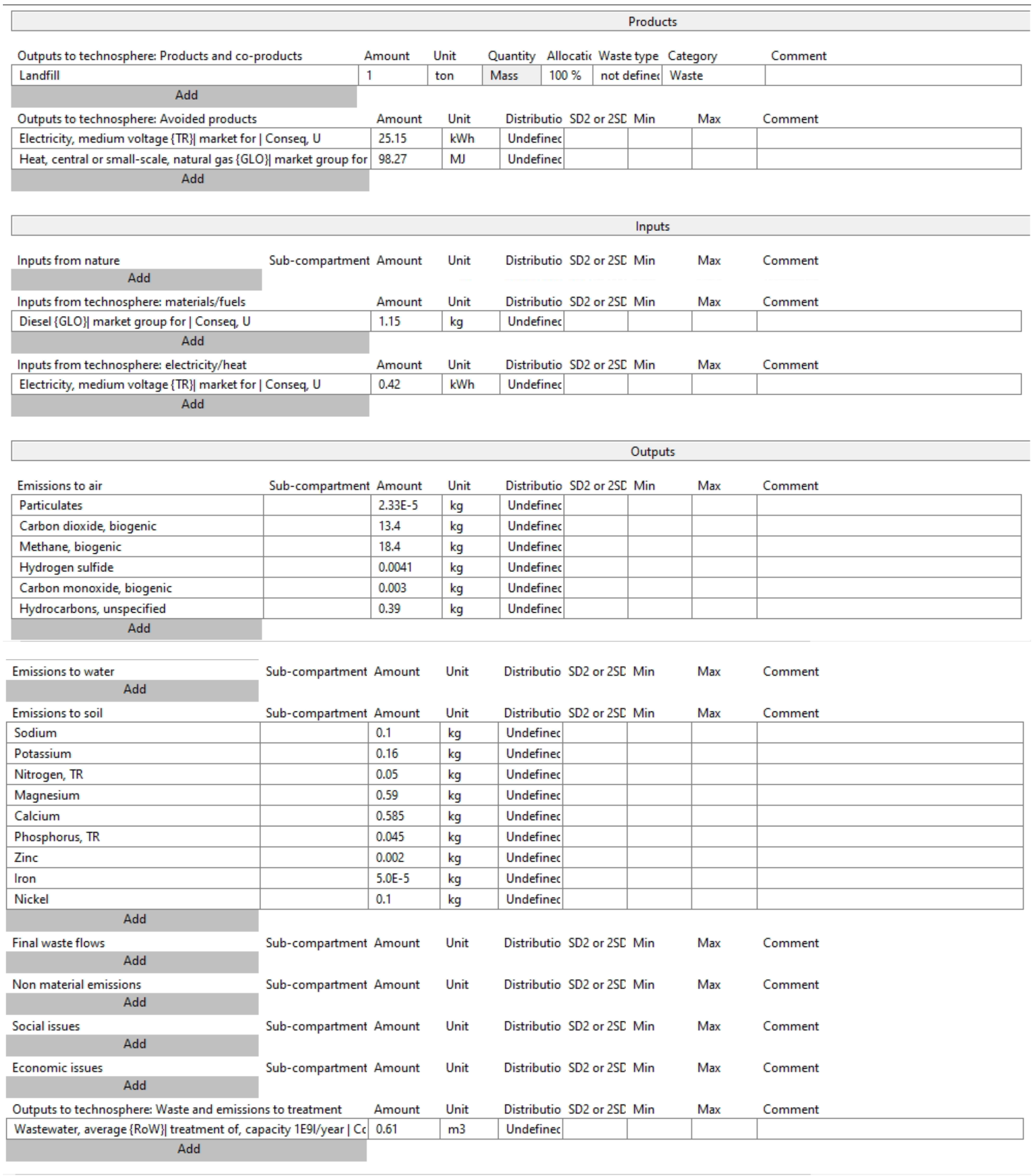
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.4	m3	Undefinec				
Digester sludge {GLO}| market for | Cut-off, U	0.28	ton	Undefinec				

Landfill



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatio	Waste type	Category	Comment
Landfill	1	ton	Mass	100 %	not defined	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	25.15	kWh	Undefined				
Heat, central or small-scale, natural gas {GLO}| market group for	98.27	MJ	Undefined				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Diesel {GLO}| market group for | Conseq, U	1.15	kg	Undefined				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	0.42	kWh	Undefined				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Particulates		2.33E-5	kg	Undefined				
Carbon dioxide, biogenic		13.4	kg	Undefined				
Methane, biogenic		18.4	kg	Undefined				
Hydrogen sulfide		0.0041	kg	Undefined				
Carbon monoxide, biogenic		0.003	kg	Undefined				
Hydrocarbons, unspecified		0.39	kg	Undefined				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Sodium		0.1	kg	Undefined				
Potassium		0.16	kg	Undefined				
Nitrogen, TR		0.05	kg	Undefined				
Magnesium		0.59	kg	Undefined				
Calcium		0.585	kg	Undefined				
Phosphorus, TR		0.045	kg	Undefined				
Zinc		0.002	kg	Undefined				
Iron		5.0E-5	kg	Undefined				
Nickel		0.1	kg	Undefined				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

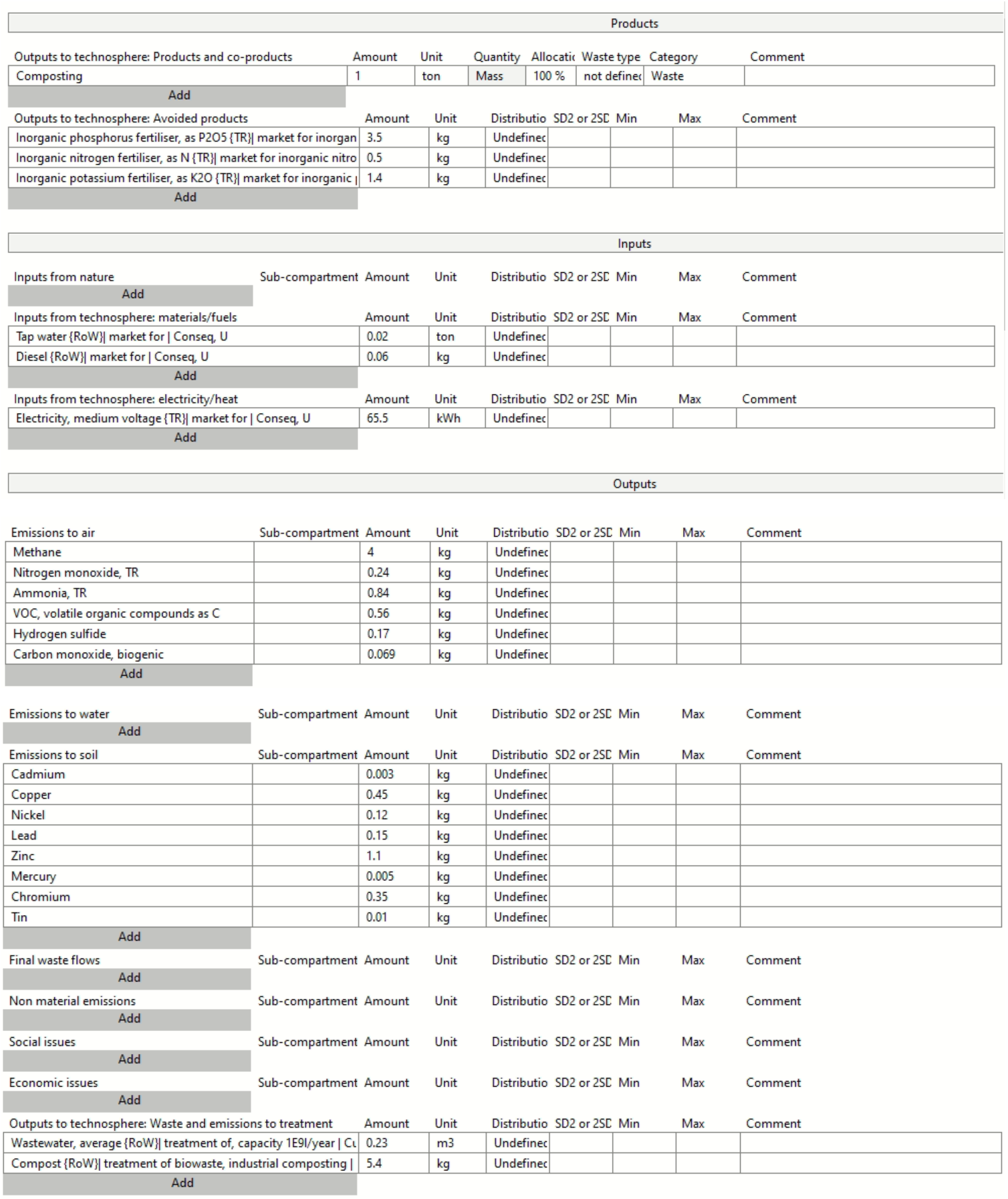
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Co	0.61	m3	Undefined				

Composting



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Composting	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Inorganic phosphorus fertiliser, as P2O5 {TR}| market for inorgan	3.5	kg	Undefinec				
Inorganic nitrogen fertiliser, as N {TR}| market for inorganic nitro	0.5	kg	Undefinec				
Inorganic potassium fertiliser, as K2O {TR}| market for inorganic	1.4	kg	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {RoW}| market for | Conseq, U	0.02	ton	Undefinec				
Diesel {RoW}| market for | Conseq, U	0.06	kg	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	65.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Methane		4	kg	Undefinec				
Nitrogen monoxide, TR		0.24	kg	Undefinec				
Ammonia, TR		0.84	kg	Undefinec				
VOC, volatile organic compounds as C		0.56	kg	Undefinec				
Hydrogen sulfide		0.17	kg	Undefinec				
Carbon monoxide, biogenic		0.069	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Cadmium		0.003	kg	Undefinec				
Copper		0.45	kg	Undefinec				
Nickel		0.12	kg	Undefinec				
Lead		0.15	kg	Undefinec				
Zinc		1.1	kg	Undefinec				
Mercury		0.005	kg	Undefinec				
Chromium		0.35	kg	Undefinec				
Tin		0.01	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

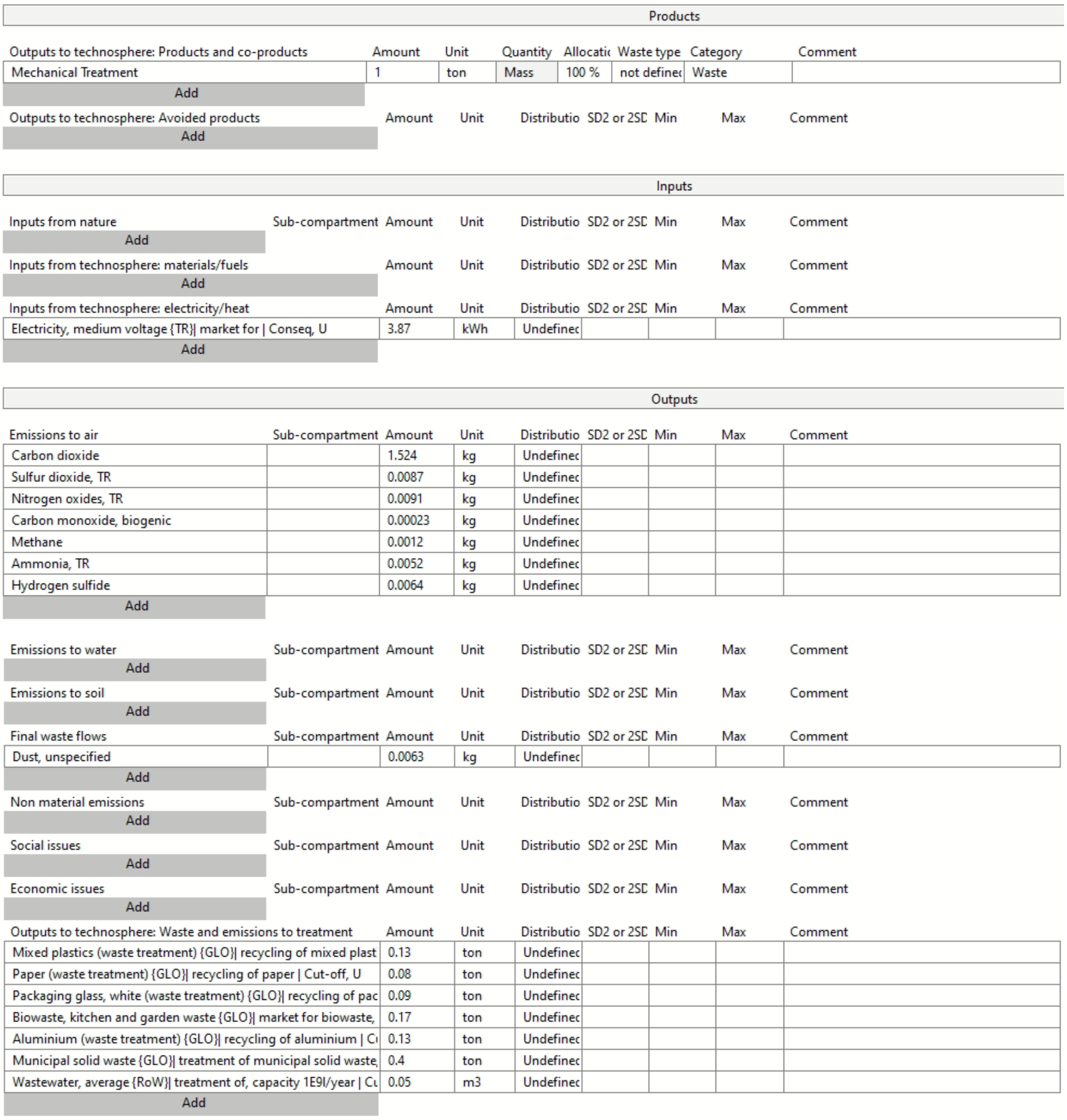
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.23	m3	Undefinec				
Compost {RoW}| treatment of biowaste, industrial composting |	5.4	kg	Undefinec				

Mechanical Treatment



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatio	Waste type	Category	Comment
Mechanical Treatment	1	ton	Mass	100 %	not defined	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.87	kWh	Undefined				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		1.524	kg	Undefined				
Sulfur dioxide, TR		0.0087	kg	Undefined				
Nitrogen oxides, TR		0.0091	kg	Undefined				
Carbon monoxide, biogenic		0.00023	kg	Undefined				
Methane		0.0012	kg	Undefined				
Ammonia, TR		0.0052	kg	Undefined				
Hydrogen sulfide		0.0064	kg	Undefined				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Dust, unspecified		0.0063	kg	Undefined				

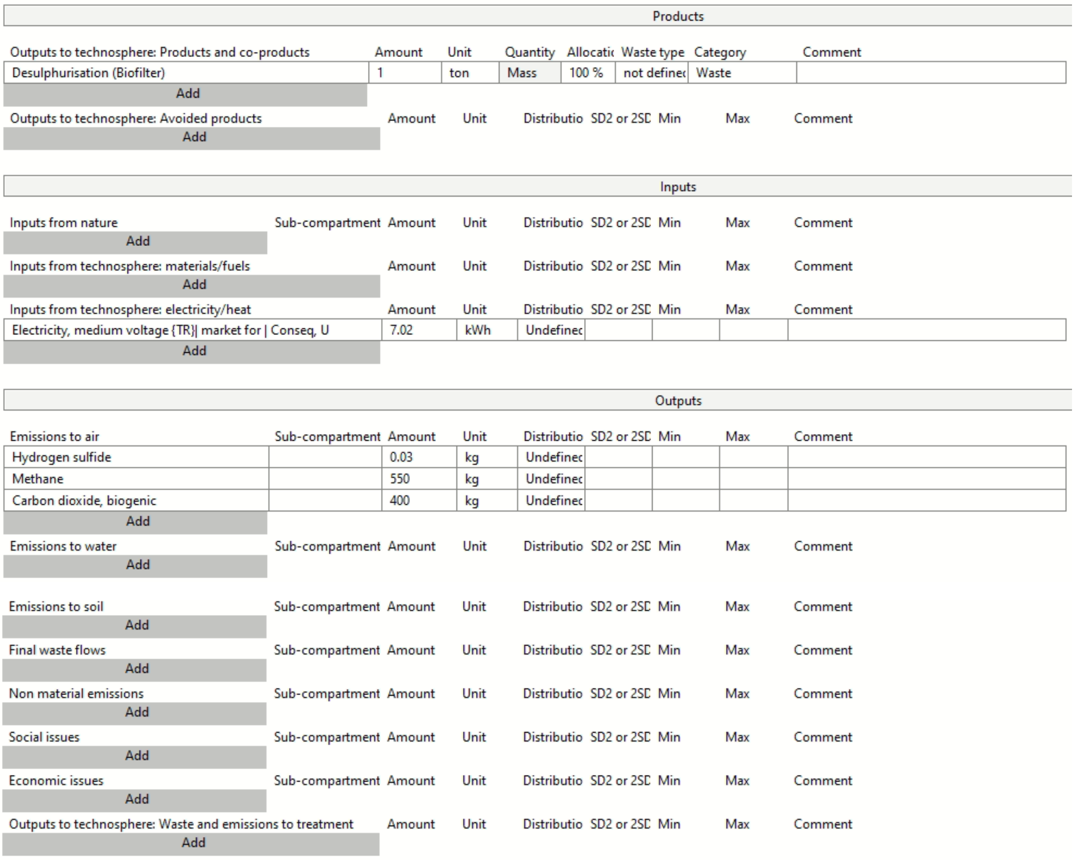
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Mixed plastics (waste treatment) {GLO}| recycling of mixed plast	0.13	ton	Undefined				
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	0.08	ton	Undefined				
Packaging glass, white (waste treatment) {GLO}| recycling of pac	0.09	ton	Undefined				
Biowaste, kitchen and garden waste {GLO}| market for biowaste,	0.17	ton	Undefined				
Aluminium (waste treatment) {GLO}| recycling of aluminium | C	0.13	ton	Undefined				
Municipal solid waste {GLO}| treatment of municipal solid waste,	0.4	ton	Undefined				
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | C	0.05	m3	Undefined				

Desulphurization (Biofilter)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Biofilter)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	7.02	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.03	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

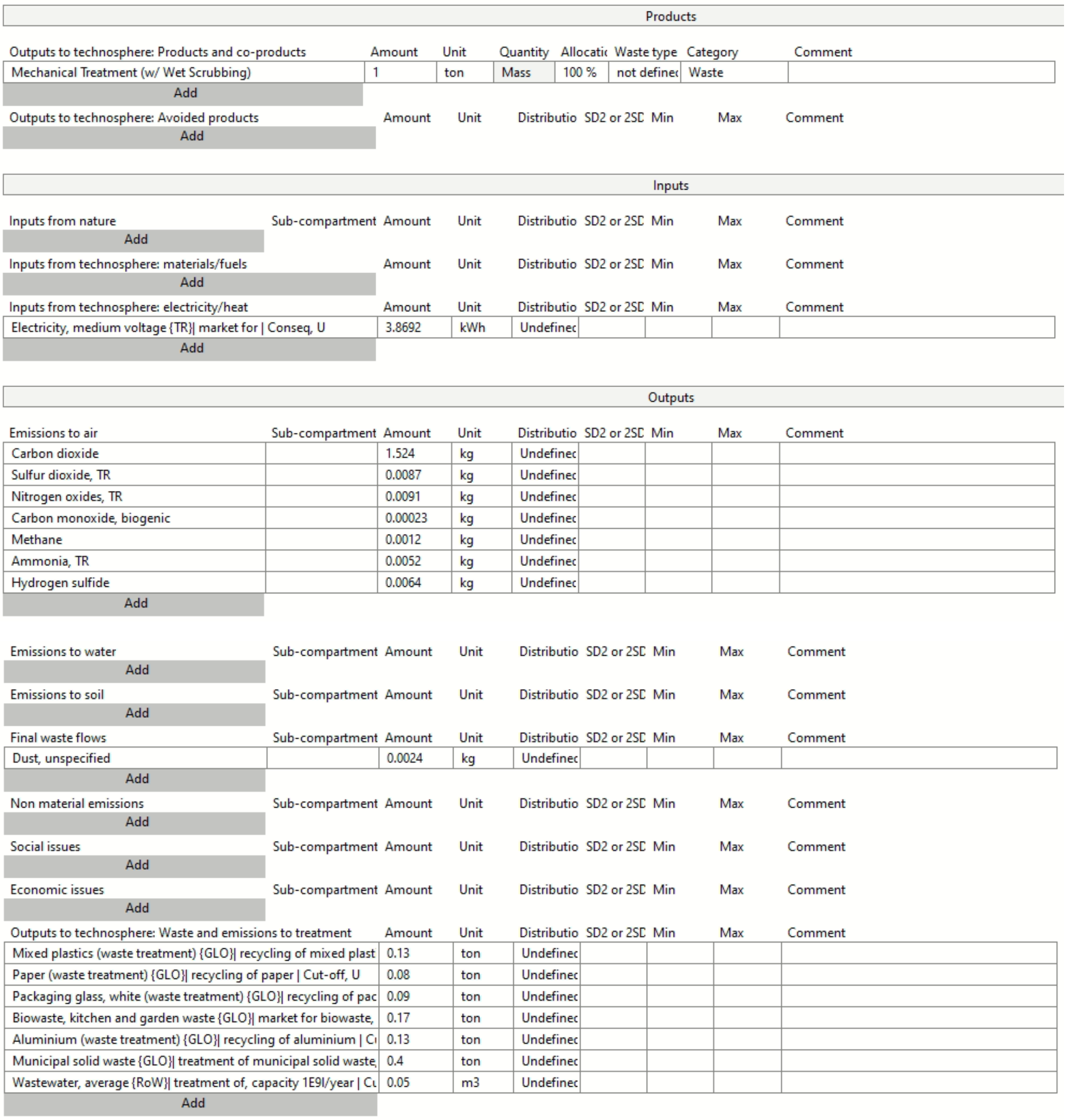
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Mechanical Treatment (w/ Wet Scrubbing)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Mechanical Treatment (w/ Wet Scrubbing)	1	ton	Mass	100 %	not definec	Waste	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.8692	kWh	Undefinec				

Add

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		1.524	kg	Undefinec				
Sulfur dioxide, TR		0.0087	kg	Undefinec				
Nitrogen oxides, TR		0.0091	kg	Undefinec				
Carbon monoxide, biogenic		0.00023	kg	Undefinec				
Methane		0.0012	kg	Undefinec				
Ammonia, TR		0.0052	kg	Undefinec				
Hydrogen sulfide		0.0064	kg	Undefinec				

Add

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Dust, unspecified		0.0024	kg	Undefinec				

Add

Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

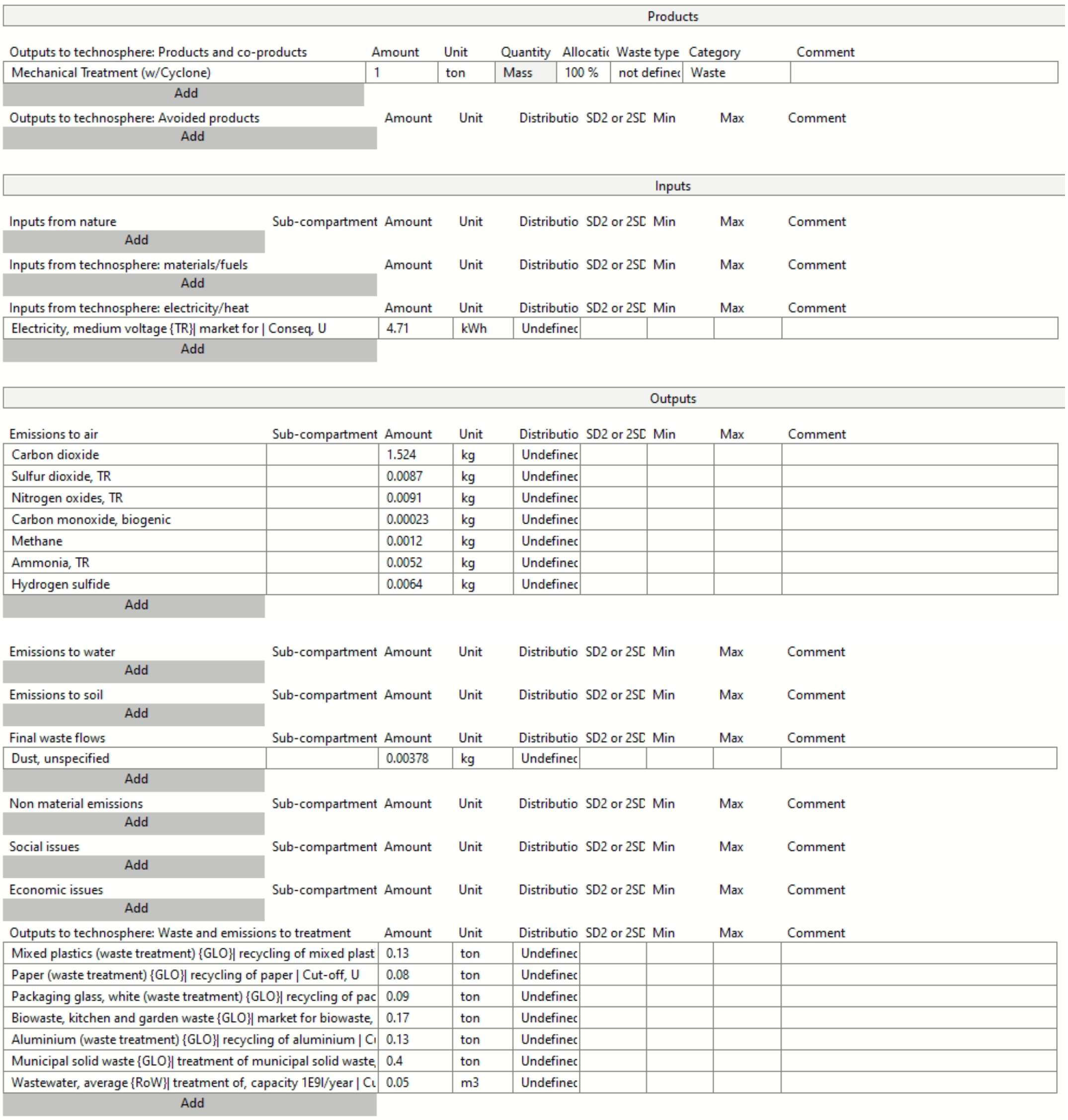
Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Mixed plastics (waste treatment) {GLO}| recycling of mixed plast	0.13	ton	Undefinec				
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	0.08	ton	Undefinec				
Packaging glass, white (waste treatment) {GLO}| recycling of pac	0.09	ton	Undefinec				
Biowaste, kitchen and garden waste {GLO}| market for biowaste,	0.17	ton	Undefinec				
Aluminium (waste treatment) {GLO}| recycling of aluminium | C	0.13	ton	Undefinec				
Municipal solid waste {GLO}| treatment of municipal solid waste,	0.4	ton	Undefinec				
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | C	0.05	m3	Undefinec				

Add

Mechanical Treatment (w/ Cyclone)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Mechanical Treatment (w/Cyclone)	1	ton	Mass	100 %	not definec	Waste	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	4.71	kWh	Undefinec				

Add

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		1.524	kg	Undefinec				
Sulfur dioxide, TR		0.0087	kg	Undefinec				
Nitrogen oxides, TR		0.0091	kg	Undefinec				
Carbon monoxide, biogenic		0.00023	kg	Undefinec				
Methane		0.0012	kg	Undefinec				
Ammonia, TR		0.0052	kg	Undefinec				
Hydrogen sulfide		0.0064	kg	Undefinec				

Add

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Dust, unspecified		0.00378	kg	Undefinec				

Add

Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

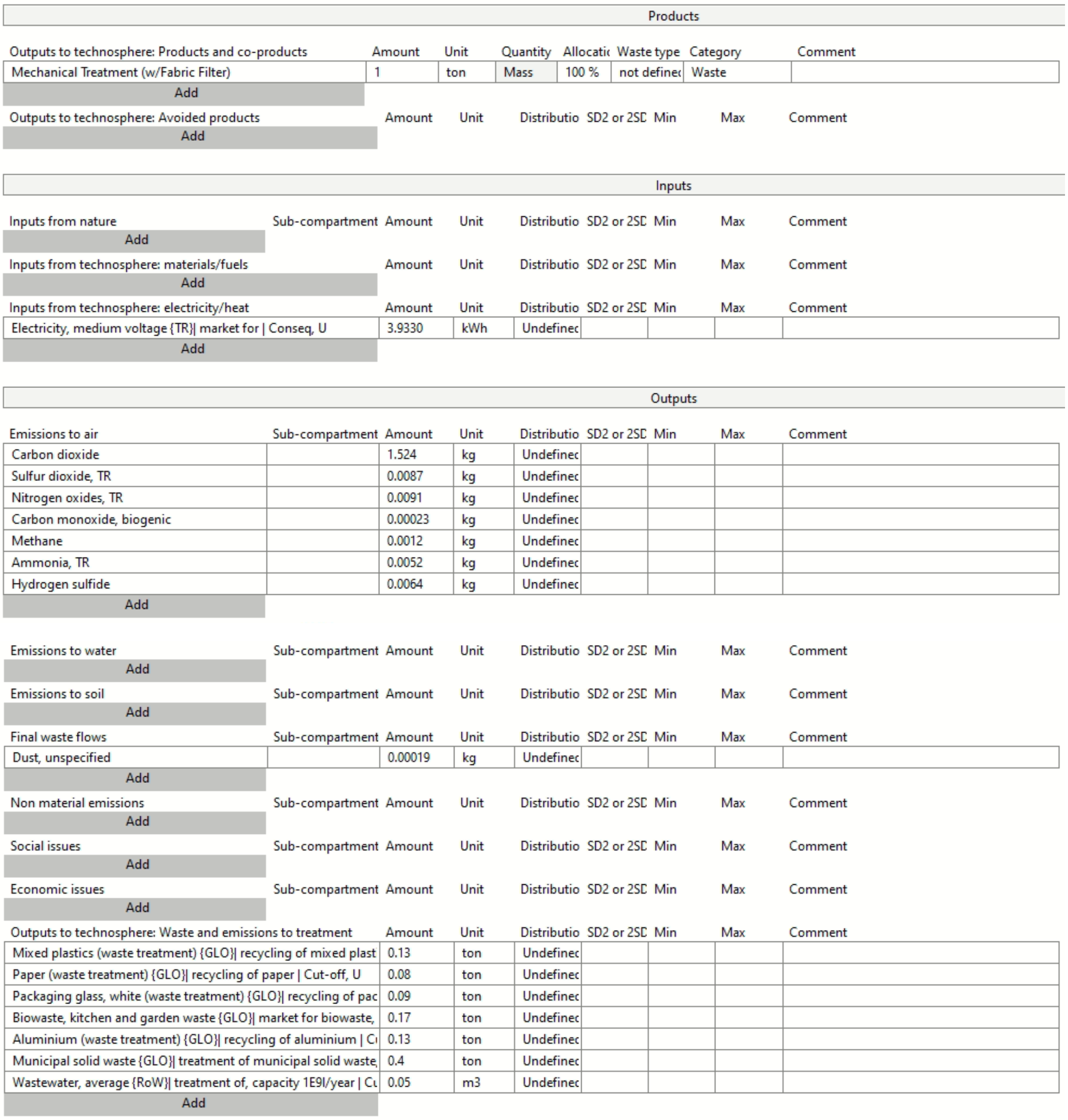
Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Mixed plastics (waste treatment) {GLO}| recycling of mixed plast	0.13	ton	Undefinec				
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	0.08	ton	Undefinec				
Packaging glass, white (waste treatment) {GLO}| recycling of pac	0.09	ton	Undefinec				
Biowaste, kitchen and garden waste {GLO}| market for biowaste,	0.17	ton	Undefinec				
Aluminium (waste treatment) {GLO}| recycling of aluminium | C	0.13	ton	Undefinec				
Municipal solid waste {GLO}| treatment of municipal solid waste,	0.4	ton	Undefinec				
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | C	0.05	m3	Undefinec				

Add

Mechanical Treatment (w/ Fabric Filter)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Mechanical Treatment (w/Fabric Filter)	1	ton	Mass	100 %	not definec	Waste	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.9330	kWh	Undefinec				

Add

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		1.524	kg	Undefinec				
Sulfur dioxide, TR		0.0087	kg	Undefinec				
Nitrogen oxides, TR		0.0091	kg	Undefinec				
Carbon monoxide, biogenic		0.00023	kg	Undefinec				
Methane		0.0012	kg	Undefinec				
Ammonia, TR		0.0052	kg	Undefinec				
Hydrogen sulfide		0.0064	kg	Undefinec				

Add

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Dust, unspecified		0.00019	kg	Undefinec				

Add

Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

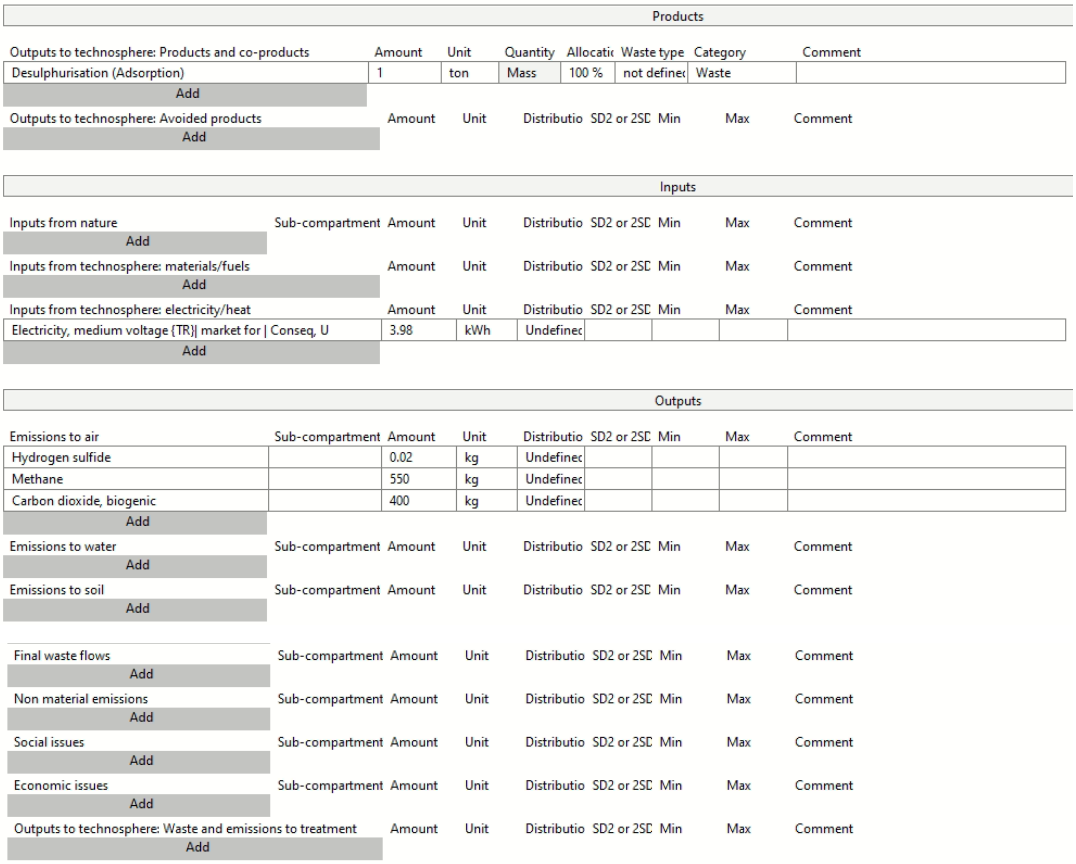
Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Mixed plastics (waste treatment) {GLO}| recycling of mixed plast	0.13	ton	Undefinec				
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	0.08	ton	Undefinec				
Packaging glass, white (waste treatment) {GLO}| recycling of pac	0.09	ton	Undefinec				
Biowaste, kitchen and garden waste {GLO}| market for biowaste,	0.17	ton	Undefinec				
Aluminium (waste treatment) {GLO}| recycling of aluminium | C	0.13	ton	Undefinec				
Municipal solid waste {GLO}| treatment of municipal solid waste,	0.4	ton	Undefinec				
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.05	m3	Undefinec				

Add

Desulphurization (Adsorption)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Adsorption)	1	ton	Mass	100 %	not definec	Waste	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.98	kWh	Undefinec				

Add

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.02	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Add

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

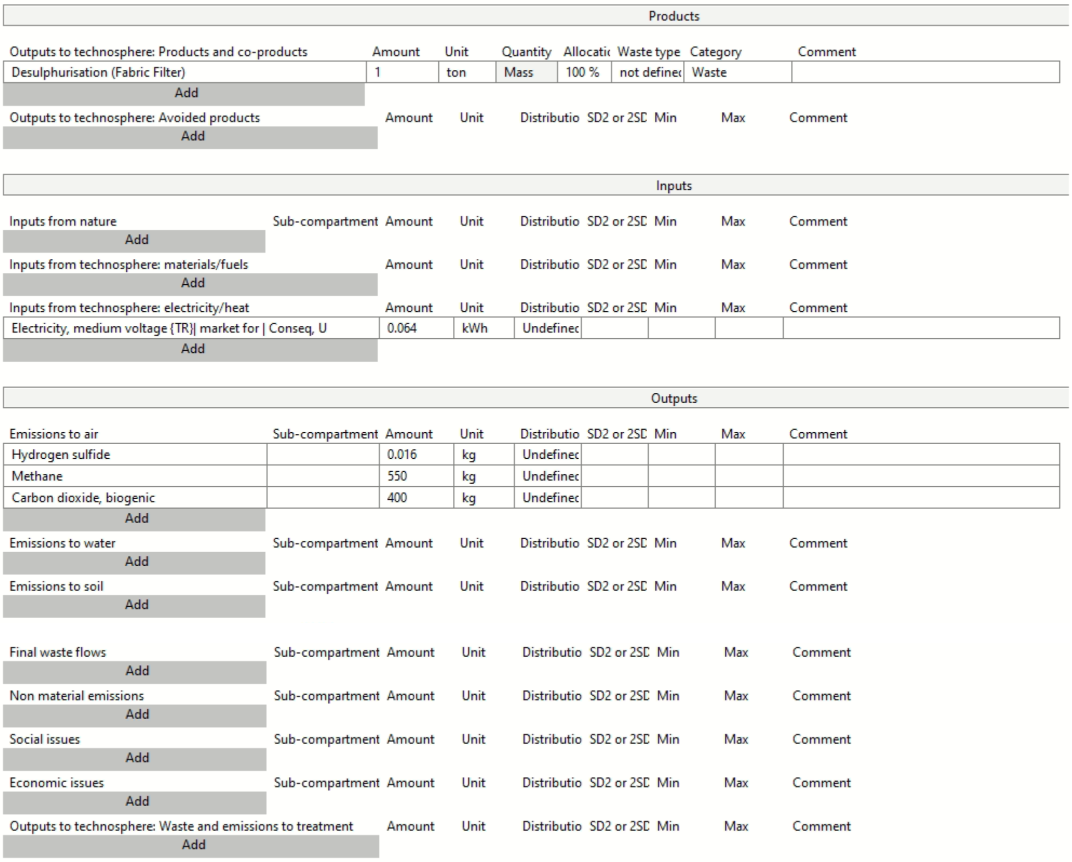
Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Add

Desulphurization (Fabric Filter)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Fabric Filter)	1	ton	Mass	100 %	not definec	Waste	

Add

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	0.064	kWh	Undefinec				

Add

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment
Hydrogen sulfide		0.016	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Add

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

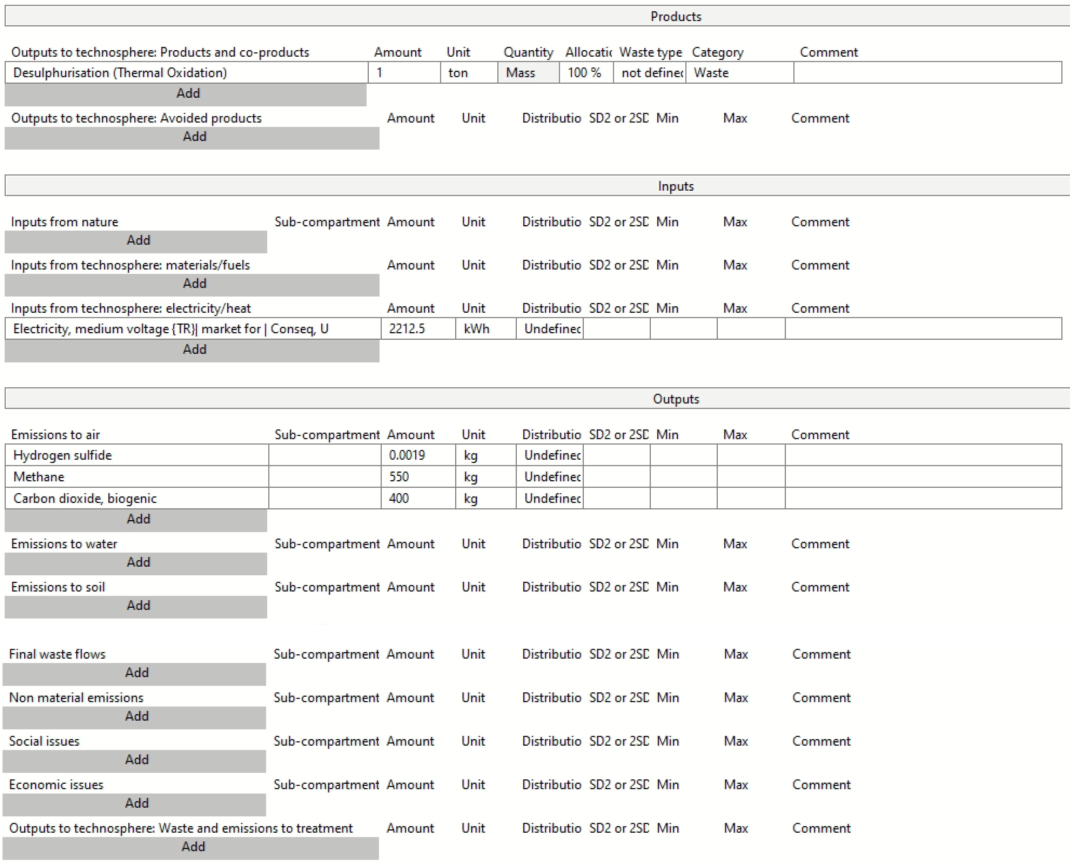
Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SE	Min	Max	Comment

Add

Desulphurization (Thermal Oxidation)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Thermal Oxidation)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	2212.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.0019	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

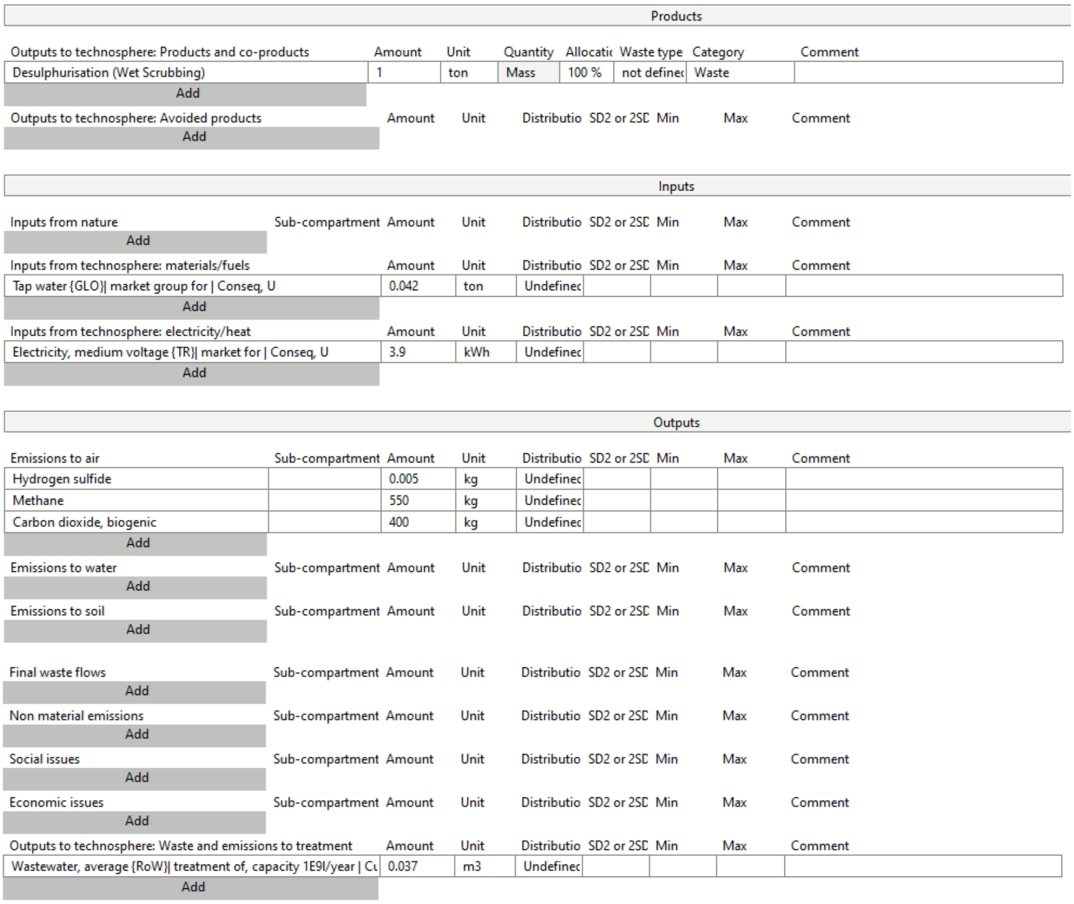
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Desulphurization (Wet Scrubbing)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Wet Scrubbing)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {GLO}| market group for | Conseq, U	0.042	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.9	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.005	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

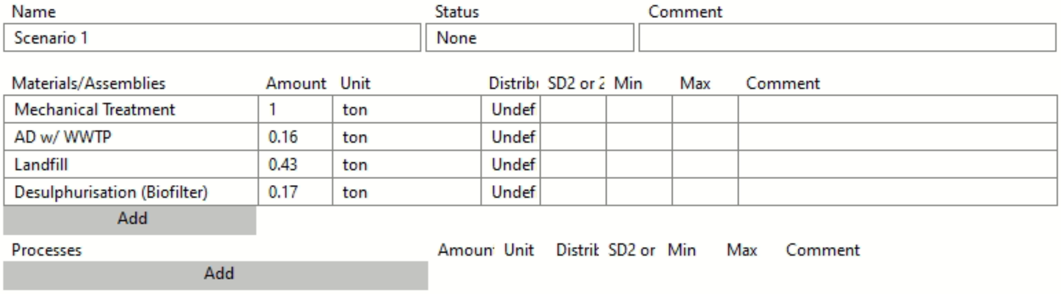
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.037	m3	Undefinec				

Scenario 1

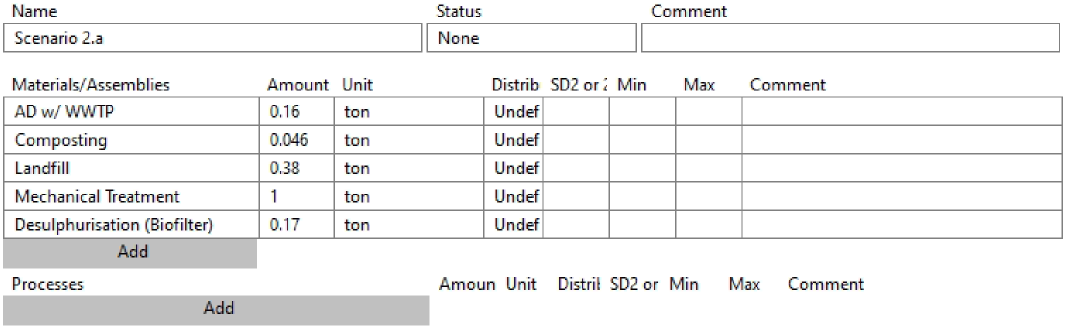


Name	Status	Comment
Scenario 1	None	

Materials/Assemblies	Amount	Unit	Distribı	SD2 or 2	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 2.a

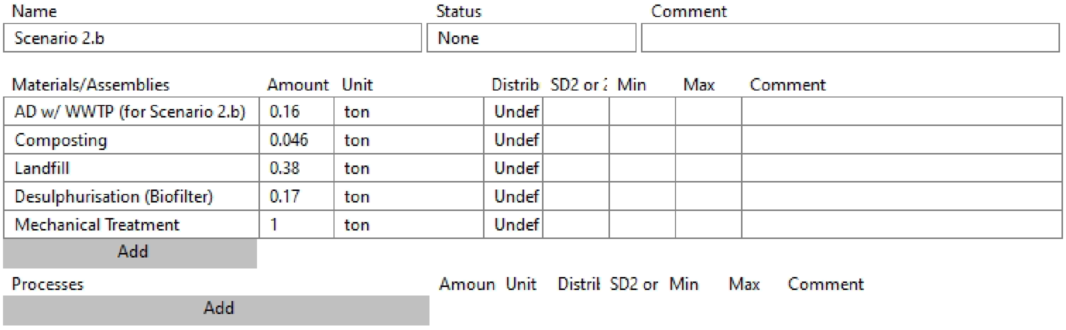


Name	Status	Comment
Scenario 2.a	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or 2	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Composting	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Mechanical Treatment	1	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 2.b

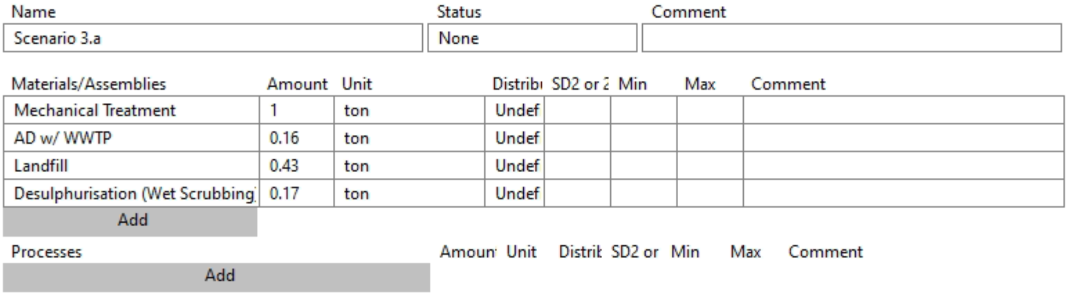


Name	Status	Comment
Scenario 2.b	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or 2	Min	Max	Comment
AD w/ WWTP (for Scenario 2.b)	0.16	ton	Undef				
Composting	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				
Mechanical Treatment	1	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 3.a

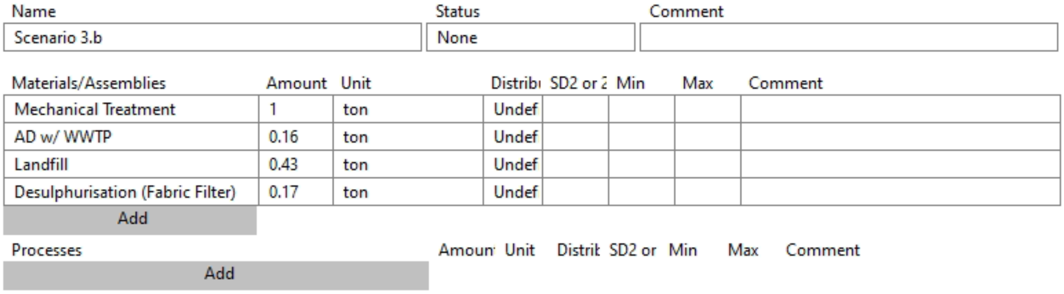


Name	Status	Comment
Scenario 3.a	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Wet Scrubbing	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 3.b

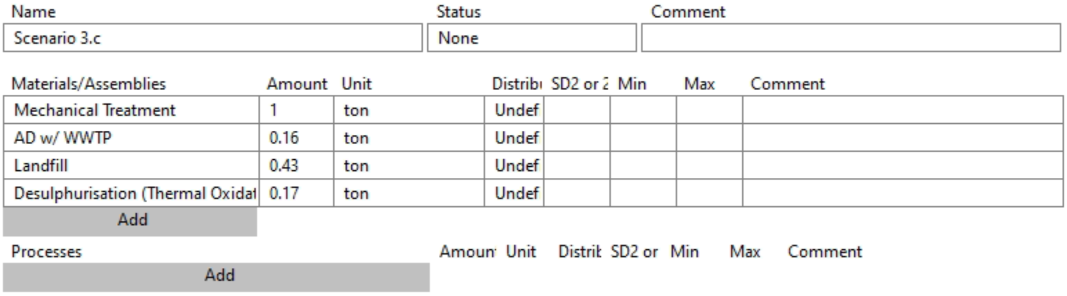


Name	Status	Comment
Scenario 3.b	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Fabric Filter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 3.c

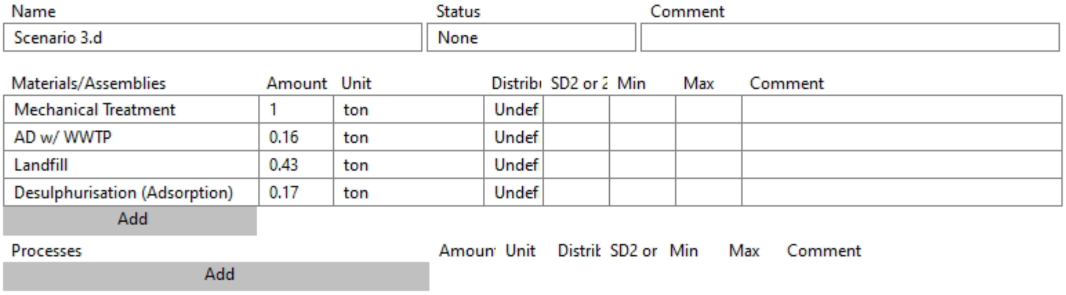


Name	Status	Comment
Scenario 3.c	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Thermal Oxidat	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 3.d



Name: Scenario 3.d

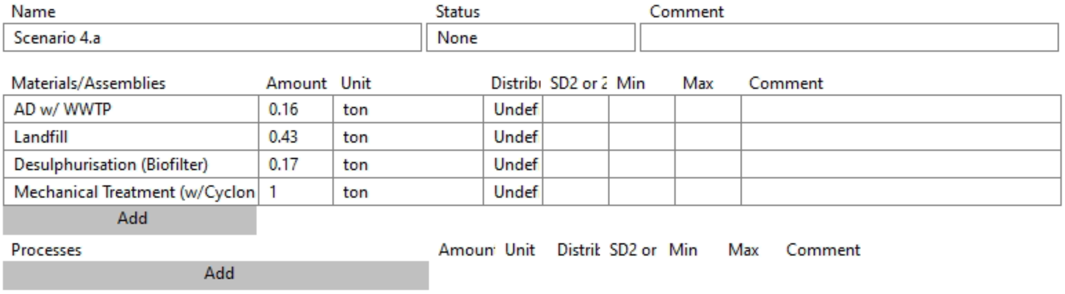
Status: None

Comment:

Materials/Assemblies	Amount	Unit	Distribı	SD2 or 2	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Adsorption)	0.17	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 4.a



Name: Scenario 4.a

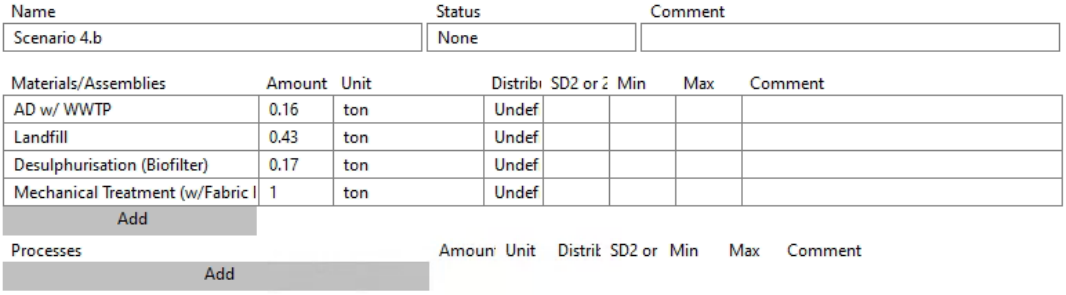
Status: None

Comment:

Materials/Assemblies	Amount	Unit	Distribı	SD2 or 2	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				
Mechanical Treatment (w/Cyclon	1	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 4.b



Name: Scenario 4.b

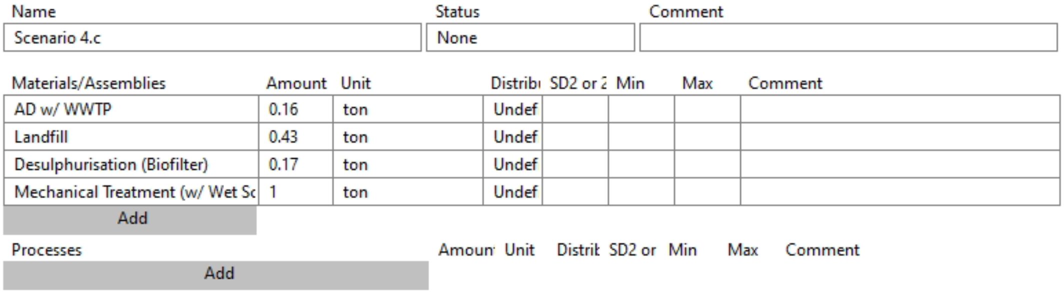
Status: None

Comment:

Materials/Assemblies	Amount	Unit	Distribı	SD2 or 2	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				
Mechanical Treatment (w/Fabric I	1	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 4.c



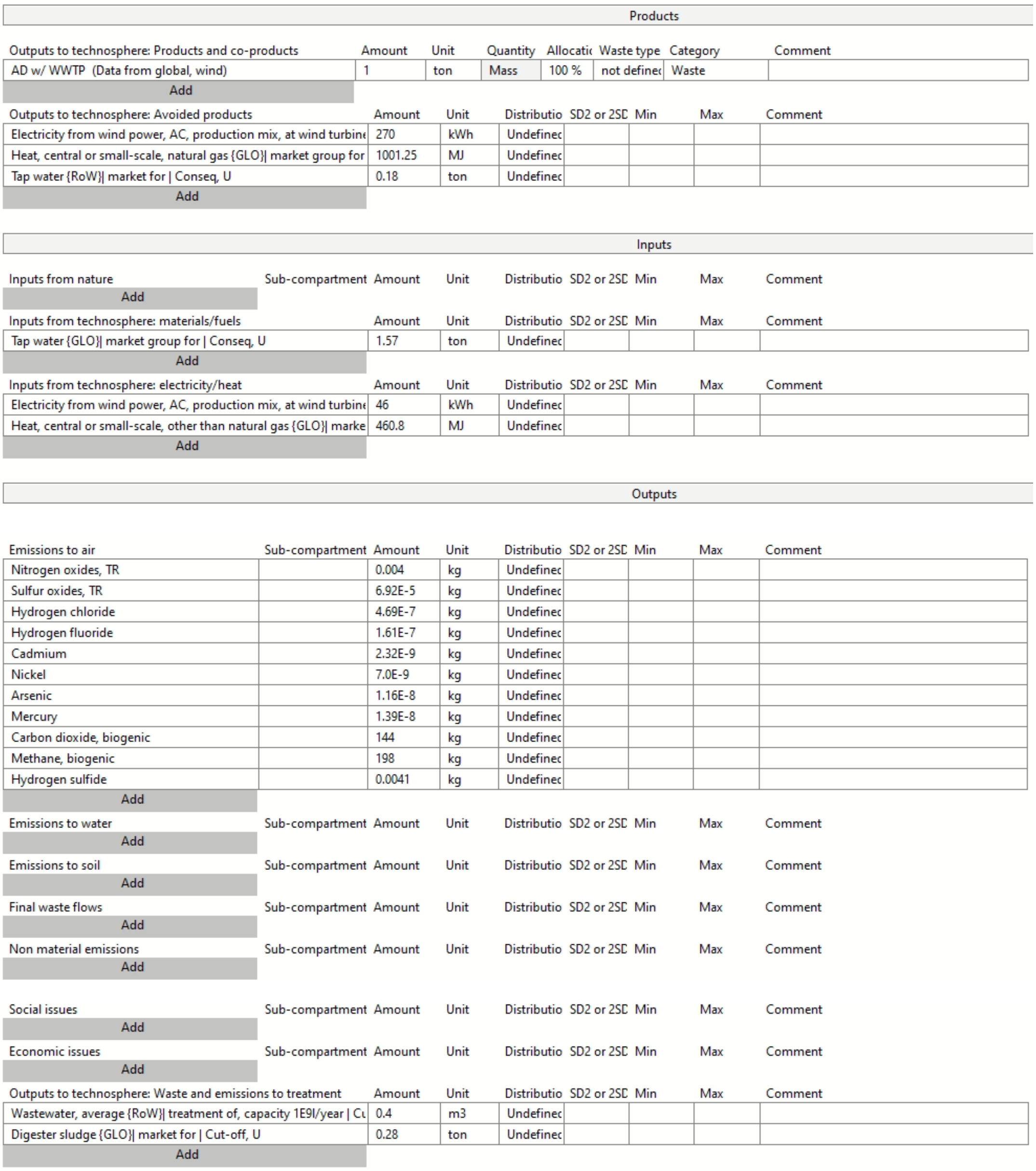
Name	Status	Comment
Scenario 4.c	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				
Mechanical Treatment (w/ Wet Sc	1	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

For Sensitivity Analysis:

AD w/ WWTP (Module 3)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
AD w/ WWTP (Data from global, wind)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity from wind power, AC, production mix, at wind turbine	270	kWh	Undefinec				
Heat, central or small-scale, natural gas {GLO}| market group for	1001.25	MJ	Undefinec				
Tap water {RoW}| market for | Conseq, U	0.18	ton	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {GLO}| market group for | Conseq, U	1.57	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity from wind power, AC, production mix, at wind turbine	46	kWh	Undefinec				
Heat, central or small-scale, other than natural gas {GLO}| marke	460.8	MJ	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Nitrogen oxides, TR		0.004	kg	Undefinec				
Sulfur oxides, TR		6.92E-5	kg	Undefinec				
Hydrogen chloride		4.69E-7	kg	Undefinec				
Hydrogen fluoride		1.61E-7	kg	Undefinec				
Cadmium		2.32E-9	kg	Undefinec				
Nickel		7.0E-9	kg	Undefinec				
Arsenic		1.16E-8	kg	Undefinec				
Mercury		1.39E-8	kg	Undefinec				
Carbon dioxide, biogenic		144	kg	Undefinec				
Methane, biogenic		198	kg	Undefinec				
Hydrogen sulfide		0.0041	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

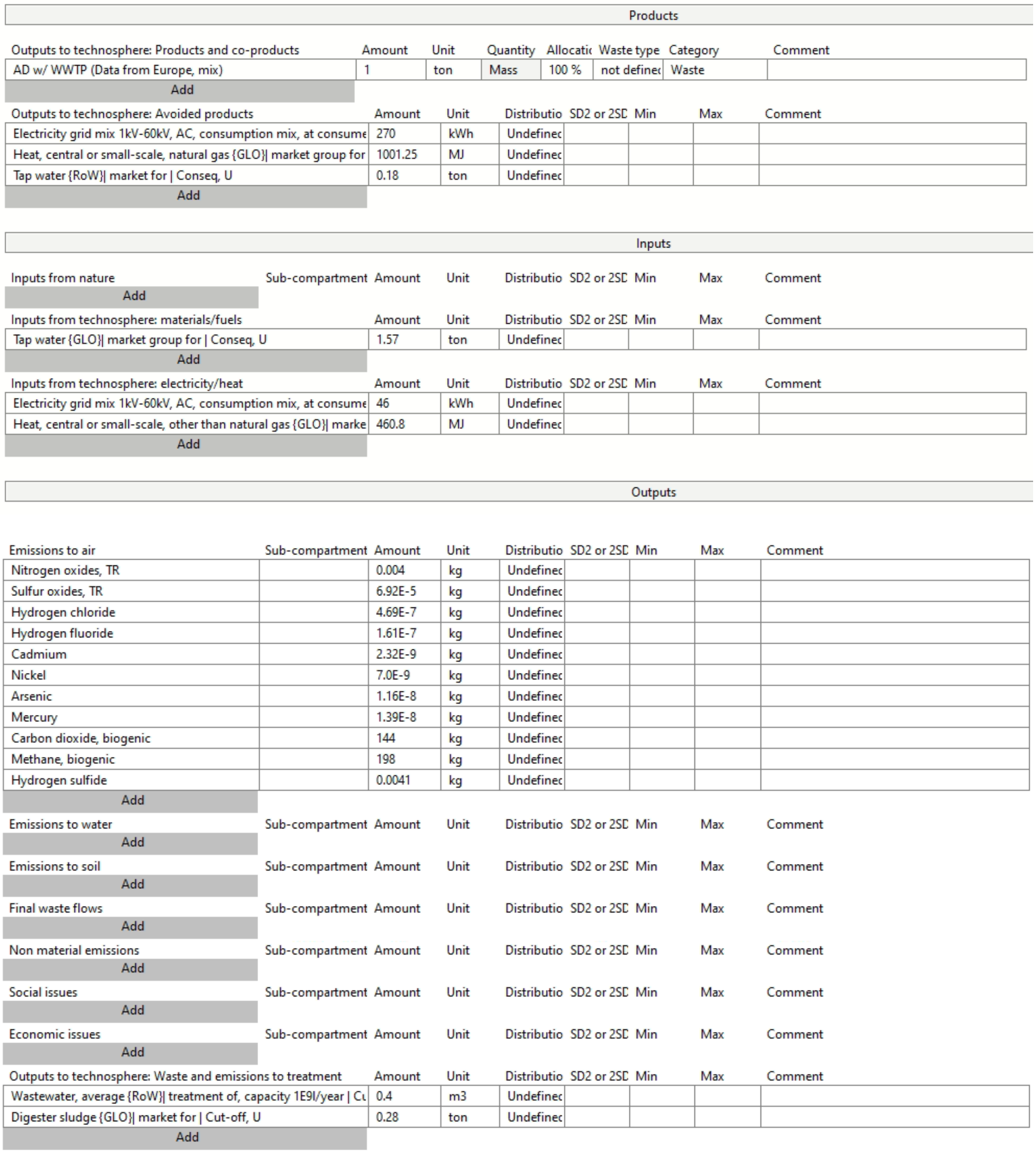
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.4	m3	Undefinec				
Digester sludge {GLO}| market for | Cut-off, U	0.28	ton	Undefinec				

AD w/ WWTP (Module 2)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatio	Waste type	Category	Comment
AD w/ WWTP (Data from Europe, mix)	1	ton	Mass	100 %	not defined	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity grid mix 1kV-60kV, AC, consumption mix, at consume	270	kWh	Undefined				
Heat, central or small-scale, natural gas {GLO}| market group for	1001.25	MJ	Undefined				
Tap water {RoW}| market for | Conseq, U	0.18	ton	Undefined				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {GLO}| market group for | Conseq, U	1.57	ton	Undefined				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity grid mix 1kV-60kV, AC, consumption mix, at consume	46	kWh	Undefined				
Heat, central or small-scale, other than natural gas {GLO}| marke	460.8	MJ	Undefined				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Nitrogen oxides, TR		0.004	kg	Undefined				
Sulfur oxides, TR		6.92E-5	kg	Undefined				
Hydrogen chloride		4.69E-7	kg	Undefined				
Hydrogen fluoride		1.61E-7	kg	Undefined				
Cadmium		2.32E-9	kg	Undefined				
Nickel		7.0E-9	kg	Undefined				
Arsenic		1.16E-8	kg	Undefined				
Mercury		1.39E-8	kg	Undefined				
Carbon dioxide, biogenic		144	kg	Undefined				
Methane, biogenic		198	kg	Undefined				
Hydrogen sulfide		0.0041	kg	Undefined				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

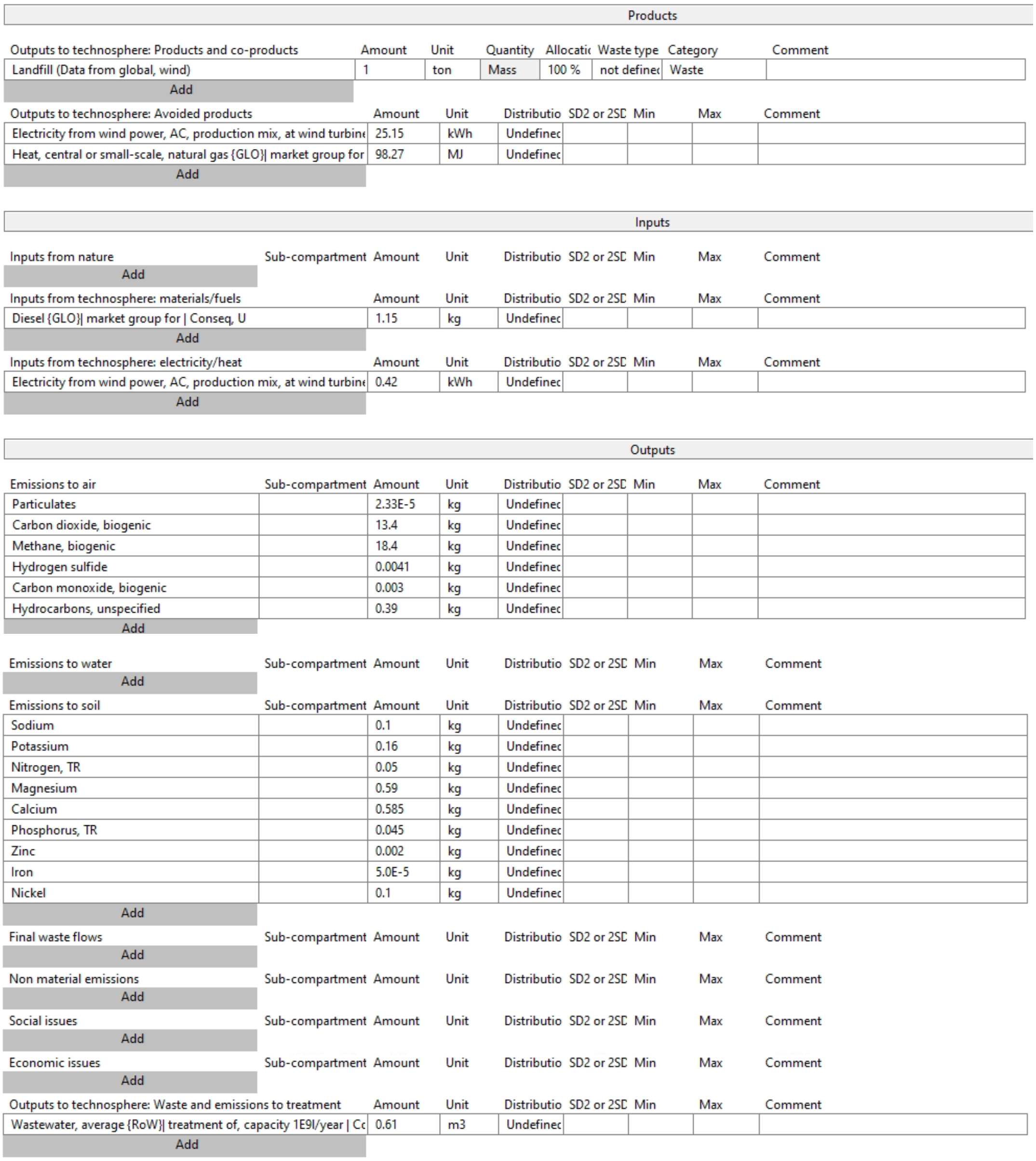
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.4	m3	Undefined				
Digester sludge {GLO}| market for | Cut-off, U	0.28	ton	Undefined				

Landfill (Module 3)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Landfill (Data from global, wind)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity from wind power, AC, production mix, at wind turbine	25.15	kWh	Undefinec				
Heat, central or small-scale, natural gas {GLO}| market group for	98.27	MJ	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Diesel {GLO}| market group for | Conseq, U	1.15	kg	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity from wind power, AC, production mix, at wind turbine	0.42	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Particulates		2.33E-5	kg	Undefinec				
Carbon dioxide, biogenic		13.4	kg	Undefinec				
Methane, biogenic		18.4	kg	Undefinec				
Hydrogen sulfide		0.0041	kg	Undefinec				
Carbon monoxide, biogenic		0.003	kg	Undefinec				
Hydrocarbons, unspecified		0.39	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Sodium		0.1	kg	Undefinec				
Potassium		0.16	kg	Undefinec				
Nitrogen, TR		0.05	kg	Undefinec				
Magnesium		0.59	kg	Undefinec				
Calcium		0.585	kg	Undefinec				
Phosphorus, TR		0.045	kg	Undefinec				
Zinc		0.002	kg	Undefinec				
Iron		5.0E-5	kg	Undefinec				
Nickel		0.1	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

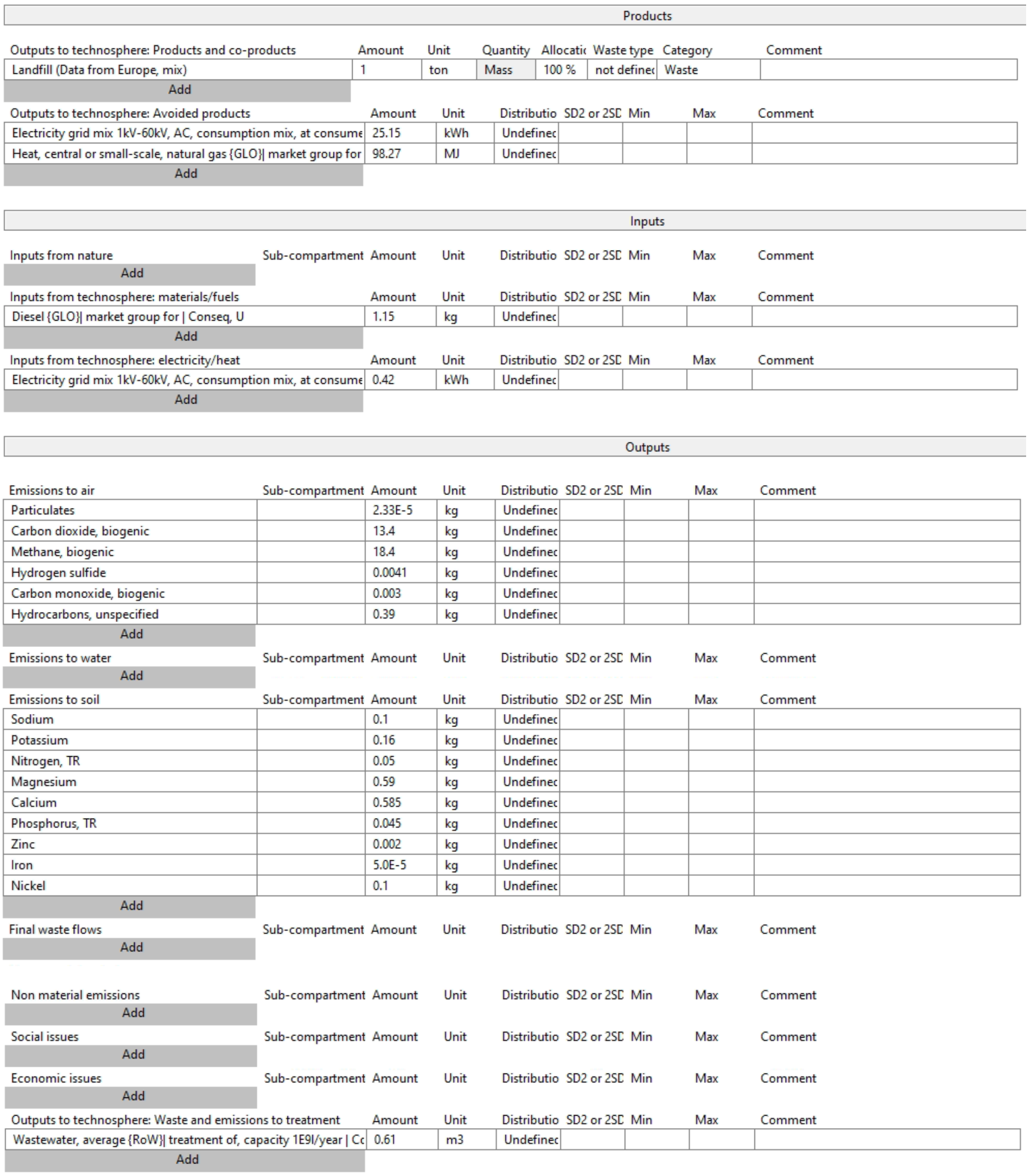
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cc	0.61	m3	Undefinec				

Landfill (Module 2)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Landfill (Data from Europe, mix)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity grid mix 1kV-60kV, AC, consumption mix, at consume	25.15	kWh	Undefinec				
Heat, central or small-scale, natural gas {GLO}| market group for	98.27	MJ	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Diesel {GLO}| market group for | Conseq, U	1.15	kg	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity grid mix 1kV-60kV, AC, consumption mix, at consume	0.42	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Particulates		2.33E-5	kg	Undefinec				
Carbon dioxide, biogenic		13.4	kg	Undefinec				
Methane, biogenic		18.4	kg	Undefinec				
Hydrogen sulfide		0.0041	kg	Undefinec				
Carbon monoxide, biogenic		0.003	kg	Undefinec				
Hydrocarbons, unspecified		0.39	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Sodium		0.1	kg	Undefinec				
Potassium		0.16	kg	Undefinec				
Nitrogen, TR		0.05	kg	Undefinec				
Magnesium		0.59	kg	Undefinec				
Calcium		0.585	kg	Undefinec				
Phosphorus, TR		0.045	kg	Undefinec				
Zinc		0.002	kg	Undefinec				
Iron		5.0E-5	kg	Undefinec				
Nickel		0.1	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

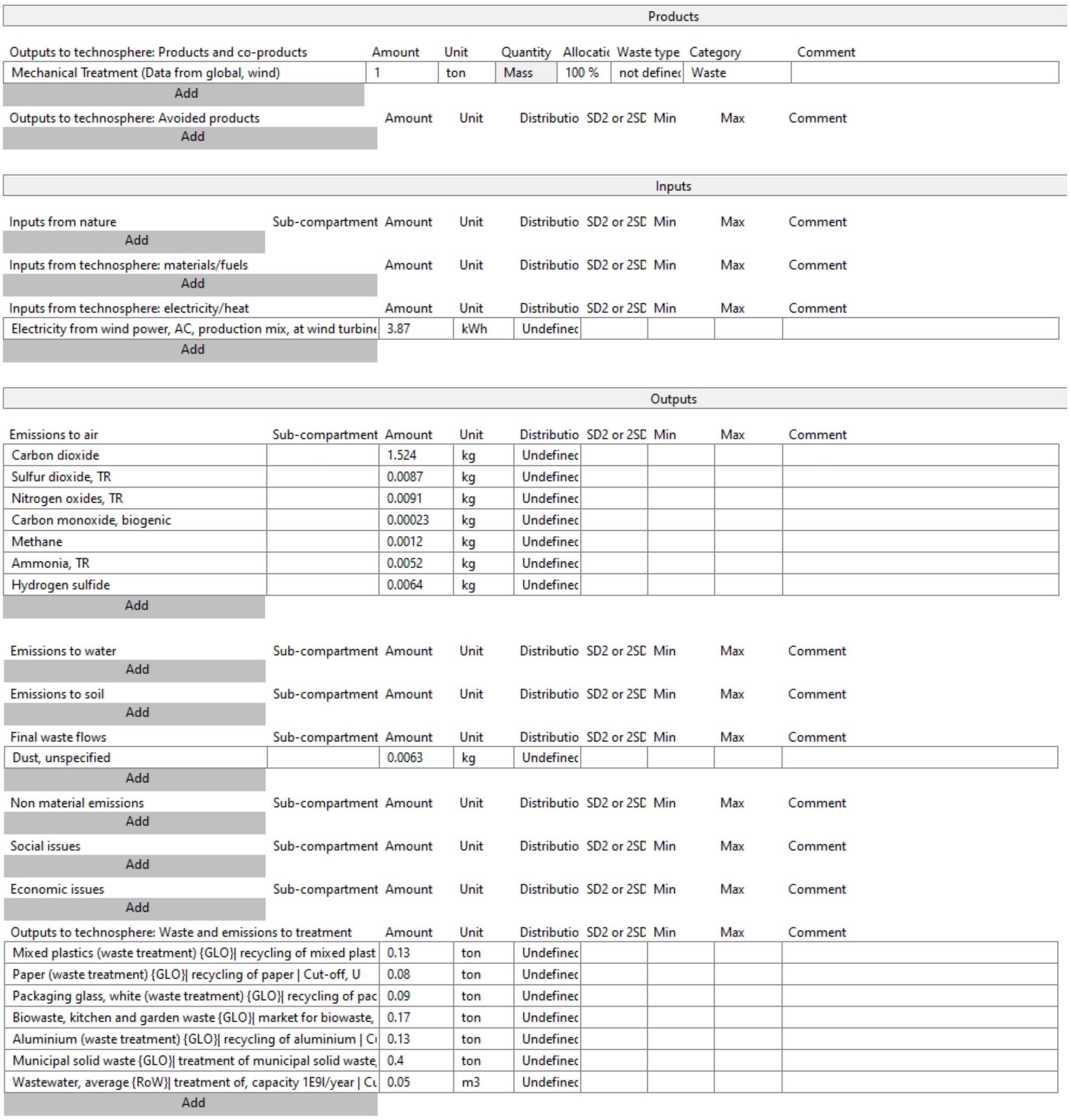
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cc	0.61	m3	Undefinec				

Mechanical Treatment (Module 3)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Mechanical Treatment (Data from global, wind)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity from wind power, AC, production mix, at wind turbine	3.87	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		1.524	kg	Undefinec				
Sulfur dioxide, TR		0.0087	kg	Undefinec				
Nitrogen oxides, TR		0.0091	kg	Undefinec				
Carbon monoxide, biogenic		0.00023	kg	Undefinec				
Methane		0.0012	kg	Undefinec				
Ammonia, TR		0.0052	kg	Undefinec				
Hydrogen sulfide		0.0064	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Dust, unspecified		0.0063	kg	Undefinec				

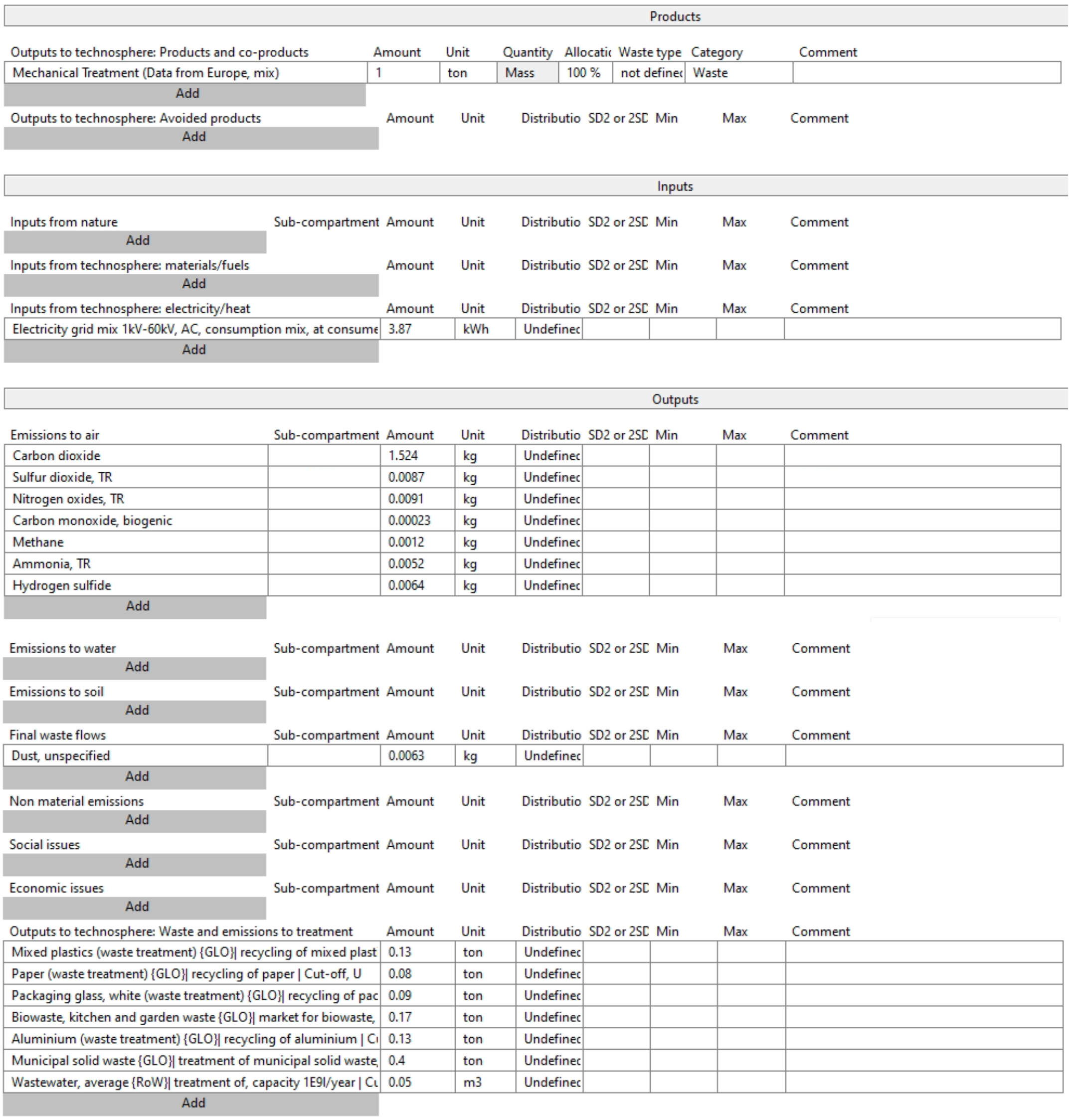
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Mixed plastics (waste treatment) {GLO}| recycling of mixed plast	0.13	ton	Undefinec				
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	0.08	ton	Undefinec				
Packaging glass, white (waste treatment) {GLO}| recycling of pac	0.09	ton	Undefinec				
Biowaste, kitchen and garden waste {GLO}| market for biowaste,	0.17	ton	Undefinec				
Aluminium (waste treatment) {GLO}| recycling of aluminium | C	0.13	ton	Undefinec				
Municipal solid waste {GLO}| treatment of municipal solid waste,	0.4	ton	Undefinec				
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.05	m3	Undefinec				

Mechanical Treatment (Module 2)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Mechanical Treatment (Data from Europe, mix)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity grid mix 1kV-60kV, AC, consumption mix, at consume	3.87	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Carbon dioxide		1.524	kg	Undefinec				
Sulfur dioxide, TR		0.0087	kg	Undefinec				
Nitrogen oxides, TR		0.0091	kg	Undefinec				
Carbon monoxide, biogenic		0.00023	kg	Undefinec				
Methane		0.0012	kg	Undefinec				
Ammonia, TR		0.0052	kg	Undefinec				
Hydrogen sulfide		0.0064	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Dust, unspecified		0.0063	kg	Undefinec				

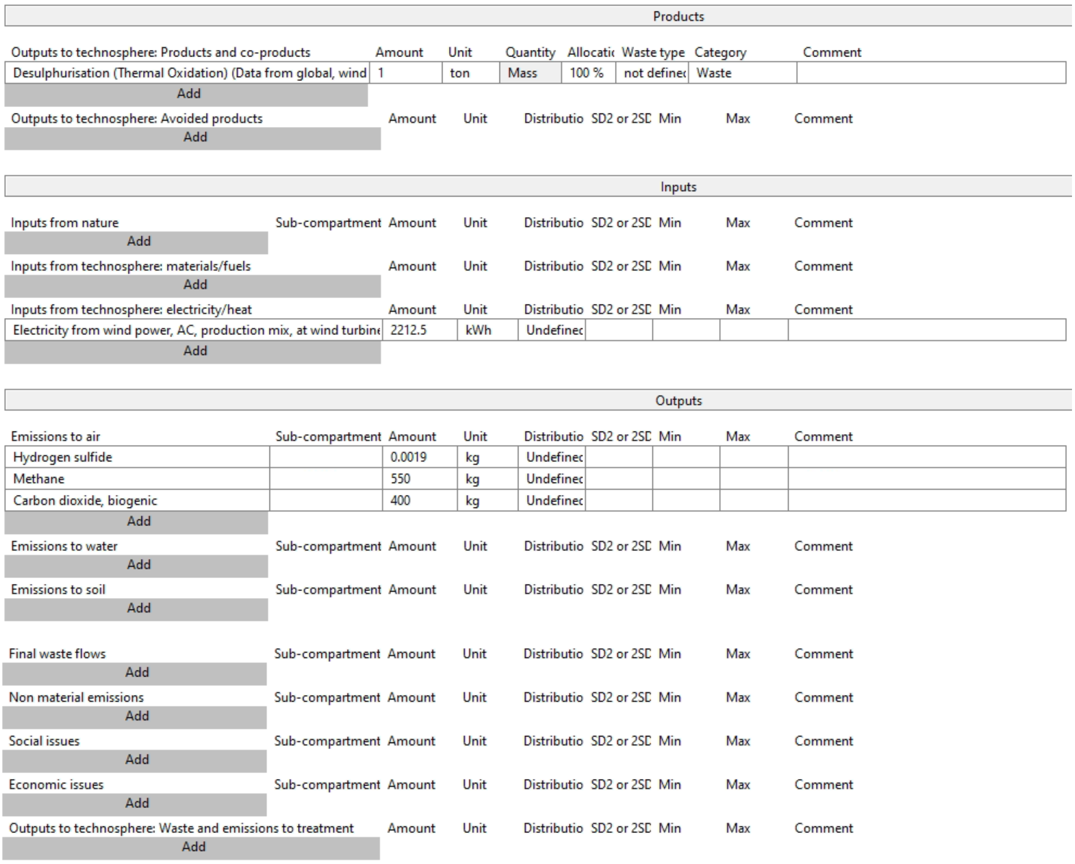
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Mixed plastics (waste treatment) {GLO}| recycling of mixed plast	0.13	ton	Undefinec				
Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U	0.08	ton	Undefinec				
Packaging glass, white (waste treatment) {GLO}| recycling of pac	0.09	ton	Undefinec				
Biowaste, kitchen and garden waste {GLO}| market for biowaste,	0.17	ton	Undefinec				
Aluminium (waste treatment) {GLO}| recycling of aluminium | Cu	0.13	ton	Undefinec				
Municipal solid waste {GLO}| treatment of municipal solid waste,	0.4	ton	Undefinec				
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.05	m3	Undefinec				

Desulphurization (Thermal Oxidation) (Module 3)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Thermal Oxidation) (Data from global, wind	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity from wind power, AC, production mix, at wind turbine	2212.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.0019	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

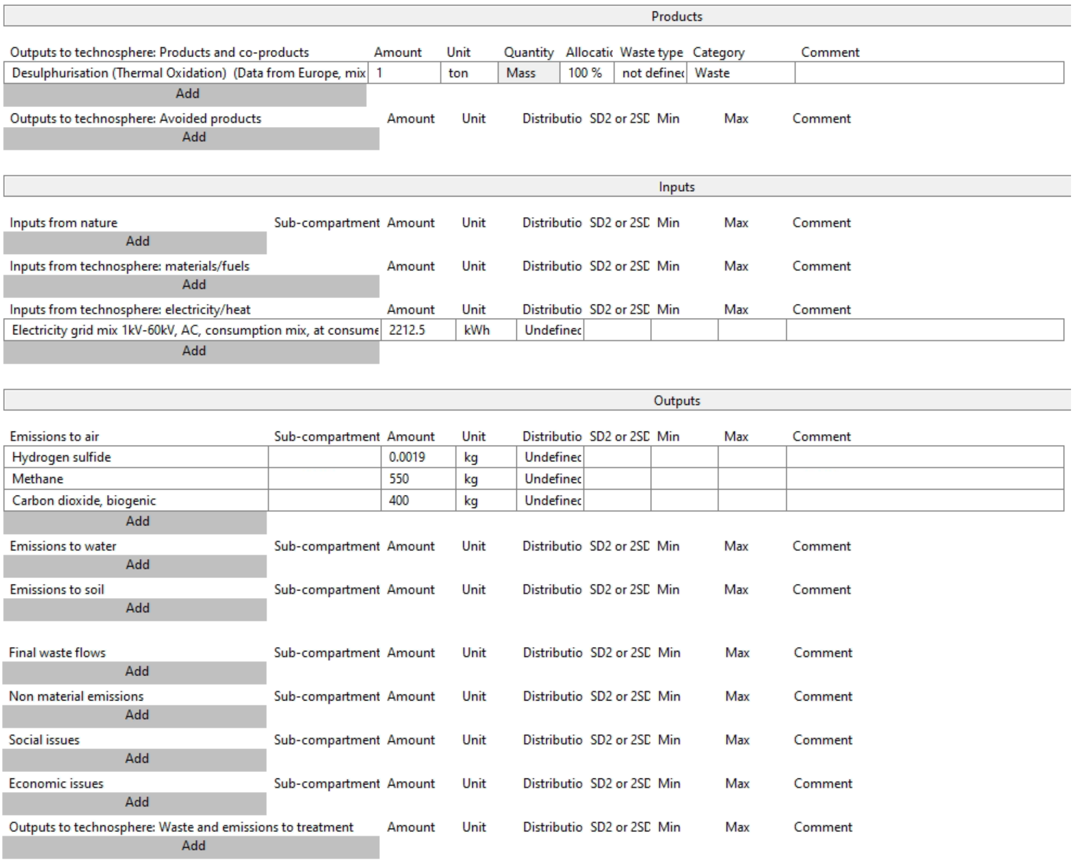
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Desulphurization (Thermal Oxidation) (Module 2)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatio	Waste type	Category	Comment
Desulphurisation (Thermal Oxidation) (Data from Europe, mix	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity grid mix 1kV-60kV, AC, consumption mix, at consume	2212.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.0019	kg	Undefinec				
Methane		550	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

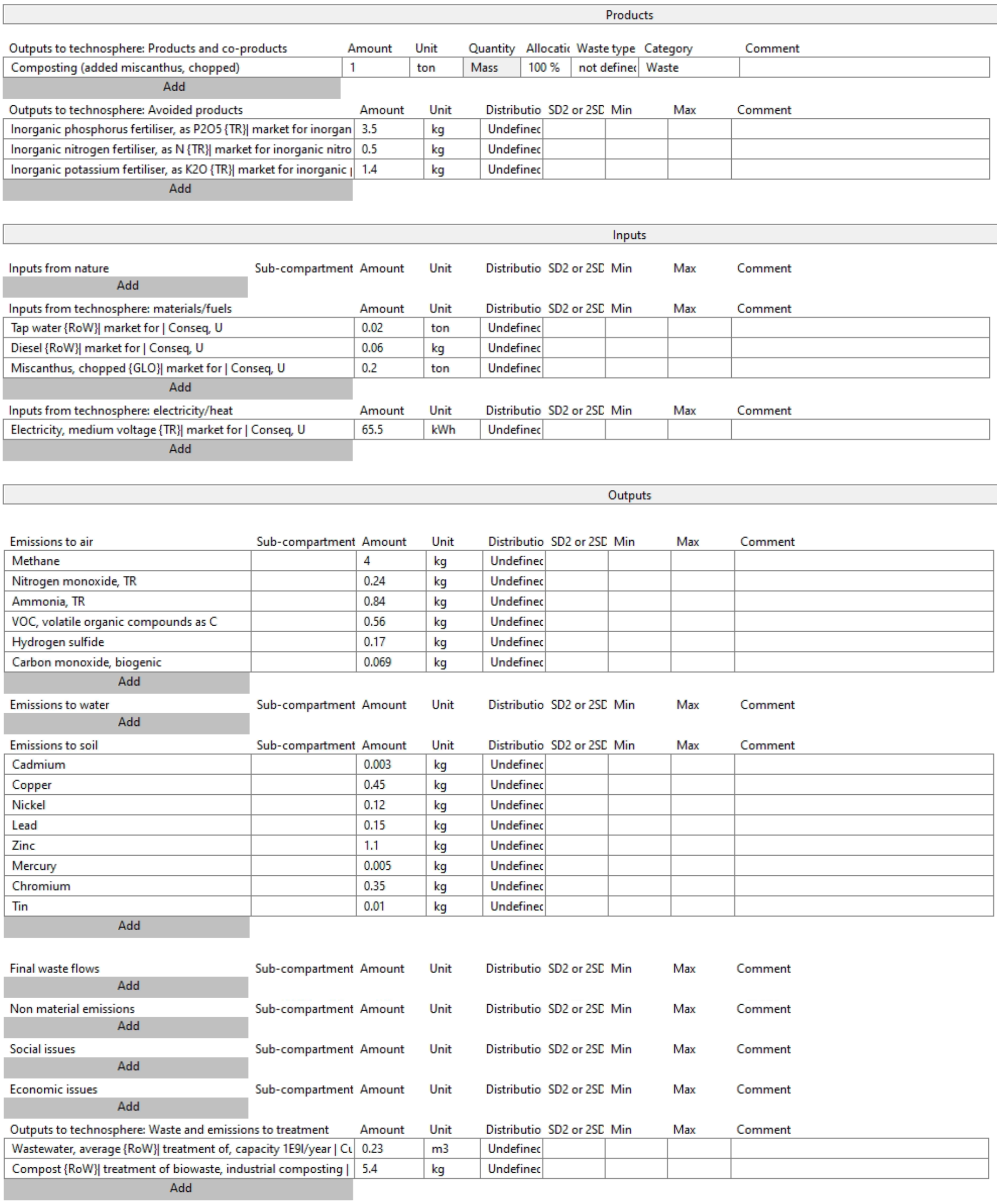
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Composting (added miscanthus chopped)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Composting (added miscanthus, chopped)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment
Inorganic phosphorus fertiliser, as P2O5 {TR}| market for inorgan	3.5	kg	Undefinec				
Inorganic nitrogen fertiliser, as N {TR}| market for inorganic nitro	0.5	kg	Undefinec				
Inorganic potassium fertiliser, as K2O {TR}| market for inorganic	1.4	kg	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment
Tap water {RoW}| market for | Conseq, U	0.02	ton	Undefinec				
Diesel {RoW}| market for | Conseq, U	0.06	kg	Undefinec				
Miscanthus, chopped {GLO}| market for | Conseq, U	0.2	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	65.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment
Methane		4	kg	Undefinec				
Nitrogen monoxide, TR		0.24	kg	Undefinec				
Ammonia, TR		0.84	kg	Undefinec				
VOC, volatile organic compounds as C		0.56	kg	Undefinec				
Hydrogen sulfide		0.17	kg	Undefinec				
Carbon monoxide, biogenic		0.069	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment
Cadmium		0.003	kg	Undefinec				
Copper		0.45	kg	Undefinec				
Nickel		0.12	kg	Undefinec				
Lead		0.15	kg	Undefinec				
Zinc		1.1	kg	Undefinec				
Mercury		0.005	kg	Undefinec				
Chromium		0.35	kg	Undefinec				
Tin		0.01	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment

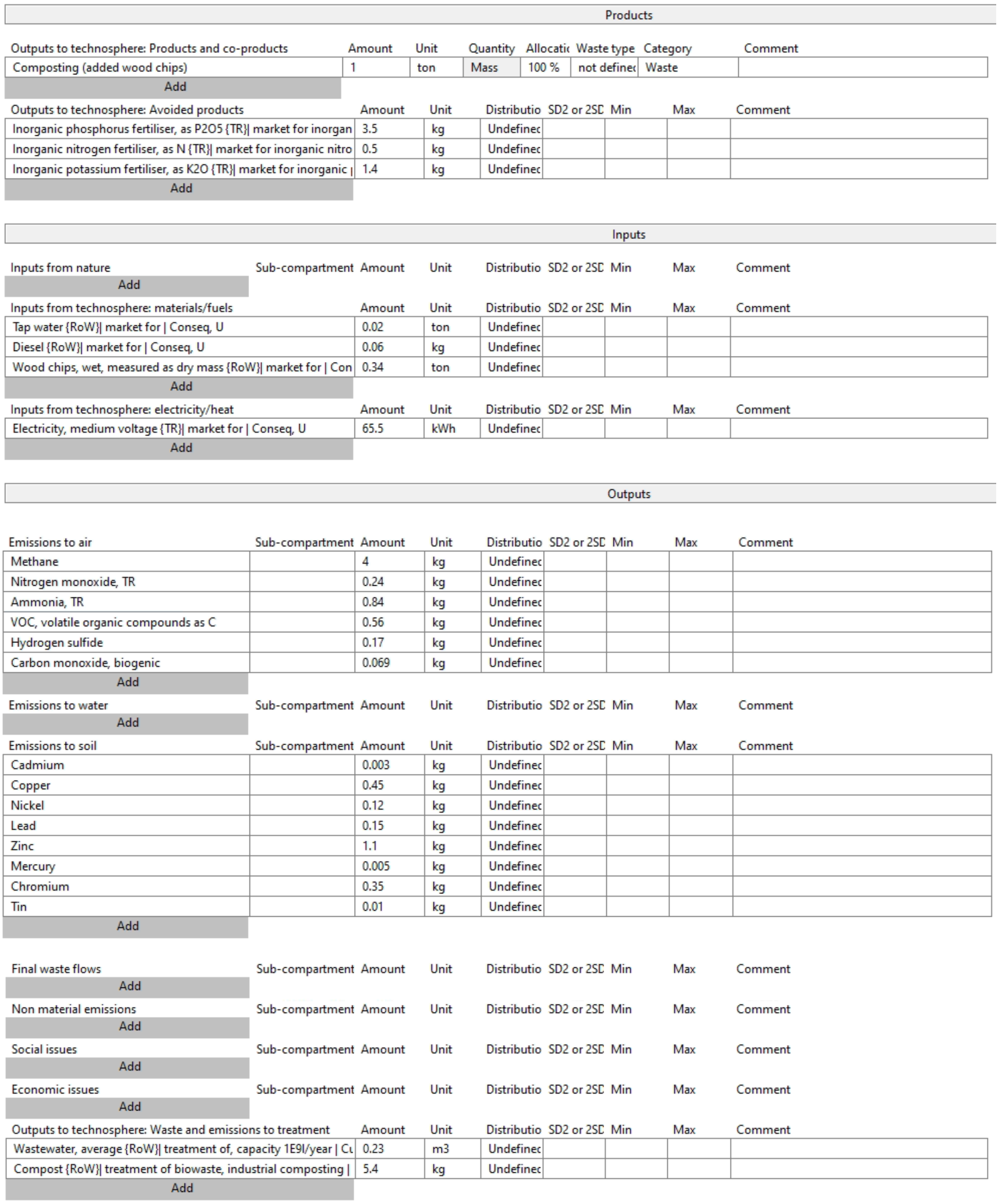
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SC	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.23	m3	Undefinec				
Compost {RoW}| treatment of biowaste, industrial composting |	5.4	kg	Undefinec				

Composting (added wood chips)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Composting (added wood chips)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Inorganic phosphorus fertiliser, as P2O5 {TR}| market for inorgan	3.5	kg	Undefinec				
Inorganic nitrogen fertiliser, as N {TR}| market for inorganic nitro	0.5	kg	Undefinec				
Inorganic potassium fertiliser, as K2O {TR}| market for inorganic	1.4	kg	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {RoW}| market for | Conseq, U	0.02	ton	Undefinec				
Diesel {RoW}| market for | Conseq, U	0.06	kg	Undefinec				
Wood chips, wet, measured as dry mass {RoW}| market for | Con	0.34	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	65.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Methane		4	kg	Undefinec				
Nitrogen monoxide, TR		0.24	kg	Undefinec				
Ammonia, TR		0.84	kg	Undefinec				
VOC, volatile organic compounds as C		0.56	kg	Undefinec				
Hydrogen sulfide		0.17	kg	Undefinec				
Carbon monoxide, biogenic		0.069	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Cadmium		0.003	kg	Undefinec				
Copper		0.45	kg	Undefinec				
Nickel		0.12	kg	Undefinec				
Lead		0.15	kg	Undefinec				
Zinc		1.1	kg	Undefinec				
Mercury		0.005	kg	Undefinec				
Chromium		0.35	kg	Undefinec				
Tin		0.01	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

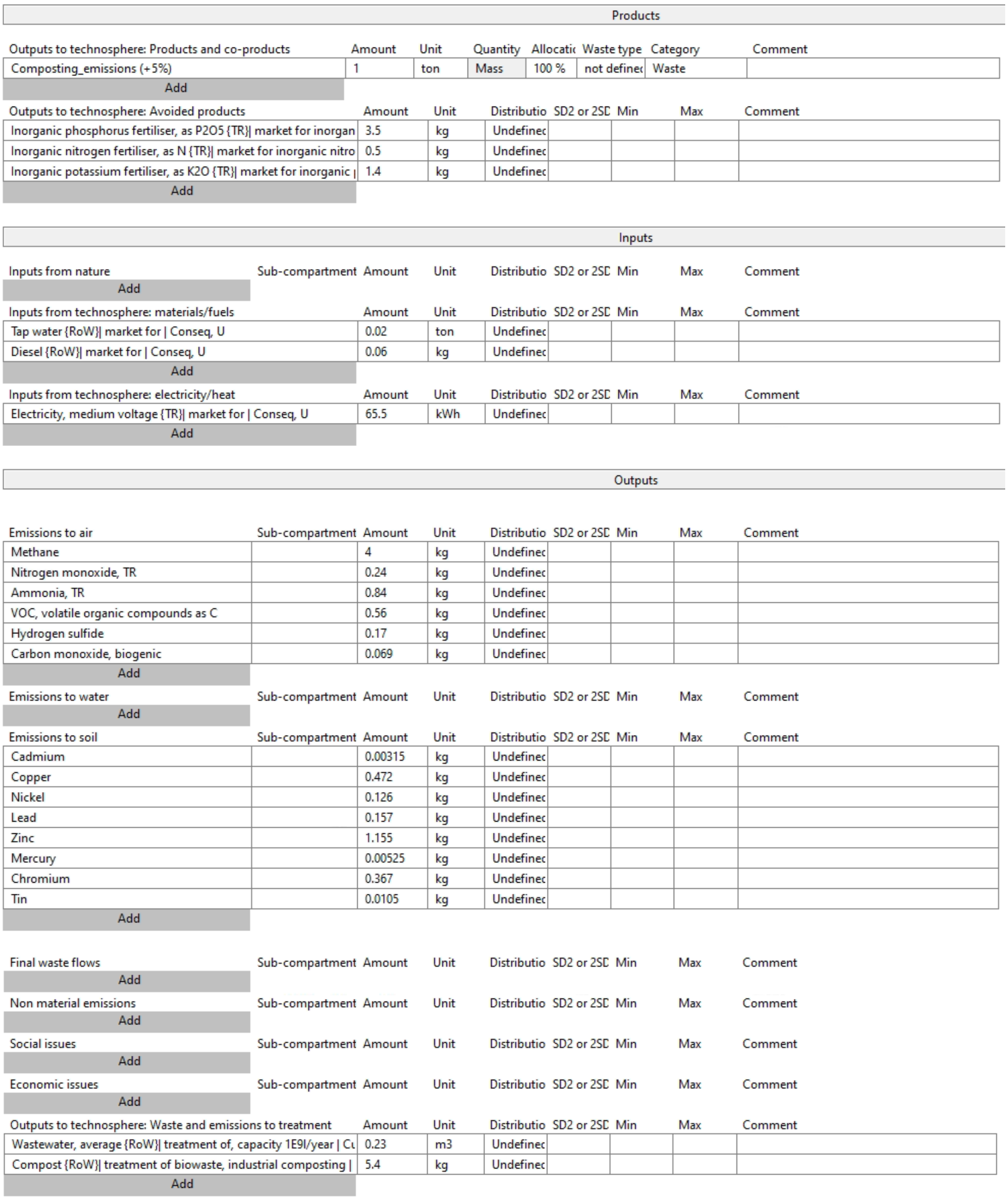
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.23	m3	Undefinec				
Compost {RoW}| treatment of biowaste, industrial composting |	5.4	kg	Undefinec				

Composting (+5% emissions to soil level)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Composting_emissions (+5%)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Inorganic phosphorus fertiliser, as P2O5 {TR}| market for inorgan	3.5	kg	Undefinec				
Inorganic nitrogen fertiliser, as N {TR}| market for inorganic nitro	0.5	kg	Undefinec				
Inorganic potassium fertiliser, as K2O {TR}| market for inorganic |	1.4	kg	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {RoW}| market for | Conseq, U	0.02	ton	Undefinec				
Diesel {RoW}| market for | Conseq, U	0.06	kg	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	65.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Methane		4	kg	Undefinec				
Nitrogen monoxide, TR		0.24	kg	Undefinec				
Ammonia, TR		0.84	kg	Undefinec				
VOC, volatile organic compounds as C		0.56	kg	Undefinec				
Hydrogen sulfide		0.17	kg	Undefinec				
Carbon monoxide, biogenic		0.069	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Cadmium		0.00315	kg	Undefinec				
Copper		0.472	kg	Undefinec				
Nickel		0.126	kg	Undefinec				
Lead		0.157	kg	Undefinec				
Zinc		1.155	kg	Undefinec				
Mercury		0.00525	kg	Undefinec				
Chromium		0.367	kg	Undefinec				
Tin		0.0105	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

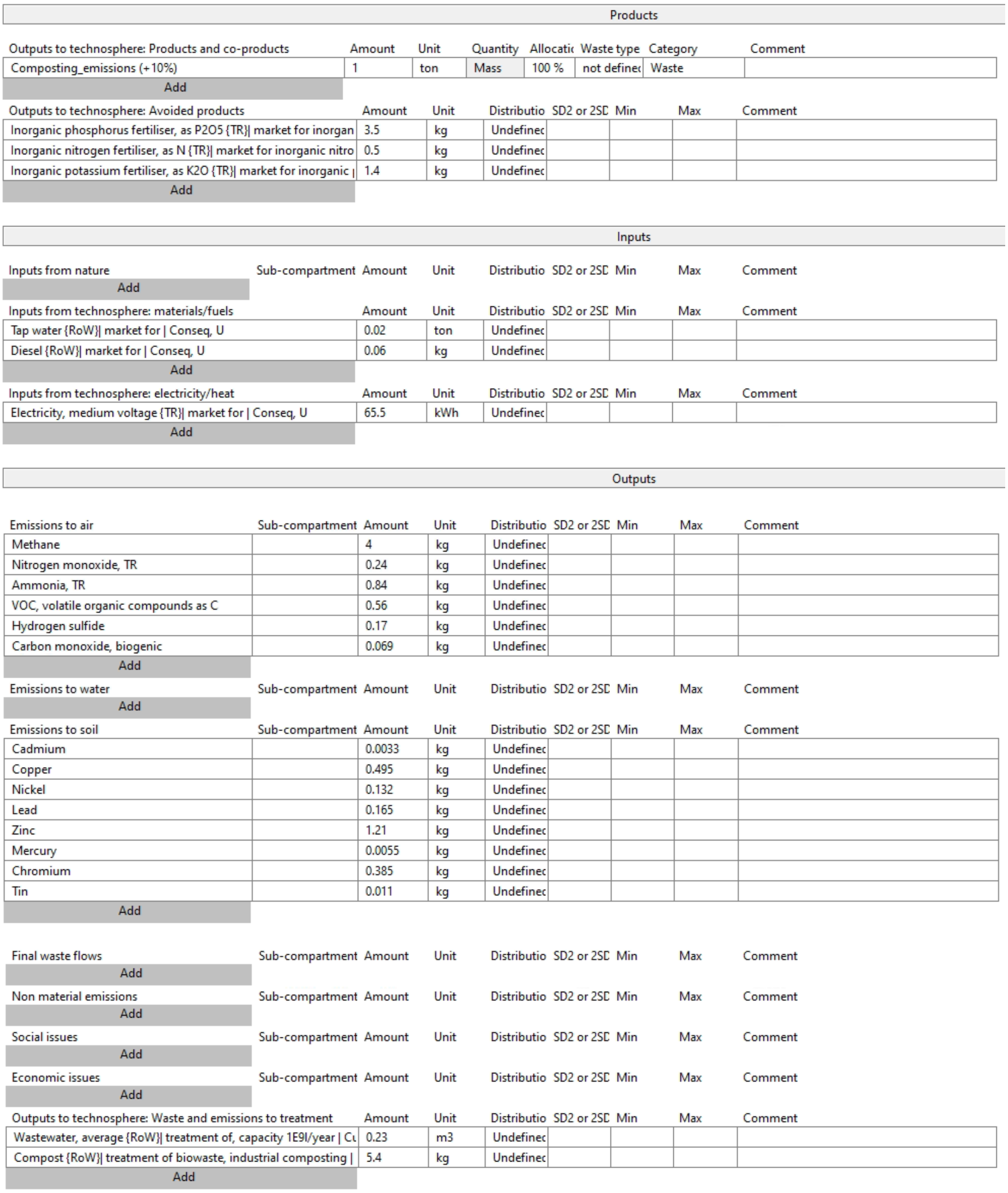
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.23	m3	Undefinec				
Compost {RoW}| treatment of biowaste, industrial composting |	5.4	kg	Undefinec				

Composting (+10% emissions to soil level)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Composting_emissions (+10%)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Inorganic phosphorus fertiliser, as P2O5 {TR}| market for inorgan	3.5	kg	Undefinec				
Inorganic nitrogen fertiliser, as N {TR}| market for inorganic nitro	0.5	kg	Undefinec				
Inorganic potassium fertiliser, as K2O {TR}| market for inorganic |	1.4	kg	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {RoW}| market for | Conseq, U	0.02	ton	Undefinec				
Diesel {RoW}| market for | Conseq, U	0.06	kg	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	65.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Methane		4	kg	Undefinec				
Nitrogen monoxide, TR		0.24	kg	Undefinec				
Ammonia, TR		0.84	kg	Undefinec				
VOC, volatile organic compounds as C		0.56	kg	Undefinec				
Hydrogen sulfide		0.17	kg	Undefinec				
Carbon monoxide, biogenic		0.069	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Cadmium		0.0033	kg	Undefinec				
Copper		0.495	kg	Undefinec				
Nickel		0.132	kg	Undefinec				
Lead		0.165	kg	Undefinec				
Zinc		1.21	kg	Undefinec				
Mercury		0.0055	kg	Undefinec				
Chromium		0.385	kg	Undefinec				
Tin		0.011	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

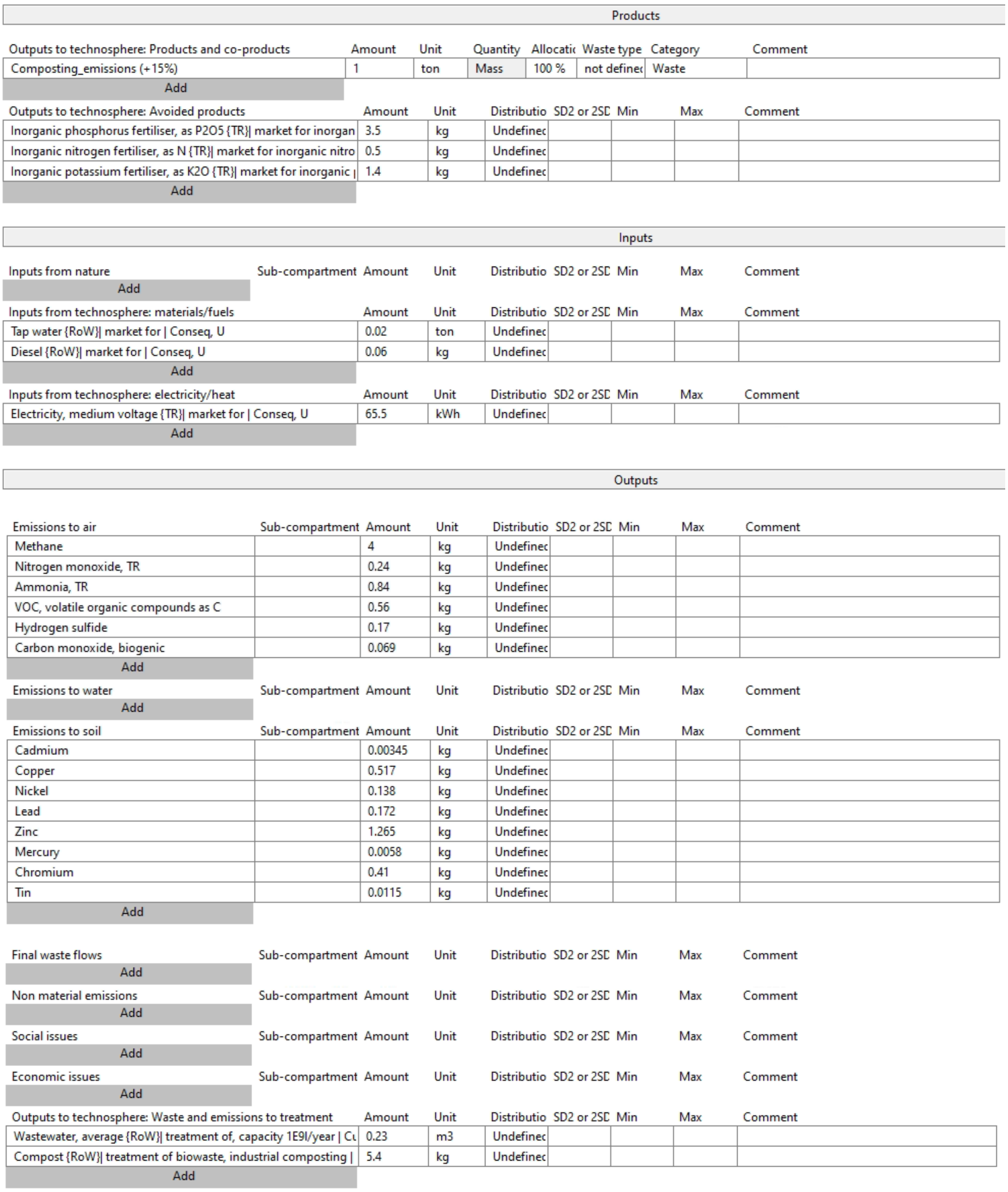
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.23	m3	Undefinec				
Compost {RoW}| treatment of biowaste, industrial composting |	5.4	kg	Undefinec				

Composting (+15% emissions to soil level)



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Composting_emissions (+15%)	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Inorganic phosphorus fertiliser, as P2O5 {TR}| market for inorgan	3.5	kg	Undefinec				
Inorganic nitrogen fertiliser, as N {TR}| market for inorganic nitro	0.5	kg	Undefinec				
Inorganic potassium fertiliser, as K2O {TR}| market for inorganic	1.4	kg	Undefinec				

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {RoW}| market for | Conseq, U	0.02	ton	Undefinec				
Diesel {RoW}| market for | Conseq, U	0.06	kg	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	65.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Methane		4	kg	Undefinec				
Nitrogen monoxide, TR		0.24	kg	Undefinec				
Ammonia, TR		0.84	kg	Undefinec				
VOC, volatile organic compounds as C		0.56	kg	Undefinec				
Hydrogen sulfide		0.17	kg	Undefinec				
Carbon monoxide, biogenic		0.069	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Cadmium		0.00345	kg	Undefinec				
Copper		0.517	kg	Undefinec				
Nickel		0.138	kg	Undefinec				
Lead		0.172	kg	Undefinec				
Zinc		1.265	kg	Undefinec				
Mercury		0.0058	kg	Undefinec				
Chromium		0.41	kg	Undefinec				
Tin		0.0115	kg	Undefinec				

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

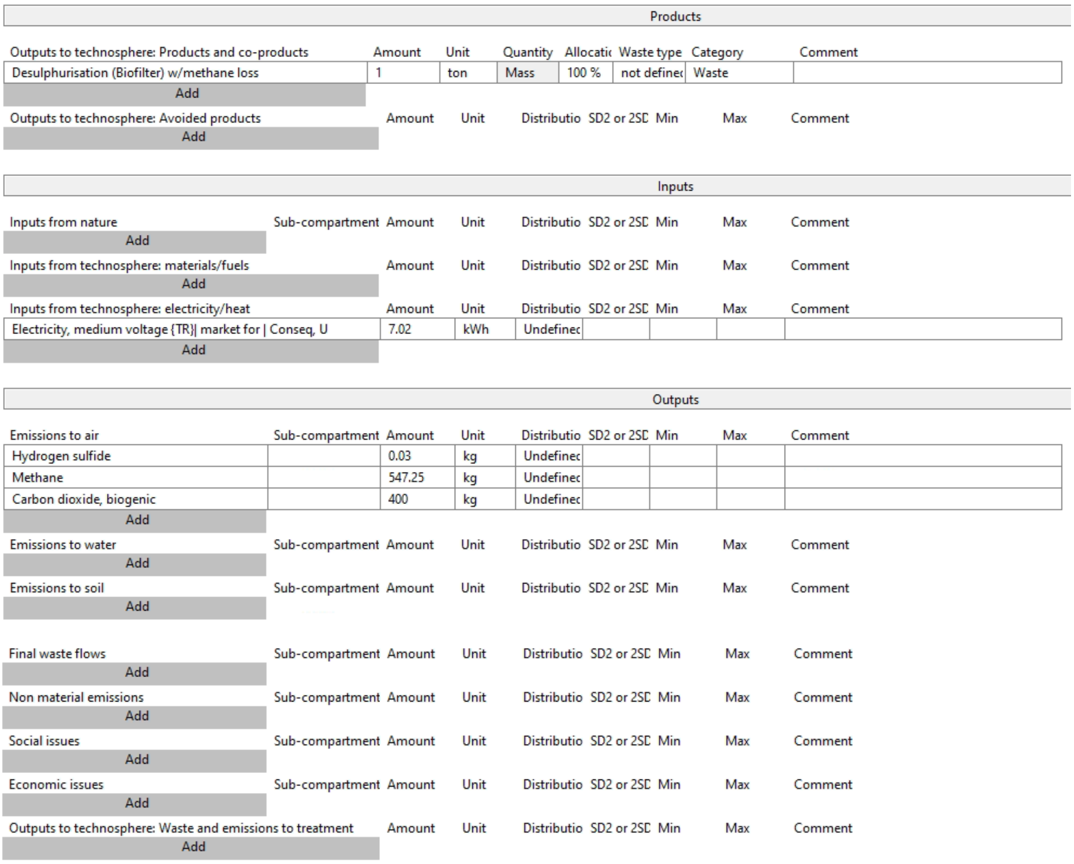
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.23	m3	Undefinec				
Compost {RoW}| treatment of biowaste, industrial composting |	5.4	kg	Undefinec				

Desulphurization (Biofilter) w/ methane loss



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Biofilter) w/methane loss	1	ton	Mass	100 %	not definec	Waste	
Add							

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add							

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add							

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	7.02	kWh	Undefinec				
Add							

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.03	kg	Undefinec				
Methane		547.25	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				
Add								

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

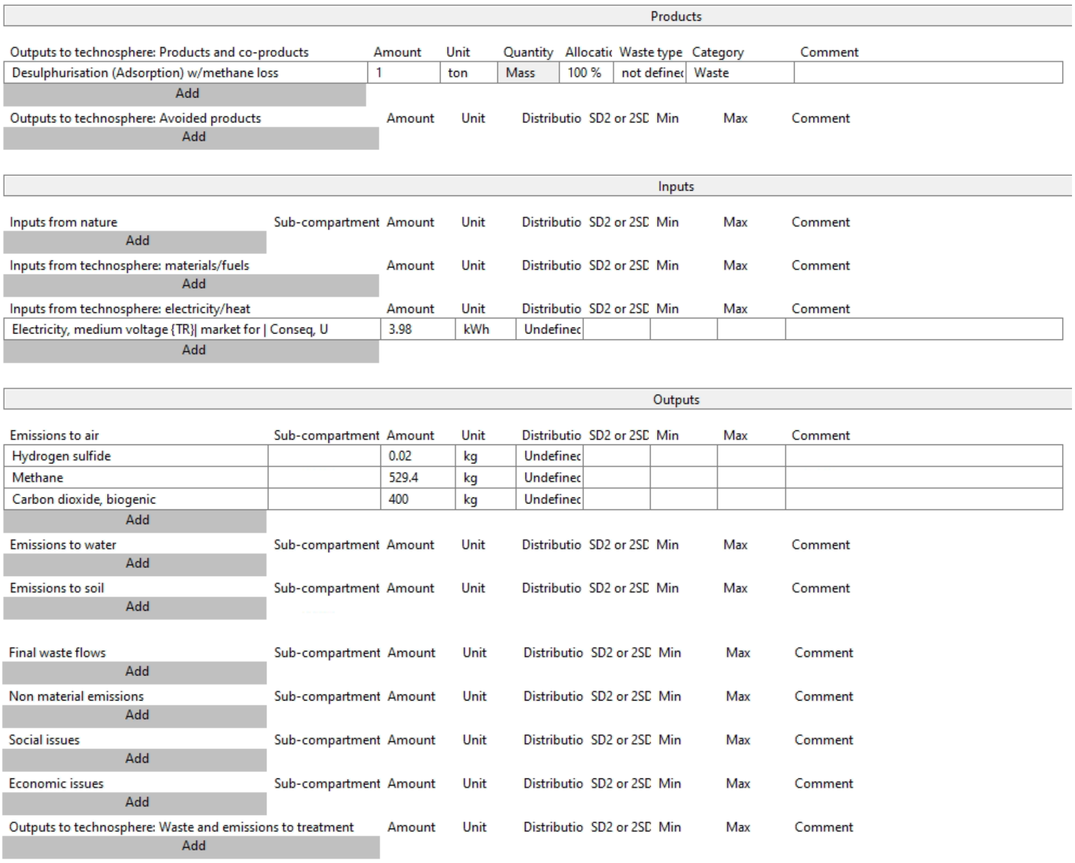
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add								

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Add							

Desulphurization (Adsorption) w/ methane loss



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatio	Waste type	Category	Comment
Desulphurisation (Adsorption) w/methane loss	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.98	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.02	kg	Undefinec				
Methane		529.4	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

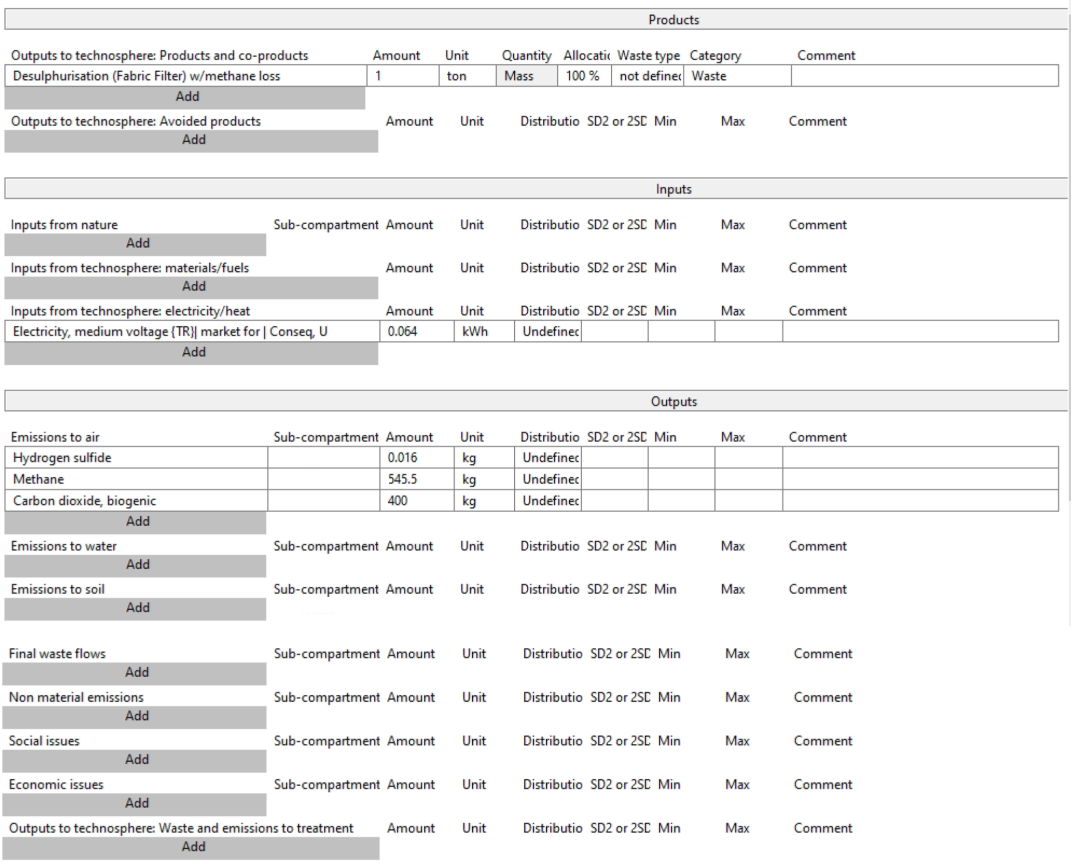
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Desulphurization (Fabric Filter) w/ methane loss



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatio	Waste type	Category	Comment
Desulphurisation (Fabric Filter) w/methane loss	1	ton	Mass	100 %	not define	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	0.064	kWh	Undefined				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.016	kg	Undefined				
Methane		545.5	kg	Undefined				
Carbon dioxide, biogenic		400	kg	Undefined				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

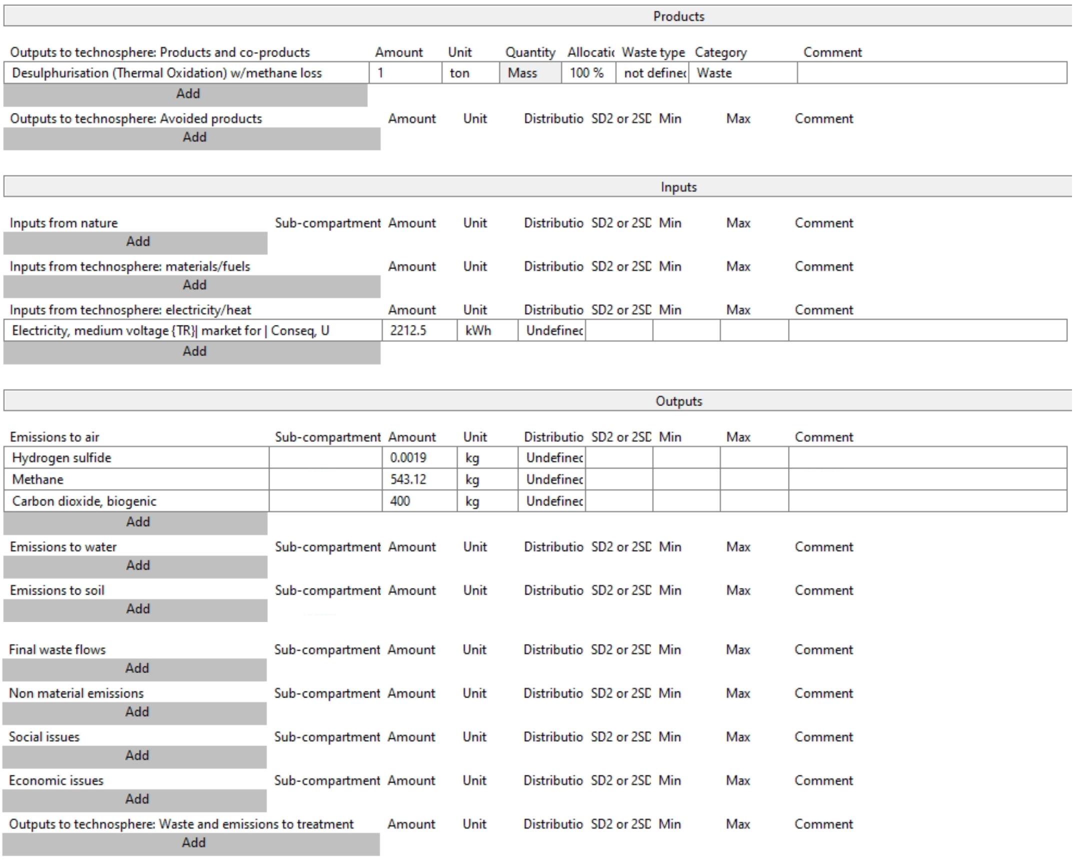
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Desulphurization (Thermal Oxidation) w/ methane loss



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Thermal Oxidation) w/methane loss	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	2212.5	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.0019	kg	Undefinec				
Methane		543.12	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

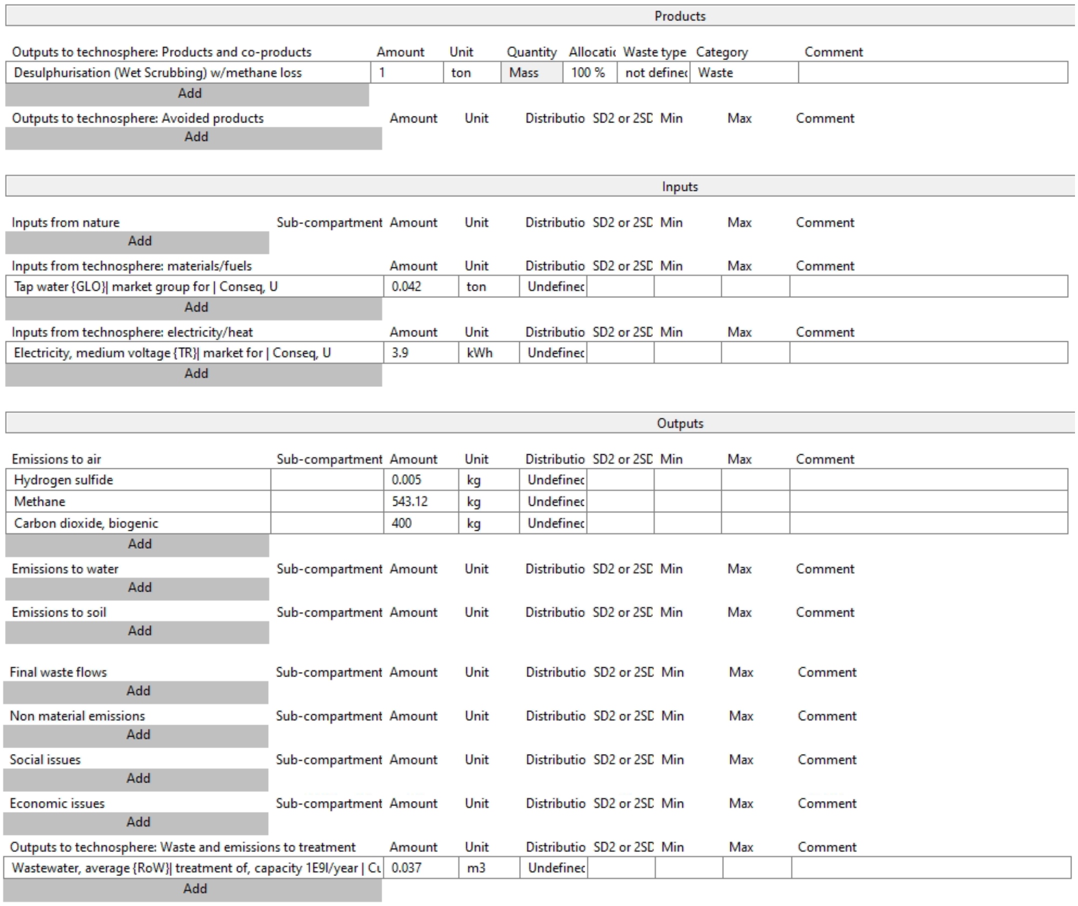
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Desulphurization (Wet Scrubbing) w/methane loss



Products

Outputs to technosphere: Products and co-products	Amount	Unit	Quantity	Allocatic	Waste type	Category	Comment
Desulphurisation (Wet Scrubbing) w/methane loss	1	ton	Mass	100 %	not definec	Waste	

Outputs to technosphere: Avoided products	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Inputs from technosphere: materials/fuels	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Tap water {GLO}| market group for | Conseq, U	0.042	ton	Undefinec				

Inputs from technosphere: electricity/heat	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Electricity, medium voltage {TR}| market for | Conseq, U	3.9	kWh	Undefinec				

Outputs

Emissions to air	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Hydrogen sulfide		0.005	kg	Undefinec				
Methane		543.12	kg	Undefinec				
Carbon dioxide, biogenic		400	kg	Undefinec				

Emissions to water	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Emissions to soil	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Final waste flows	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

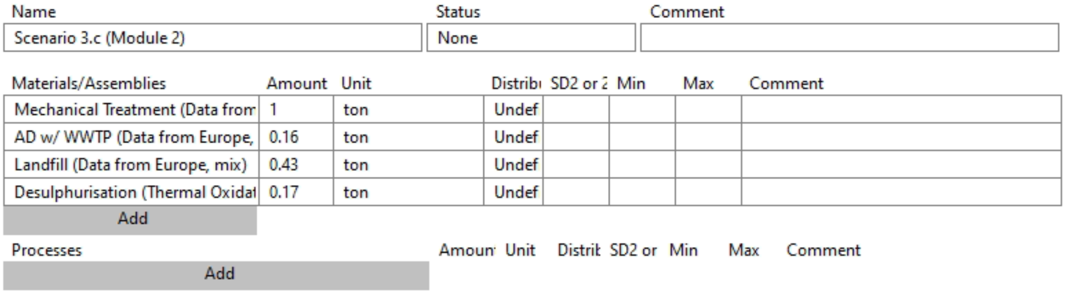
Non material emissions	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Social issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Economic issues	Sub-compartment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distributio	SD2 or 2SD	Min	Max	Comment
Wastewater, average {RoW}| treatment of, capacity 1E9l/year | Cu	0.037	m3	Undefinec				

Scenario 3.c (Module 2)

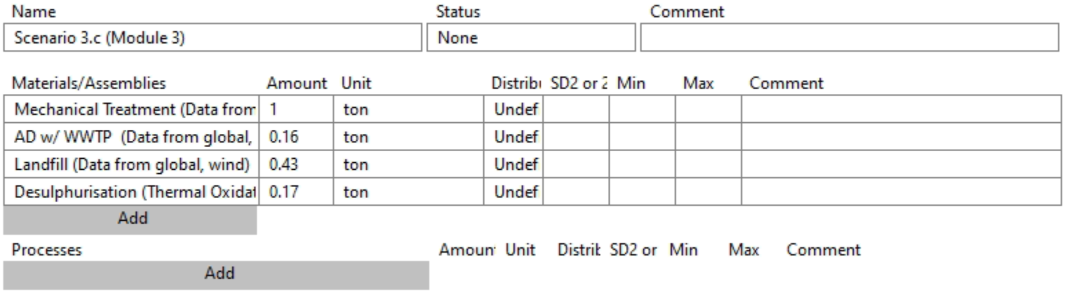


Name	Status	Comment
Scenario 3.c (Module 2)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or 2	Min	Max	Comment
Mechanical Treatment (Data from	1	ton	Undef				
AD w/ WWTP (Data from Europe,	0.16	ton	Undef				
Landfill (Data from Europe, mix)	0.43	ton	Undef				
Desulphurisation (Thermal Oxidat	0.17	ton	Undef				

Processes	Amoun	Unit	Distrib	SD2 or	Min	Max	Comment

Scenario 3.c (Module 3)

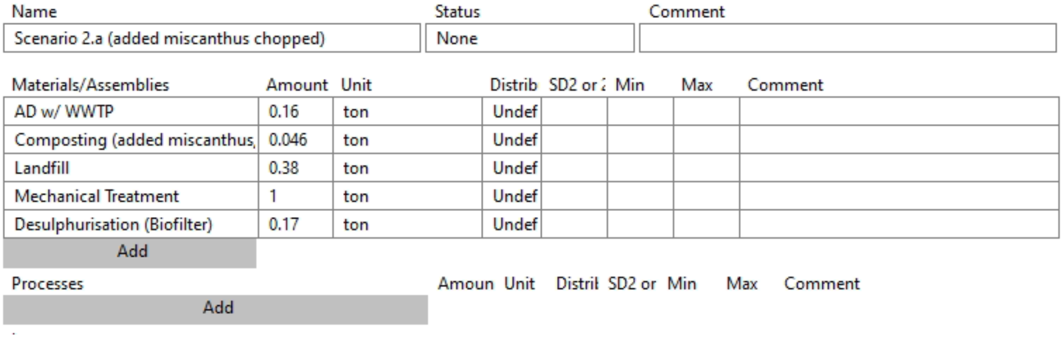


Name	Status	Comment
Scenario 3.c (Module 3)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or 2	Min	Max	Comment
Mechanical Treatment (Data from	1	ton	Undef				
AD w/ WWTP (Data from global,	0.16	ton	Undef				
Landfill (Data from global, wind)	0.43	ton	Undef				
Desulphurisation (Thermal Oxidat	0.17	ton	Undef				

Processes	Amoun	Unit	Distrib	SD2 or	Min	Max	Comment

Scenario 2.a (added miscanthus chopped)

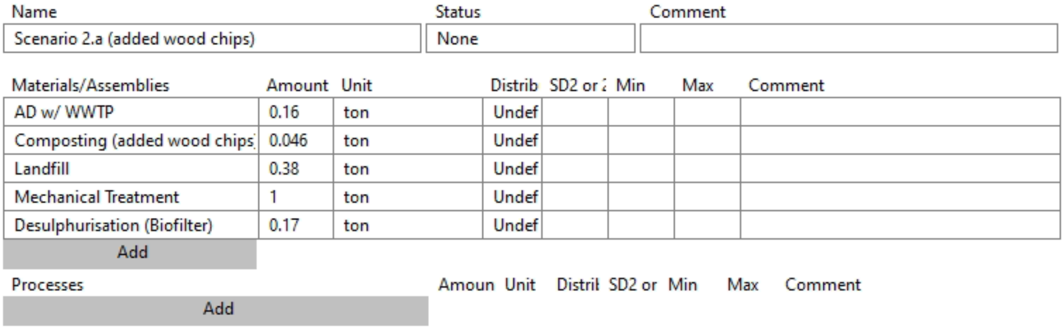


Name	Status	Comment
Scenario 2.a (added miscanthus chopped)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Composting (added miscanthus,	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Mechanical Treatment	1	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 2.a (added wood chips)

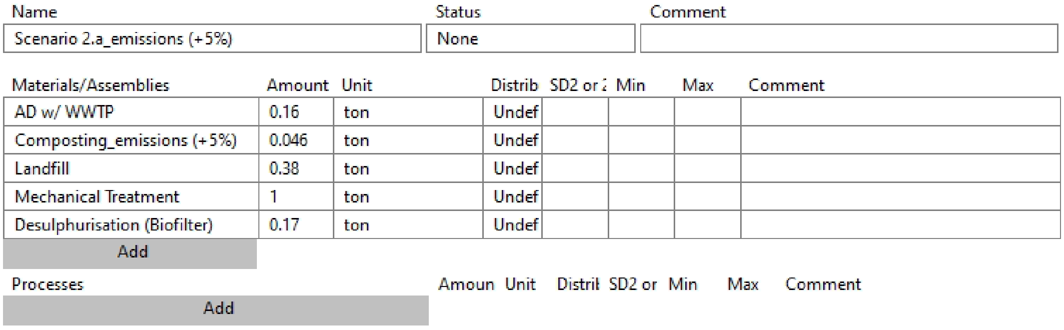


Name	Status	Comment
Scenario 2.a (added wood chips)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Composting (added wood chips	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Mechanical Treatment	1	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 2.a (5% emissions to soil level)

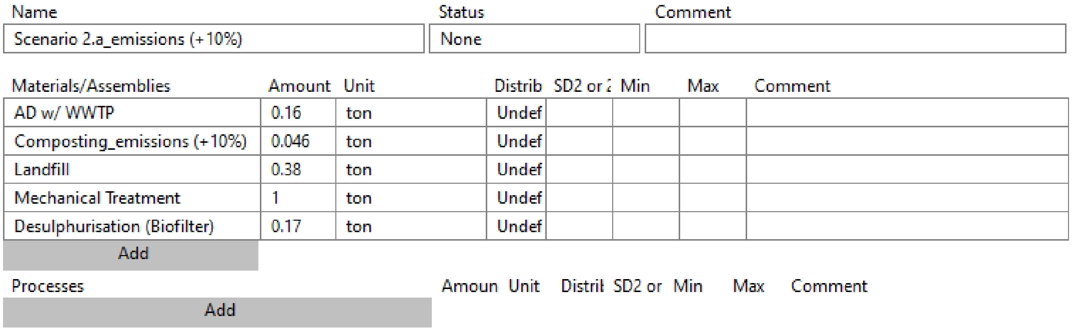


Name	Status	Comment
Scenario 2.a_emissions (+5%)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Composting_emissions (+5%)	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Mechanical Treatment	1	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 2.a (10% emissions to soil level)

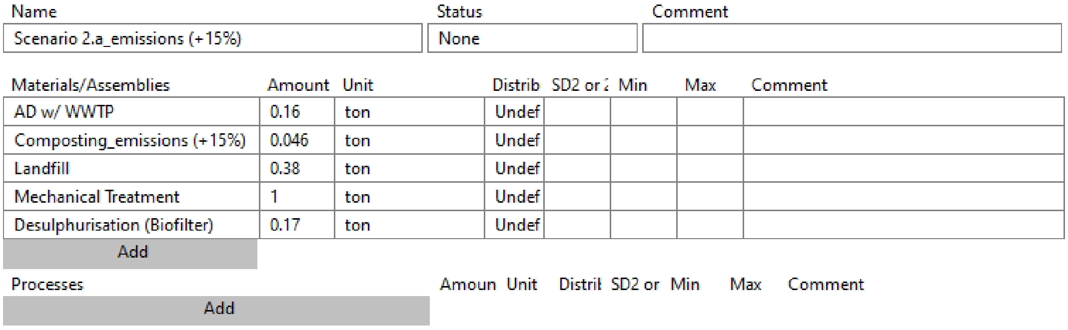


Name	Status	Comment
Scenario 2.a_emissions (+10%)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Composting_emissions (+10%)	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Mechanical Treatment	1	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 2.a (15% emissions to soil level)

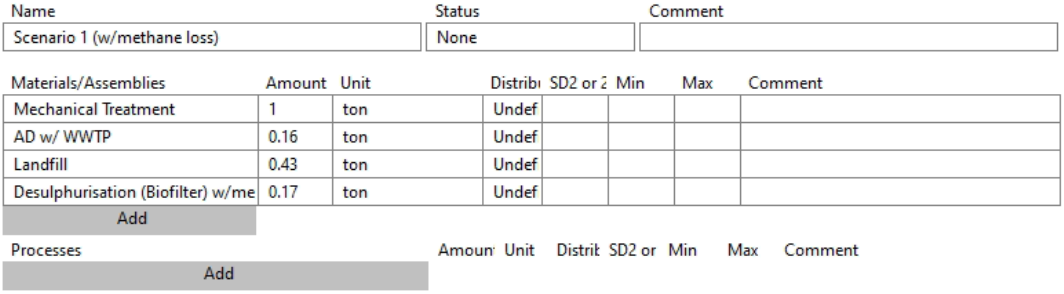


Name	Status	Comment
Scenario 2.a_emissions (+15%)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
AD w/ WWTP	0.16	ton	Undef				
Composting_emissions (+15%)	0.046	ton	Undef				
Landfill	0.38	ton	Undef				
Mechanical Treatment	1	ton	Undef				
Desulphurisation (Biofilter)	0.17	ton	Undef				

Processes	Amoun	Unit	Distri	SD2 or	Min	Max	Comment

Scenario 1 (w/ methane loss)

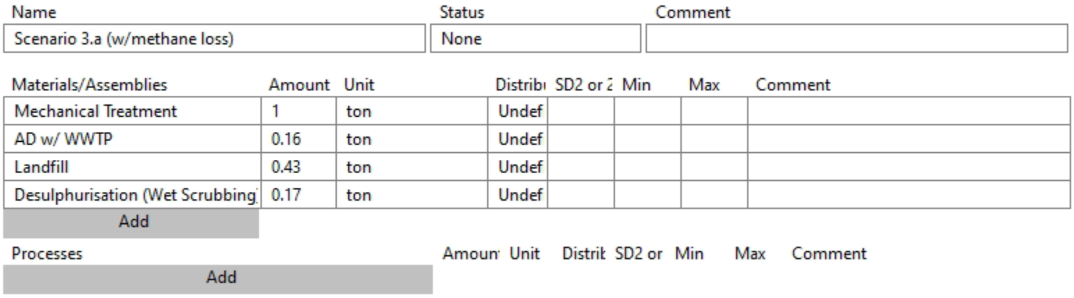


Name	Status	Comment
Scenario 1 (w/methane loss)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Biofilter) w/me	0.17	ton	Undef				

Processes	Amoun	Unit	Distrib	SD2 or	Min	Max	Comment

Scenario 3.a (w/ methane loss)

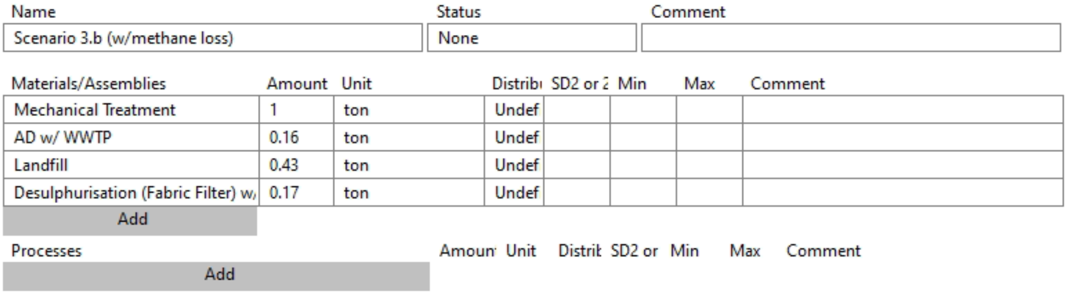


Name	Status	Comment
Scenario 3.a (w/methane loss)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Wet Scrubbing	0.17	ton	Undef				

Processes	Amoun	Unit	Distrib	SD2 or	Min	Max	Comment

Scenario 3.b (w/ methane loss)

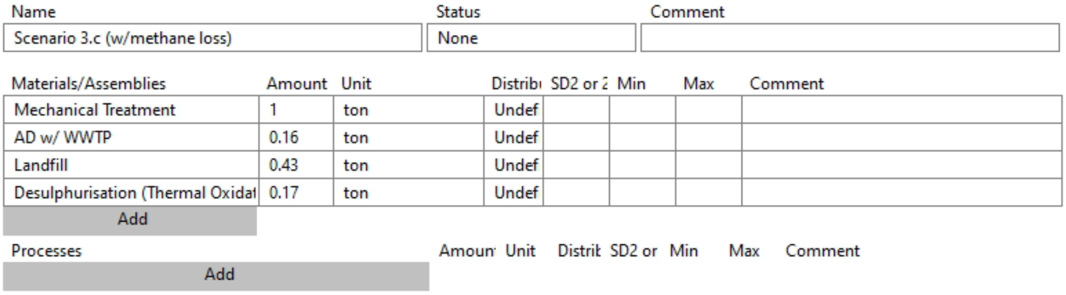


Name	Status	Comment
Scenario 3.b (w/methane loss)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Fabric Filter) w	0.17	ton	Undef				

Processes	Amoun	Unit	Distrib	SD2 or	Min	Max	Comment

Scenario 3.c (w/ methane loss)

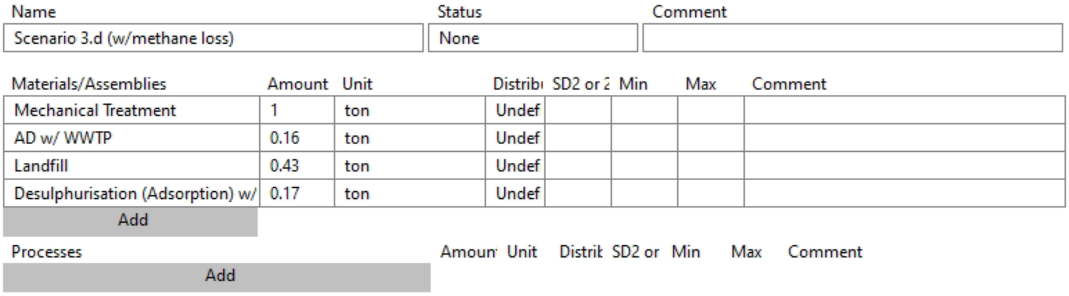


Name	Status	Comment
Scenario 3.c (w/methane loss)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Thermal Oxidat	0.17	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

Scenario 3.d (w/ methane loss)



Name	Status	Comment
Scenario 3.d (w/methane loss)	None	

Materials/Assemblies	Amount	Unit	Distrib	SD2 or	Min	Max	Comment
Mechanical Treatment	1	ton	Undef				
AD w/ WWTP	0.16	ton	Undef				
Landfill	0.43	ton	Undef				
Desulphurisation (Adsorption) w/	0.17	ton	Undef				

Processes	Amoun	Unit	Distrik	SD2 or	Min	Max	Comment

B. Results of Waste Treatment Scenarios

Table B. 1 End-Point Single Score Result Data for Waste Treatment Scenarios

Label	Scenario 1	Scenario 2.a	Scenario 2.b
Human health	93.8283	93.8943	93.8939
Ecosystems	4.5013	4.4876	4.4876
Resources	-0.02	-0.02	-0.02

Table B. 2 Mid-Point Single Score Result Data for Waste Treatment Scenarios

Label	**Scenario 1**	**Scenario 2.a**	**Scenario 2.b**
Global warming, Human health	78.35	77.9814	77.9813
Global warming, Terrestrial ecosystems	3.8265	3.8085	3.8085
Global warming, Freshwater ecosystems	0.0001	0.0001	0.0001
Stratospheric ozone depletion	0.001	0.0009	0.0009
Ionizing radiation	-0.00031	-0.00027	-0.0003
Ozone formation, Human health	0.0046	0.0048	0.0048
Fine particulate matter formation	-2	-1	-1
Ozone formation, Terrestrial ecosystems	0.0179	0.0199	0.0199
Terrestrial acidification	-0.00150	0.0005	0.0005
Freshwater eutrophication	0.6083	0.6085	0.6085
Marine eutrophication	0.0002	0.0002	0.0002
Terrestrial ecotoxicity	-1.75E-05	-3.31E-05	-3.31E-05

Freshwater ecotoxicity	0.036	0.036	0.0359
Marine ecotoxicity	0.0072	0.0072	0.0072
Human carcinogenic toxicity	0.3827	0.3878	0.3878
Human non-carcinogenic toxicity	16.948	16.9956	16.9956
Land use	0.0079	0.0078	0.0078
Mineral resource scarcity	9.2E-07	-3.52E-05	-3.52E-05
Fossil resource scarcity	-0.02	-0.02	-0.02
Water consumption, Human health	-1.39E-02	-1.35E-02	-0.01
Water consumption, Terrestrial ecosystem	-1.05E-03	-1.02E-03	-0.001

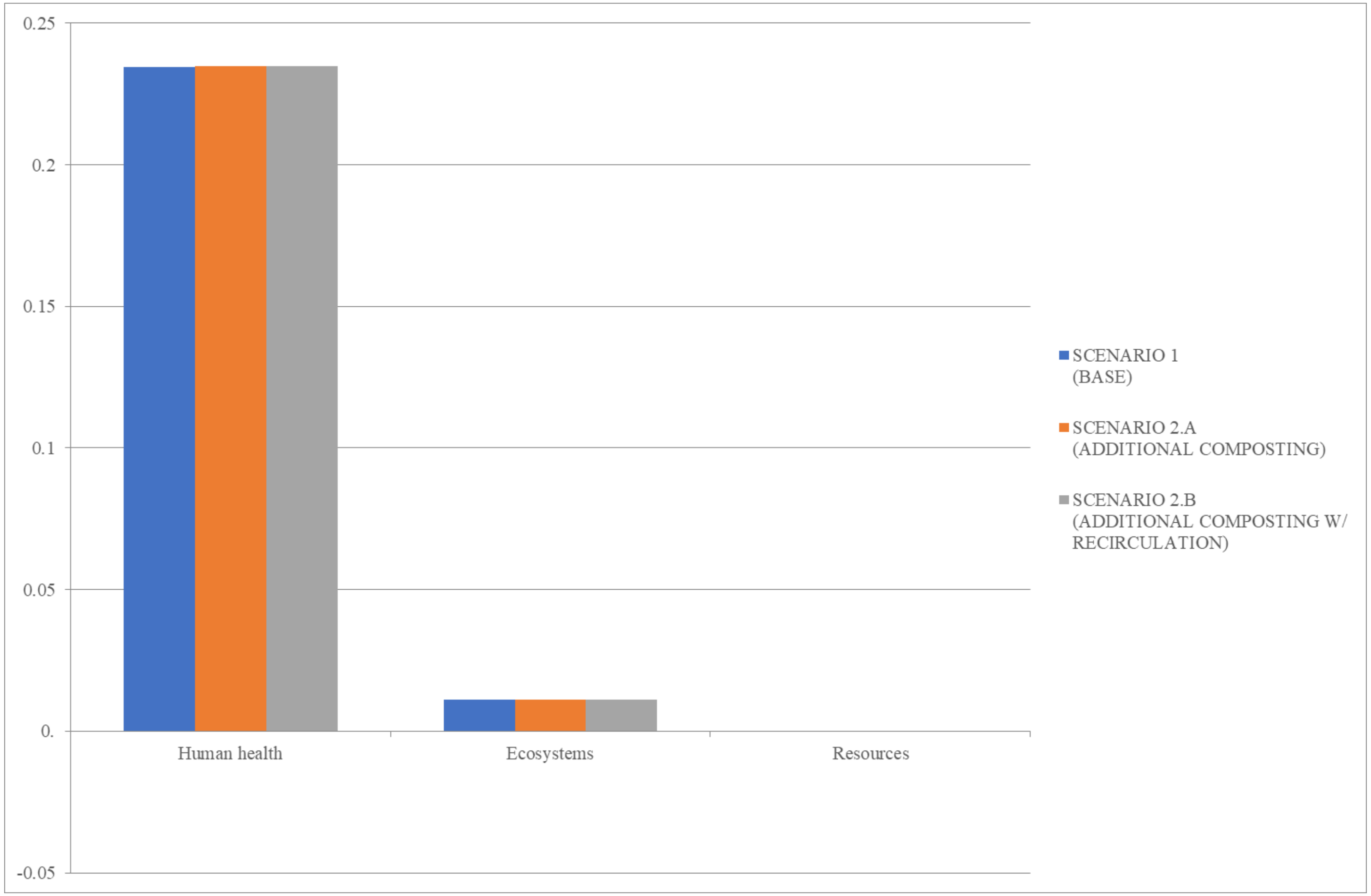


Figure B.1 Comparative end-point normalization results for waste treatment scenarios.

Table B.3 End-Point Normalization Result Data for Waste Treatment Scenarios

Label	**Scenario 1**	**Scenario 2.a**	**Scenario 2.b**
Human health	0.2346	0.2347	0.2347
Ecosystems	0.0113	0.0112	0.0112
Resources	-0.0001	-0.0001	-0.0001

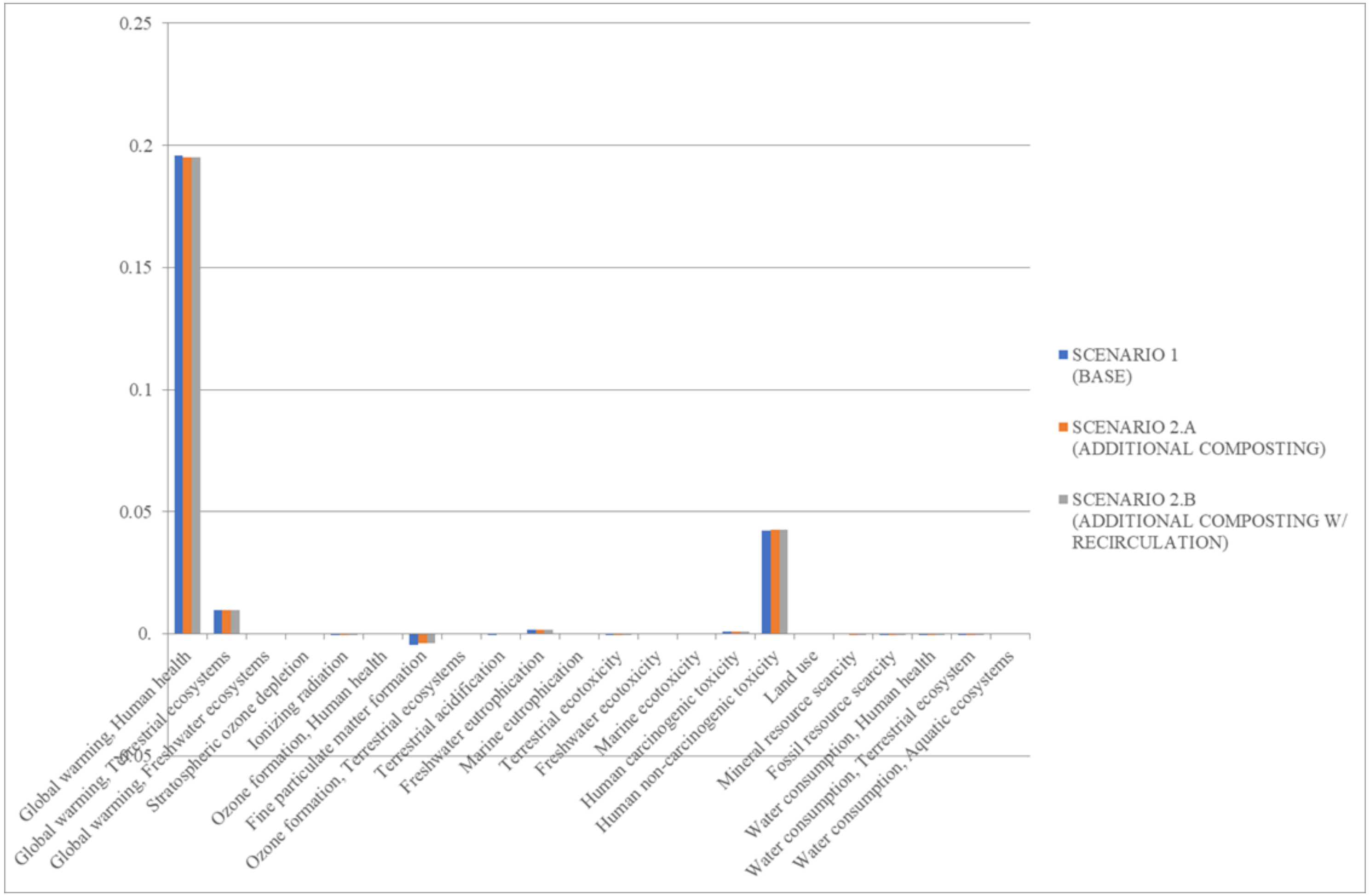


Figure B.2 Mid-point normalization results for waste treatment scenarios.

Table B.4 Mid-Point Normalization Result Data for Waste Treatment Scenarios

Label	**Scenario 1**	**Scenario 2.a**	**Scenario 2.b**
Global warming, Human health	0.1959	0.195	0.195
Global warming, Terrestrial ecosystems	0.0096	0.0095	0.0095
Global warming, Freshwater ecosystems	2.61E-07	2.6E-07	2.6E-07
Stratospheric ozone depletion	2.44E-06	2.25E-06	2.25E-06
Ionizing radiation	-7.73E-07	-6.8E-07	-6.8E-07
Ozone formation, Human health	1.15E-05	1.2E-05	1.2E-05
Fine particulate matter formation	-0.005	-0.004	-0.004
Ozone formation, Terrestrial ecosystems	4.48E-05	4.98E-05	4.98E-05
Terrestrial acidification	-3.73E-06	1.18E-06	1.18E-06
Freshwater eutrophication	0.0015	0.0015	0.0015
Marine eutrophication	4.17E-07	4.16E-07	4.16E-07
Terrestrial ecotoxicity	-4.36E-08	-8.26E-08	-8.27E-08

Freshwater ecotoxicity	8.96E-05	8.99E-05	8.99E-05
Marine ecotoxicity	1.8E-05	1.8E-05	1.8E-05
Human carcinogenic toxicity	0.001	0.001	0.001
Human non-carcinogenic toxicity	0.0424	0.0425	0.0425
Land use	1.97E-05	1.94E-05	1.94E-05
Mineral resource scarcity	5.11E-09	-1.75E-07	-1.76E-07
Fossil resource scarcity	-0.0001	-9.98E-05	-9.99E-05
Water consumption, Human health	-3.53E-05	-3.43E-05	-3.46E-05
Water consumption, Terrestrial ecosystem	-2.67E-06	-2.59E-06	-2.62E-06
Water consumption, Aquatic ecosystem	1.28E-10	1.26E-10	1.24E-10

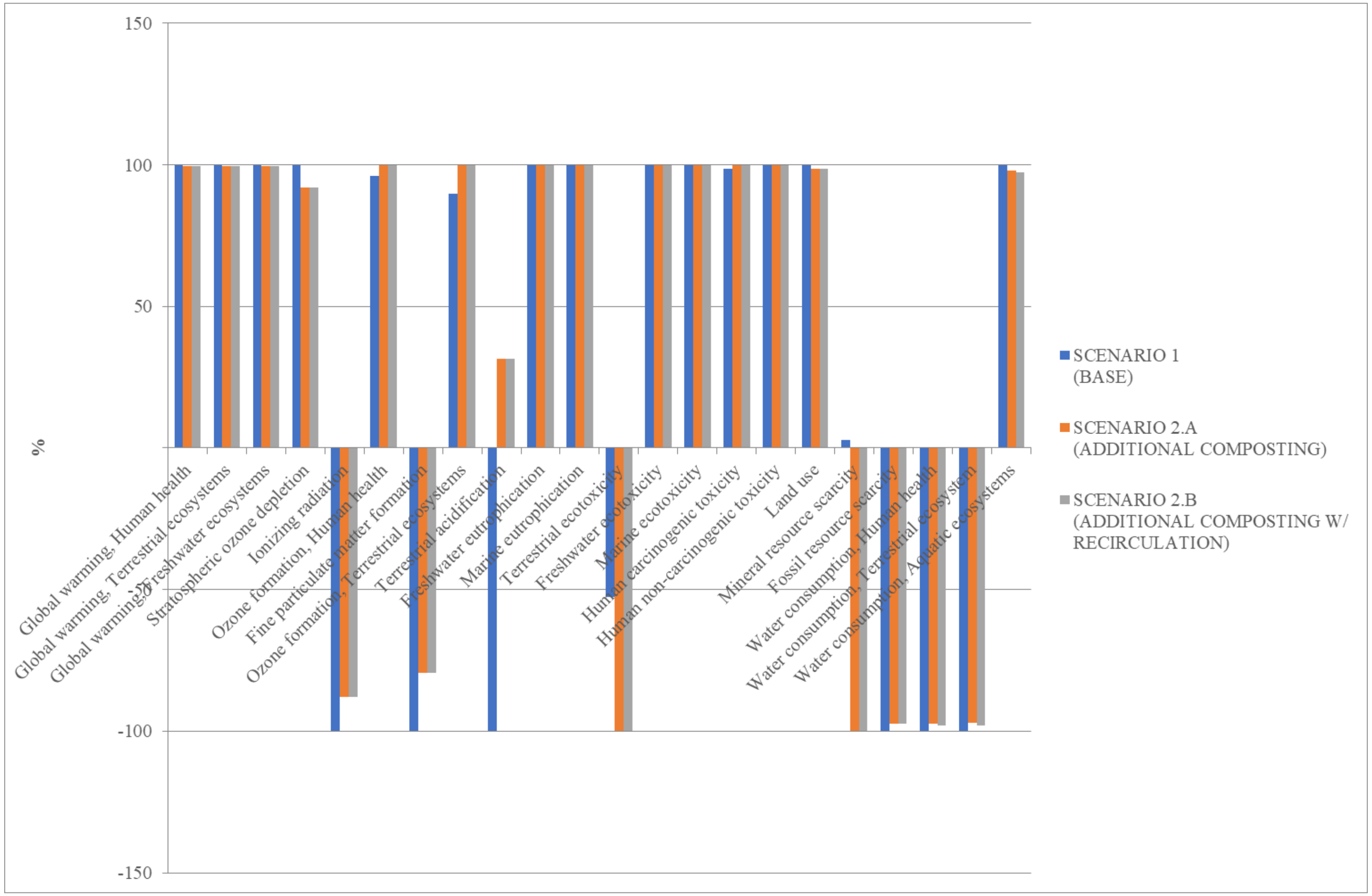


Figure B.3 Comparative characterization results for waste treatment scenarios.

Table B.5 Comparative Characterization Result Data for Waste Treatment Scenarios

Label	**Scenario 1**	**Scenario 2.a**	**Scenario 2.b**
Global warming, Human health	100	99.5295	99.5293
Global warming, Terrestrial ecosystems	100	99.5295	99.5294
Global warming, Freshwater ecosystems	100	99.5295	99.5294
Stratospheric ozone depletion	100	92.118	92.1009
Ionizing radiation	-100	-88	-88
Ozone formation, Human health	96.1338	100	99.9955
Fine particulate matter formation	-100	-79	-79
Ozone formation, Terrestrial ecosystems	89.892	100	99.9974
Terrestrial acidification	-100	31.5813	31.5086
Freshwater eutrophication	99.9548	100	99.9999
Marine eutrophication	100	99.9076	99.9075
Terrestrial ecotoxicity	-53	-100	-100

Freshwater ecotoxicity	99.7585	100	99.9998
Marine ecotoxicity	99.8468	100	99.9998
Human carcinogenic toxicity	98.7004	100	99.9866
Human non-carcinogenic toxicity	99.7203	100	99.9999
Land use	100	98.4955	98.4936
Mineral resource scarcity	2.904	-100	-100
Fossil resource scarcity	-100	-97	-97
Water consumption, Human health	-100	-97	-98
Water consumption, Terrestrial ecosystem	-100	-97	-98

Table B. 6 Data of Influencing Input Parameter Analysis of Waste Treatment Scenarios Based on GWHH

Input Parameters	**Scenario 1**	**Scenario 2.a**	**Scenario 2.b**
Electricity_Desulphurization	0.003	0.003	0.003
Electricity_AD	0.001	0.001	0.001
Total municipal solid waste_Mechanical treatment	0.0005	0.0005	0.0005
Electricity_Mechanical treatment	0.0003	0.0002	0.0002
Electricity_Composting	0	5.81E-06	5.81E-06
Organic waste_AD	3.03E-06	3.03E-06	3.03E-06
Electricity_Landfill	-8.55E-06	-7.67E-06	-7.67E-06
Heat_AD	-1.13E-05	-1.19E-05	-1.19E-05

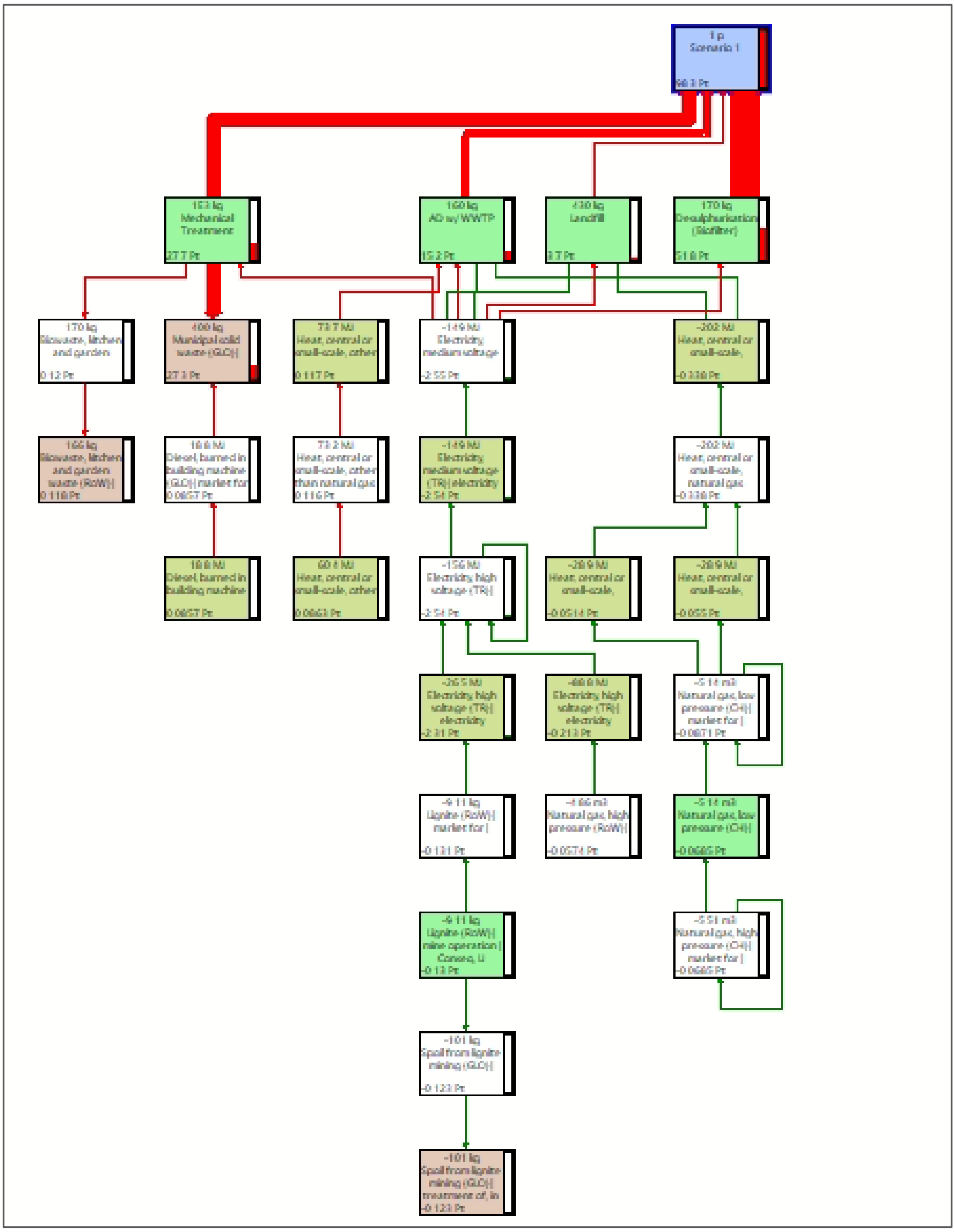


Figure B.4 Network analysis results of Scenario 1.

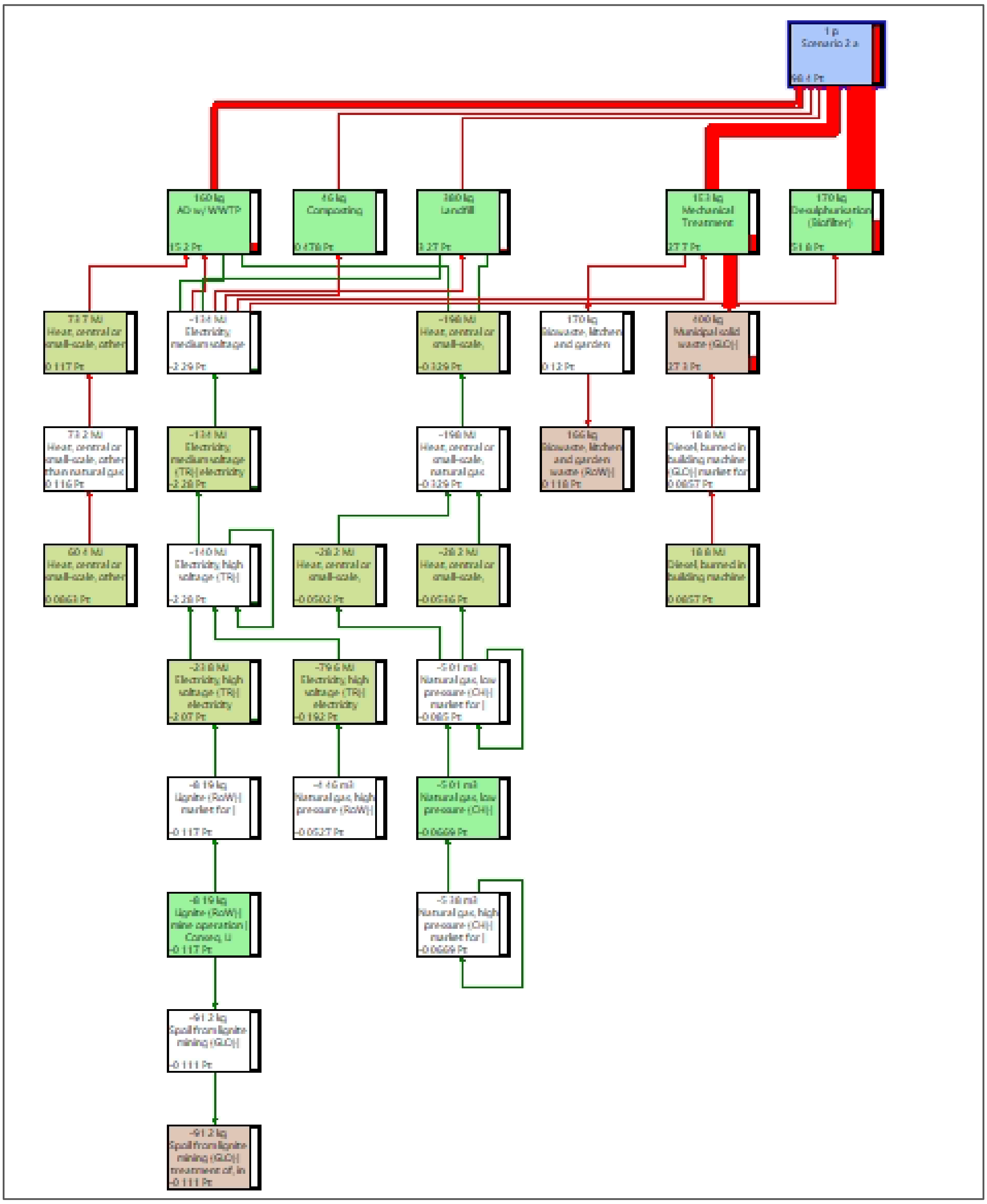


Figure B.5 Network analysis results of Scenario 2.a.

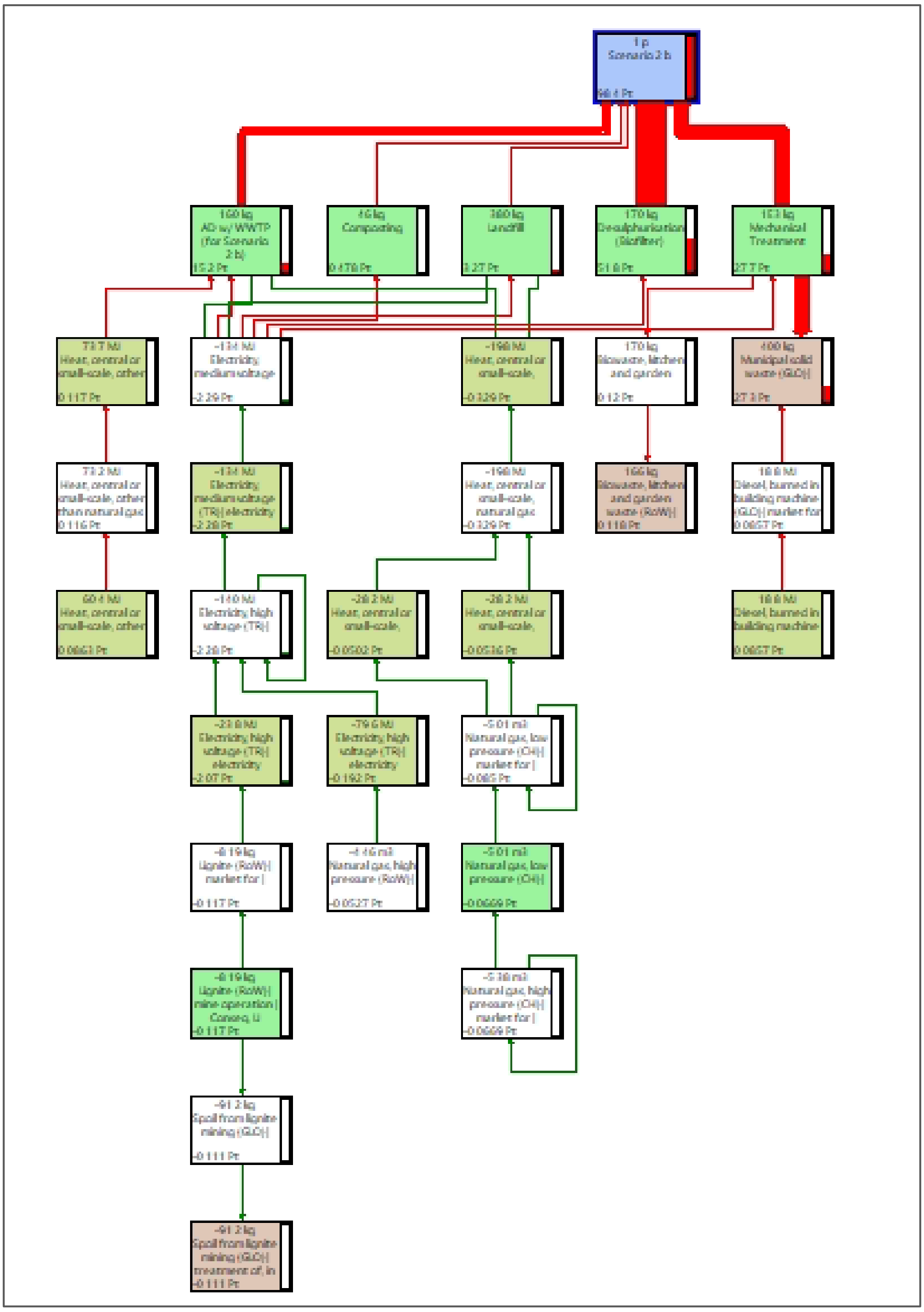


Figure B.6 Network analysis results of Scenario 2.b.

C. Results of Desulphurization Scenarios

Table C. 1 End-Point Single Score Result Data for Desulphurization Scenarios

Label	**Scenario 1**	**Scenario 3.a**	**Scenario 3.b**	**Scenario 3.c**	**Scenario 3.d**
Human health	93.8282	93.7966	93.7565	116.562	93.7968
Ecosystems	4.5014	4.501	4.5006	4.7436	4.501
Resources	-0.02	-0.02	-0.02	0.07	-0.02

Table C. 2 Mid-Point Single Score Result Data for Desulphurization Scenarios

Label	**Scenario 1**	**Scenario 3.a**	**Scenario 3.b**	**Scenario 3.c**	**Scenario 3.d**
Global warming, Human health	78.35	78.3462	78.341	81.2152	78.346
Global warming, Terrestrial ecosystems	3.8265	3.8263	3.826	3.9667	3.8263
Global warming, Freshwater ecosystems	0.0001	0.0001	0.0001	0.0001	0.0001
Stratospheric ozone depletion	0.001	0.001	0.001	0.0015	0.001
Ionizing radiation	-0.0003	-0.0003	-0.0003	0.0026	-0.0003
Ozone formation, Human health	0.0046	0.0046	0.0046	0.0088	0.0046
Fine particulate matter formation	-2	-2	-2	16.6674	-2
Ozone formation, Terrestrial ecosystems	0.0179	0.0179	0.0179	0.0276	0.0179
Terrestrial acidification	-0.001	-0.002	-0.002	0.04	-0.002
Freshwater eutrophication	0.6083	0.6082	0.6082	0.6437	0.6082
Marine eutrophication	0.0002	0.0002	0.0002	0.0002	0.0002
Terrestrial ecotoxicity	-1.75E-05	-1.79E-05	-1.87E-05	0.0004	-1.8E-05

Freshwater ecotoxicity	0.0359	0.0359	0.0359	0.037	0.0359
Marine ecotoxicity	0.0072	0.0072	0.0072	0.0074	0.0072
Human carcinogenic toxicity	0.3827	0.3821	0.381	0.9178	0.382
Human non-carcinogenic toxicity	16.948	16.947	16.9456	17.7346	16.947
Land use	0.0079	0.0079	0.0079	0.0159	0.0079
Mineral resource scarcity	9.2E-07	1.02E-06	5.71E-07	0.0001	7.67E-07
Fossil resource scarcity	-0.02	-0.02	-0.02	0.0739	-0.02
Water consumption, Human health	-0.01	-0.01	-0.01	0.0142	-0.01
Water consumption, Terrestrial ecosystem	-0.001	-0.001	-0.001	0.0013	-0.001
Water consumption, Aquatic ecosystems	5.21E-08	5.43E-08	5.21E-08	5.45E-08	5.21E-08

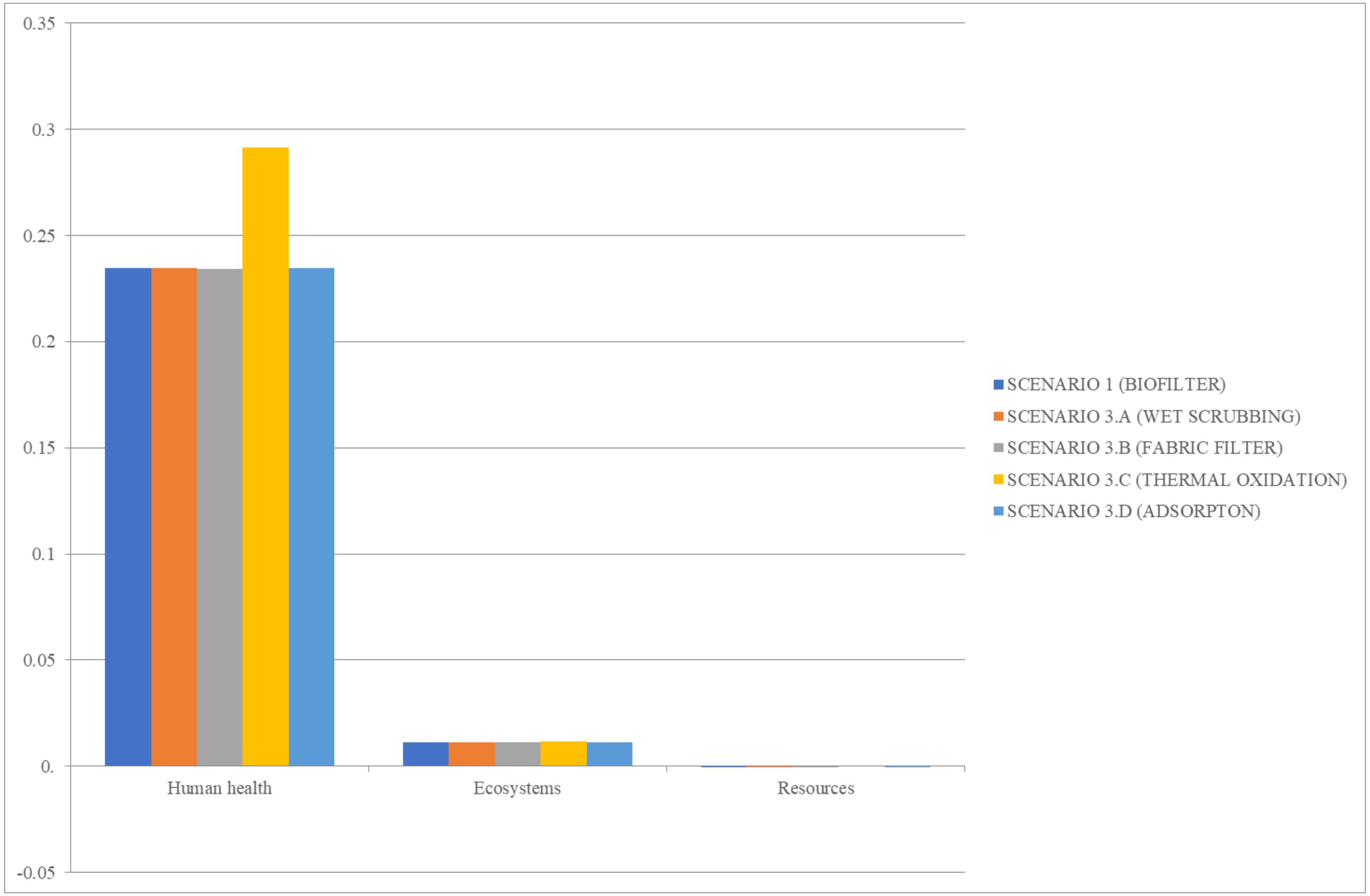


Figure C. 1 Comparative end-point normalization results for desulphurization scenarios.

Table C. 3 End-Point Normalization Result Data for Desulphurization Scenarios

Label	**Scenario 1**	**Scenario 3.a**	**Scenario 3.b**	**Scenario 3.c**	**Scenario 3.d**
Human health	0.2346	0.2345	0.2344	0.2914	0.2345
Ecosystems	0.0113	0.0113	0.0113	0.0119	0.0113
Resources	-0.0001	-0.0001	-0.0001	0.0004	-0.0001

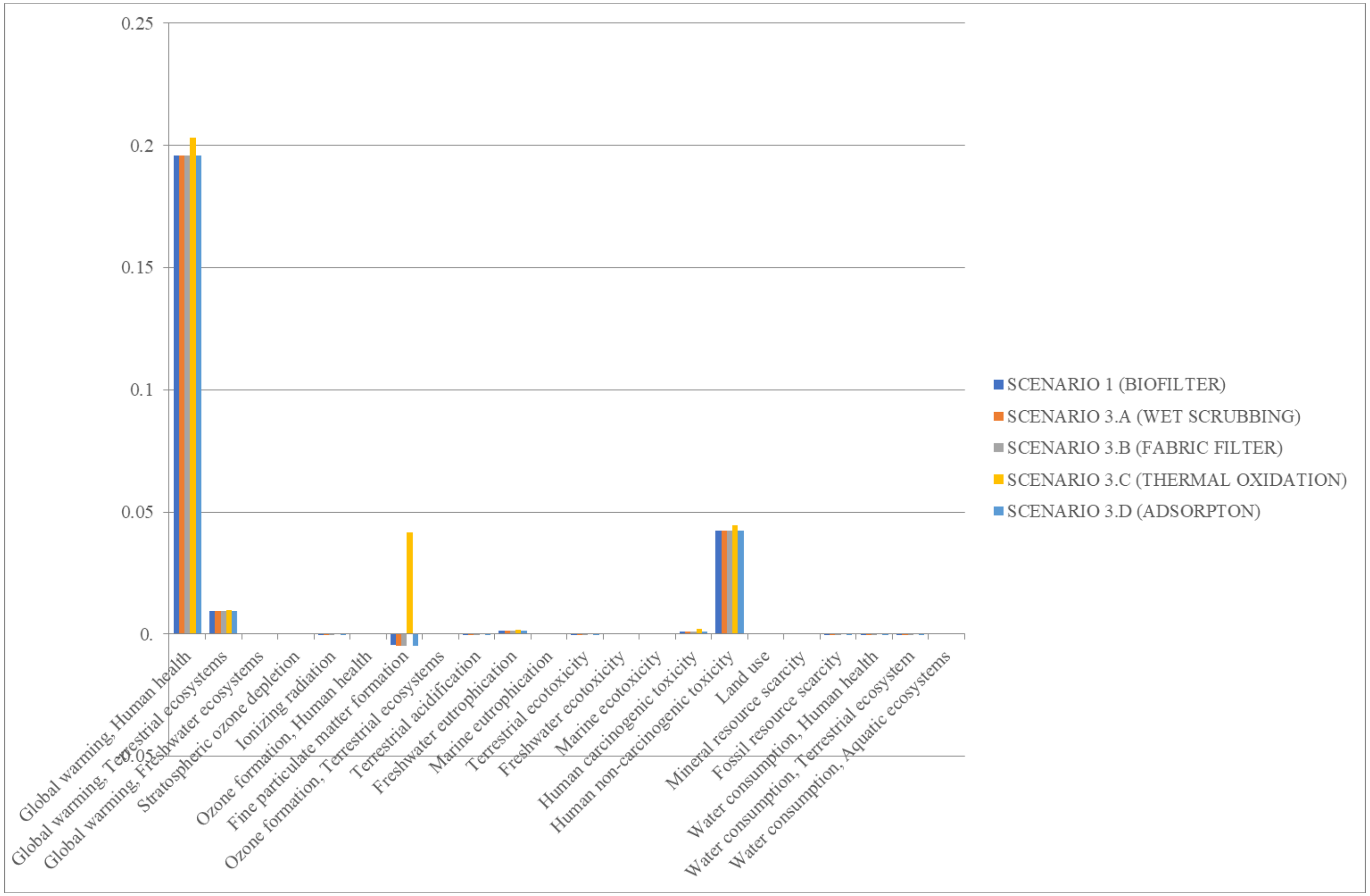


Figure C. 2 Mid-point normalization results for desulphurization scenarios.

Table C. 4 Mid-Point Normalization Result Data for Desulphurization Scenarios

Label	**Scenario 1**	**Scenario 3.a**	**Scenario 3.b**	**Scenario 3.c**	**Scenario 3.d**
Global warming, Human health	0.1959	0.1959	0.1959	0.203	0.1959
Global warming, Terrestrial ecosystems	0.0096	0.0096	0.0096	0.0099	0.0096
Global warming, Freshwater ecosystems	2.61E-07	2.61E-07	2.61E-07	2.71E-07	2.61E-07
Stratospheric ozone depletion	2.44E-06	2.44E-06	2.44E-06	3.81E-06	2.44E-06
Ionizing radiation	-7.73E-07	-7.83E-07	-7.96E-07	6.39E-06	-7.83E-07
Ozone formation, Human health	1.15E-05	1.15E-05	1.15E-05	2.19E-05	1.15E-05
Fine particulate matter formation	-0.0046	-0.0047	-0.0048	0.0417	-0.0047
Ozone formation, Terrestrial ecosystems	4.48E-05	4.48E-05	4.47E-05	6.9E-05	4.48E-05
Terrestrial acidification	-3.74E-06	-3.89E-06	-4.09E-06	0.0001	-3.89E-06
Freshwater eutrophication	0.0015	0.0015	0.0015	0.0016	0.0015
Marine eutrophication	4.17E-07	4.17E-07	4.17E-07	4.31E-07	4.17E-07
Terrestrial ecotoxicity	-4.38E-08	-4.48E-08	-4.67E-08	8.95E-07	-4.51E-08

Freshwater ecotoxicity	8.96E-05	8.96E-05	8.96E-05	9.27E-05	8.96E-05
Marine ecotoxicity	1.8E-05	1.8E-05	1.8E-05	1.86E-05	1.8E-05
Human carcinogenic toxicity	0.001	0.001	0.001	0.0023	0.001
Human non-carcinogenic toxicity	0.0424	0.0424	0.0424	0.0443	0.0424
Land use	1.97E-05	1.97E-05	1.97E-05	3.99E-05	1.97E-05
Mineral resource scarcity	4.6E-09	5.1E-09	2.85E-09	5.58E-07	3.84E-09
Fossil resource scarcity	-0.0001	-0.0001	-0.0001	0.0004	-0.0001
Water consumption, Human health	-3.48E-05	-3.52E-05	-3.5E-05	3.55E-05	-3.49E-05
Water consumption, Terrestrial ecosystem	-2.62E-06	-2.64E-06	-2.63E-06	3.36E-06	-2.62E-06
Water consumption, Aquatic ecosystems	1.3E-10	1.36E-10	1.3E-10	1.36E-10	1.3E-10

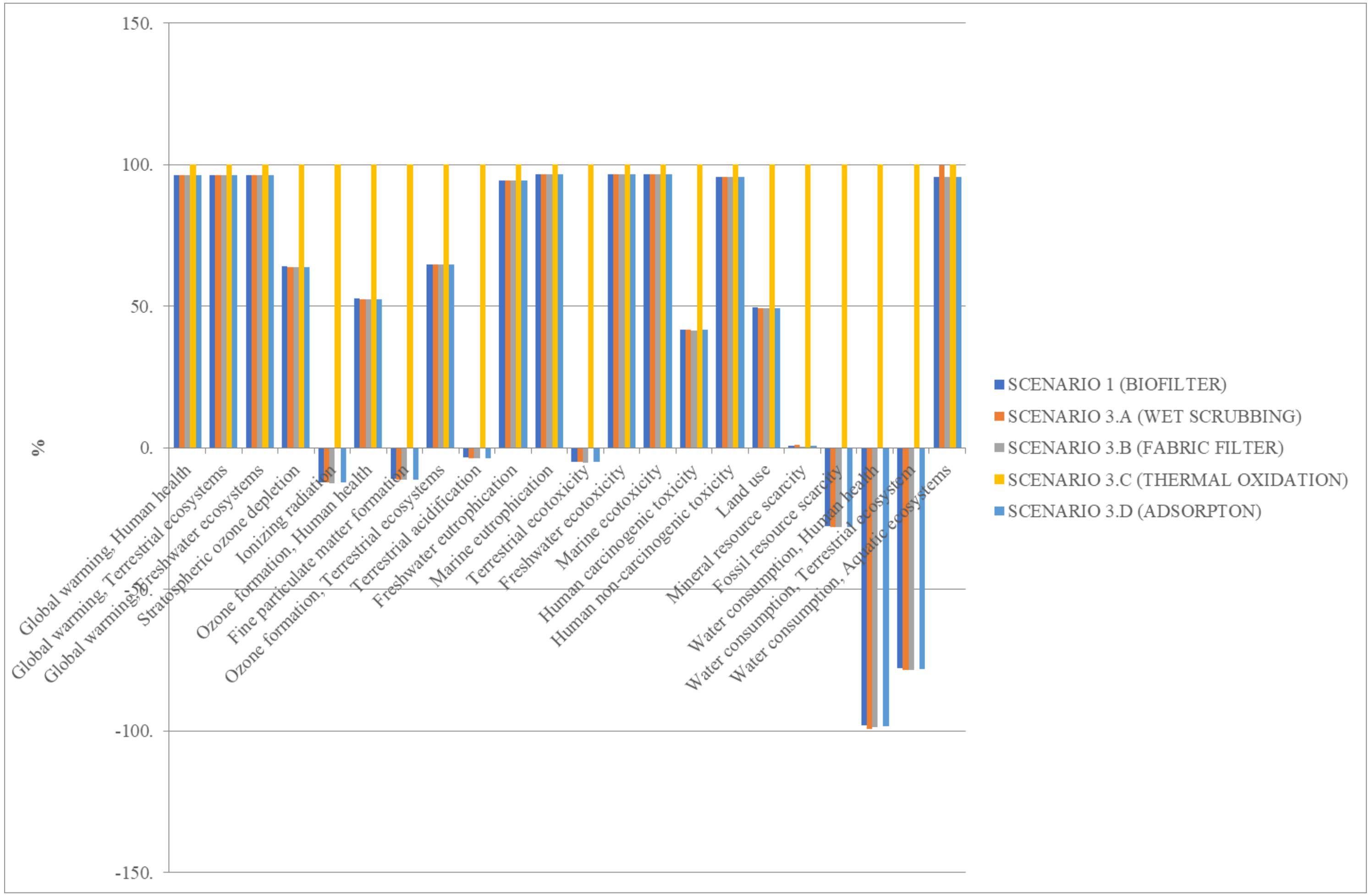


Figure C. 3 Comparative characterization results for desulphurization scenarios.

Table C. 5 Comparative Characterization Result Data for Desulphurization Scenarios

Label	**Scenario 1**	**Scenario 3.a**	**Scenario 3.b**	**Scenario 3.c**	**Scenario 3.d**
Global warming, Human health	96.4721	96.4674	96.461	100	96.4673
Global warming, Terrestrial ecosystems	96.4667	96.462	96.4556	100	96.4618
Global warming, Freshwater ecosystems	96.4658	96.461	96.4546	100	96.4609
Stratospheric ozone depletion	64.001	63.9604	63.8875	100	63.9514
Ionizing radiation	-12	-12	-12	100	-12
Ozone formation, Human health	52.6472	52.586	52.4978	100	52.5819
Fine particulate matter formation	-11	-11	-11	100	-11
Ozone formation, Terrestrial ecosystems	64.8742	64.8289	64.7634	100	64.8258
Terrestrial acidification	-3	-4	-4	100	-4
Freshwater eutrophication	94.502	94.4949	94.4847	100	94.4945
Marine eutrophication	96.7193	96.7247	96.709	100	96.7148
Terrestrial ecotoxicity	-5	-5	-5	100	-5

Freshwater ecotoxicity	96.7347	96.7305	96.7244	100	96.7302
Marine ecotoxicity	96.6897	96.6854	96.6793	100	96.6852
Human carcinogenic toxicity	41.699	41.6337	41.515	100	41.6186
Human non-carcinogenic toxicity	95.5652	95.5595	95.5512	100	95.559
Land use	49.4756	49.41	49.3163	100	49.406
Mineral resource scarcity	0.8243	0.9139	0.5115	100	0.6875
Fossil resource scarcity	-28	-28	-28	100	-28
Water consumption, Human health	-98	-99	-99	100	-98
Water consumption, Terrestrial ecosystem	-78	-79	-78	100	-78
Water consumption, Aquatic ecosystems	95.6984	99.6626	95.6848	100	95.6925

Table C. 6 Data of Influencing Input Parameter Analysis of Desulphurization Scenarios Based on GWHH

Input Parameters	**Scenario 1**	**Scenario 3.a**	**Scenario 3.b**	**Scenario 3.c**	**Scenario 3.d**
Electricity_Desulphurization	0.003	0.003	0.003	0.003	0.003
Electricity_AD	0.001	0.001	0.001	0.001	0.001
Total municipal solid waste_Mechanical treatment	0.0005	0.0005	0.0005	0.0005	0.0005
Heat_Landfill	0.0003	0.0003	0.0003	0.0003	0.0003
Electricity_Landfill	-8.55E-06	-8.66E-06	-8.80E-06	6.90E-05	-8.66E-06
Electricity_Mechanical treatment	-8.67E-06	-8.78E-06	-8.92E-06	6.80E-05	-8.78E-06
Heat_AD	-8.23E-06	-8.24E-06	-8.28E-06	9.32E-06	-8.25E-06

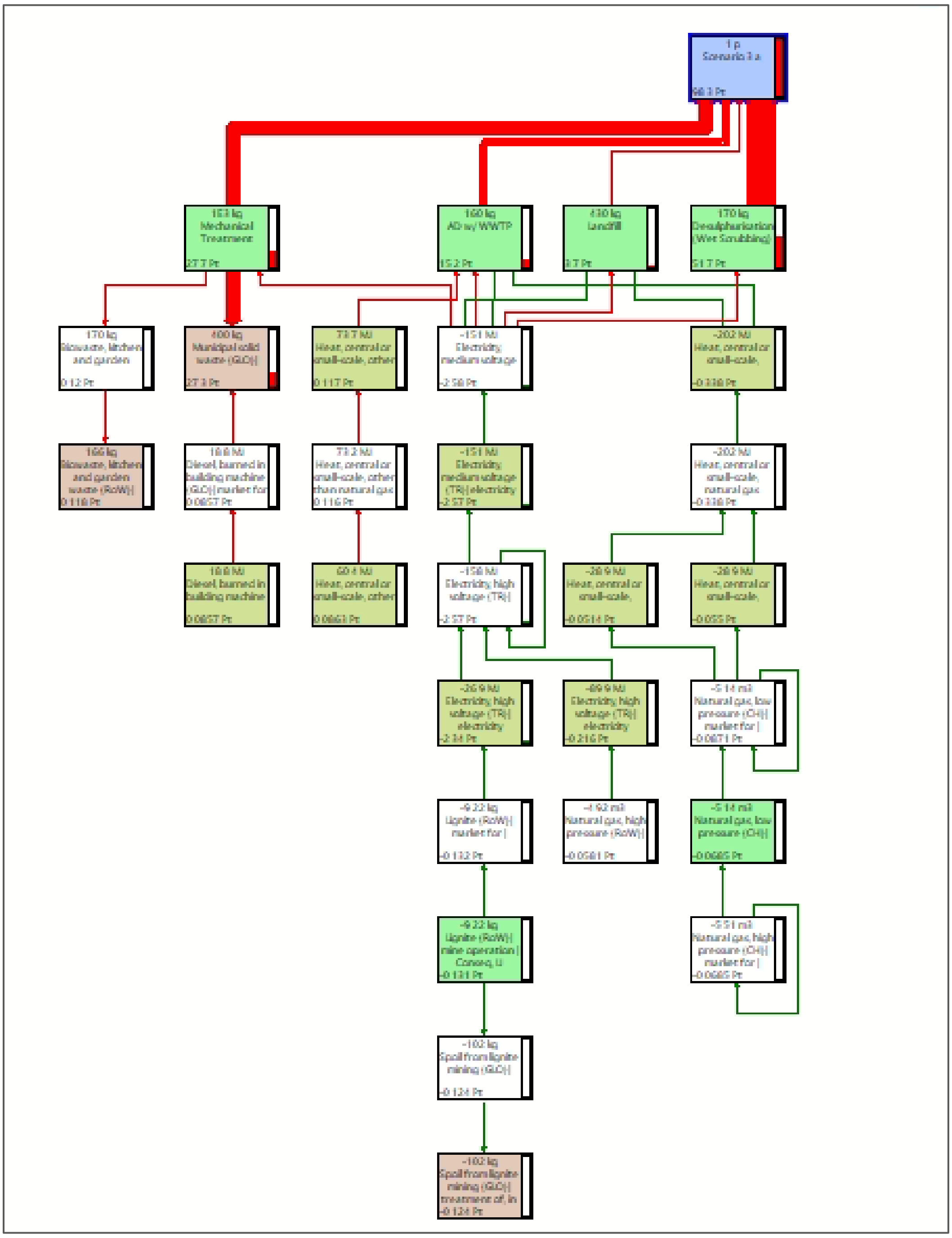


Figure C. 4 Network analysis results of Scenario 3.a.

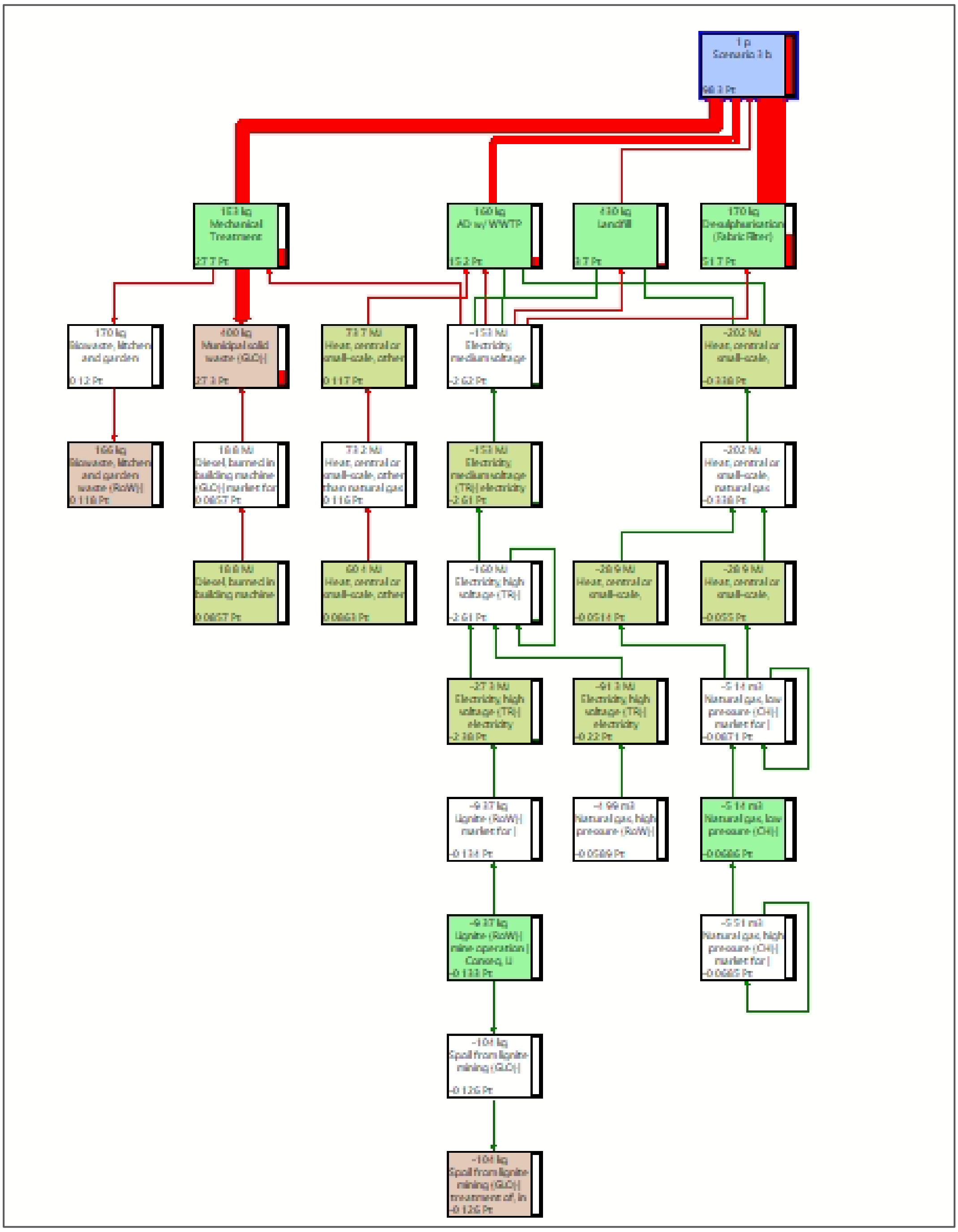


Figure C. 5 Network analysis results of Scenario 3.b.

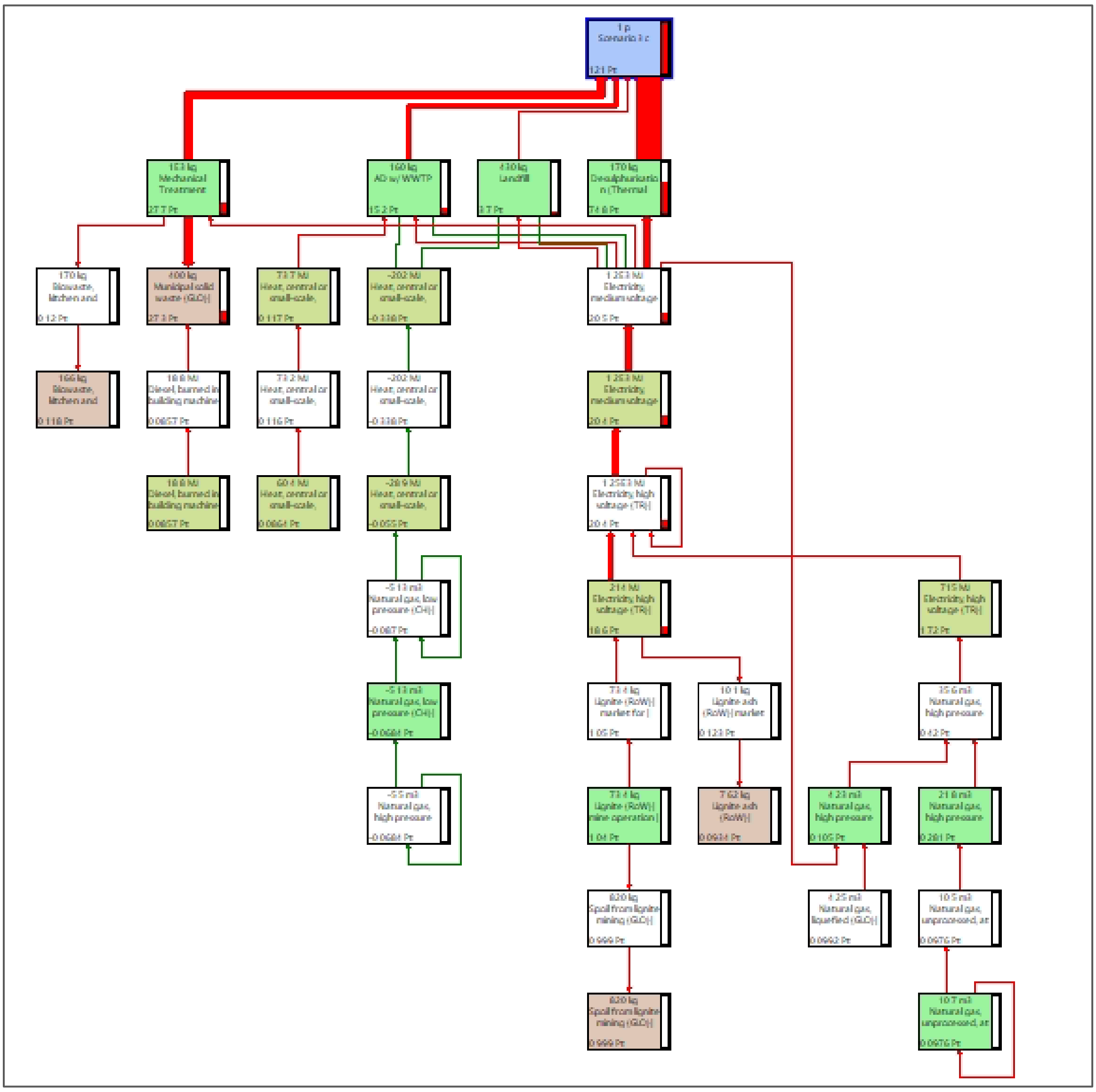


Figure C. 6 Network analysis results of Scenario 3.c.

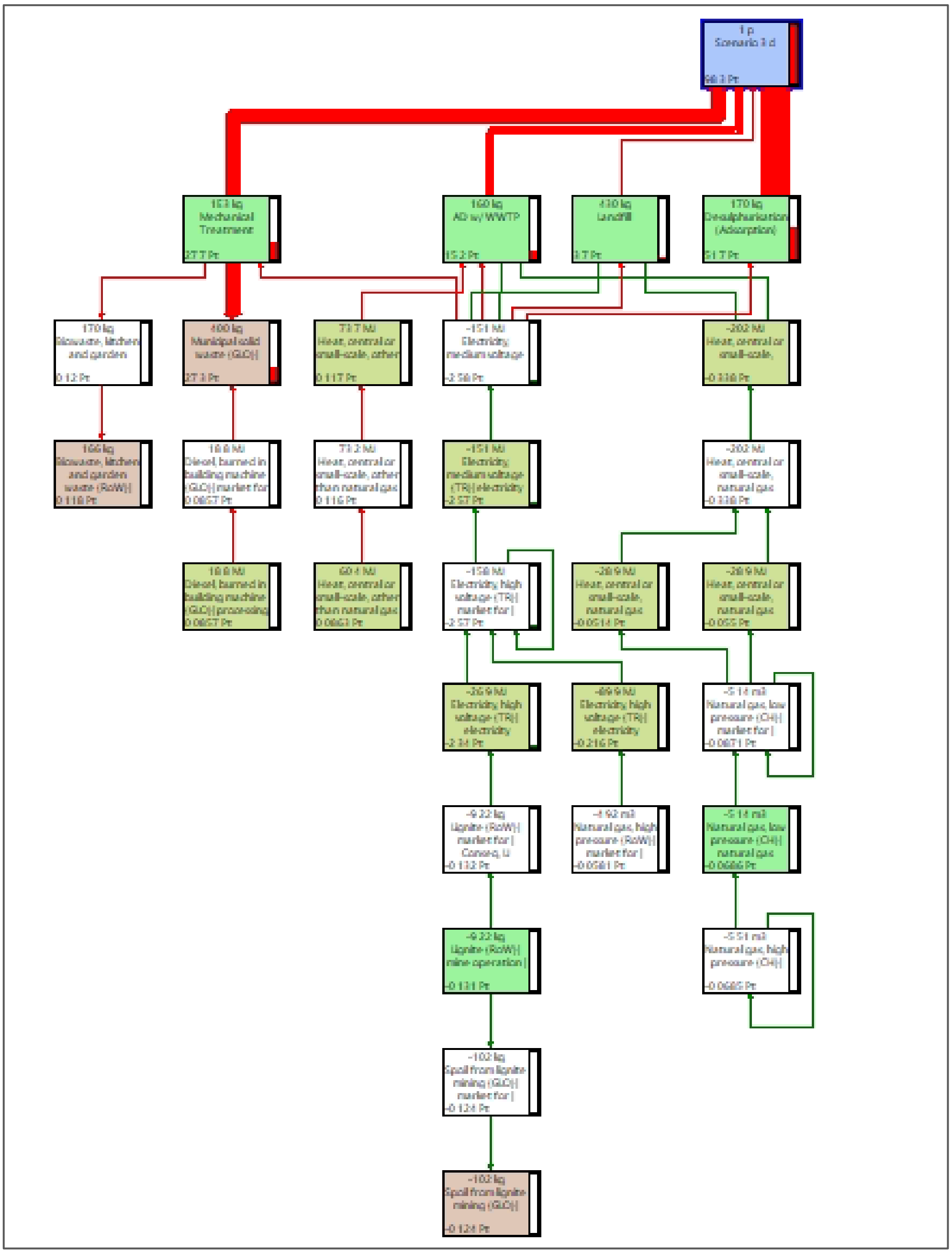


Figure C. 7 Network analysis results of Scenario 3.d.

D. Results of Mechanical Treatment Scenarios

Table D. 1 End-Point Single Score Result Data for Mechanical Treatment Scenarios

	Scenario 1	Scenario 4.a	Scenario 4.b	Scenario 4.c
Human health	93.8282	93.8791	93.832	93.8281
Ecosystems	4.5014	4.5019	4.5014	4.5014
Resources	-0.02	-0.02	-0.02	-0.02

Table D. 2 Mid-Point Single Score Result Data for Mechanical Treatment Scenarios

Label	Scenario 1	Scenario 4.a	Scenario 4.b	Scenario 4.c
Global warming, Human health	78.35	78.3564	78.3505	78.35
Global warming, Terrestrial ecosystems	3.8265	3.8268	3.8265	3.8265
Global warming, Freshwater ecosystems	0.0001	0.0001	0.0001	0.0001
Stratospheric ozone depletion	0.001	0.001	0.001	0.001
Ionizing radiation	-0.0003	-0.0003	-0.0003	-0.0003
Ozone formation, Human health	0.0046	0.0046	0.0046	0.0046
Fine particulate matter formation	-2	-2	-2	-2
Ozone formation, Terrestrial ecosystems	0.0179	0.0179	0.0179	0.0179
Terrestrial acidification	-0.0015	-0.0014	-0.0015	-0.0015
Freshwater eutrophication	0.6083	0.6083	0.6083	0.6083
Marine eutrophication	0.0002	0.0002	0.0002	0.0002

Terrestrial ecotoxicity	-1.75E-05	-1.67E-05	-1.74E-05	-1.75E-05
Freshwater ecotoxicity	0.0359	0.0359	0.0359	0.0359
Marine ecotoxicity	0.0072	0.0072	0.0072	0.0072
Human carcinogenic toxicity	0.3827	0.3839	0.3828	0.3827
Human non-carcinogenic toxicity	16.948	16.9498	16.9482	16.948
Land use	0.0079	0.0079	0.0079	0.0079
Mineral resource scarcity	9.2E-07	1.17E-06	9.39E-07	9.2E-07
Fossil resource scarcity	-0.02	-0.02	-0.02	-0.02
Water consumption, Human health	-0.01	-0.01	-0.01	-0.01
Water consumption, Terrestrial ecosystem	-0.00105	-0.00104	-0.00105	-0.00105
Water consumption, Aquatic ecosystems	5.21E-08	5.21E-08	5.21E-08	5.21E-08

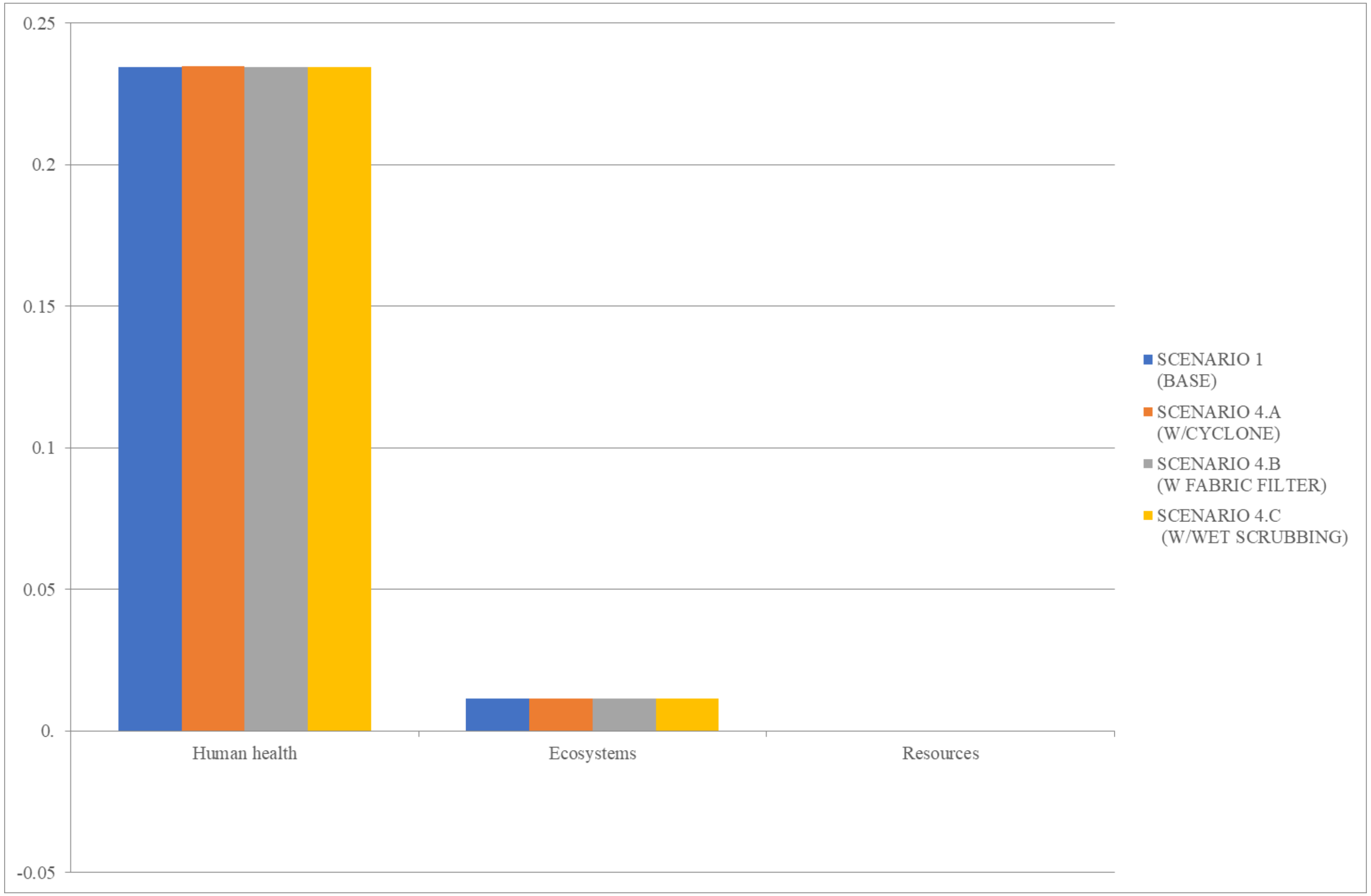


Figure D. 1 Comparative end-point normalization results for mechanical treatment scenarios.

Table D. 3 End-Point Normalization Result Data for Mechanical Treatment Scenarios

Label	**Scenario 1**	**Scenario 4.a**	**Scenario 4.b**	**Scenario 4.c**
Human health	0.2346	0.2347	0.2346	0.2346
Ecosystems	0.0113	0.0113	0.0113	0.0113
Resources	-0.0001	-0.0001	-0.0001	-0.0001

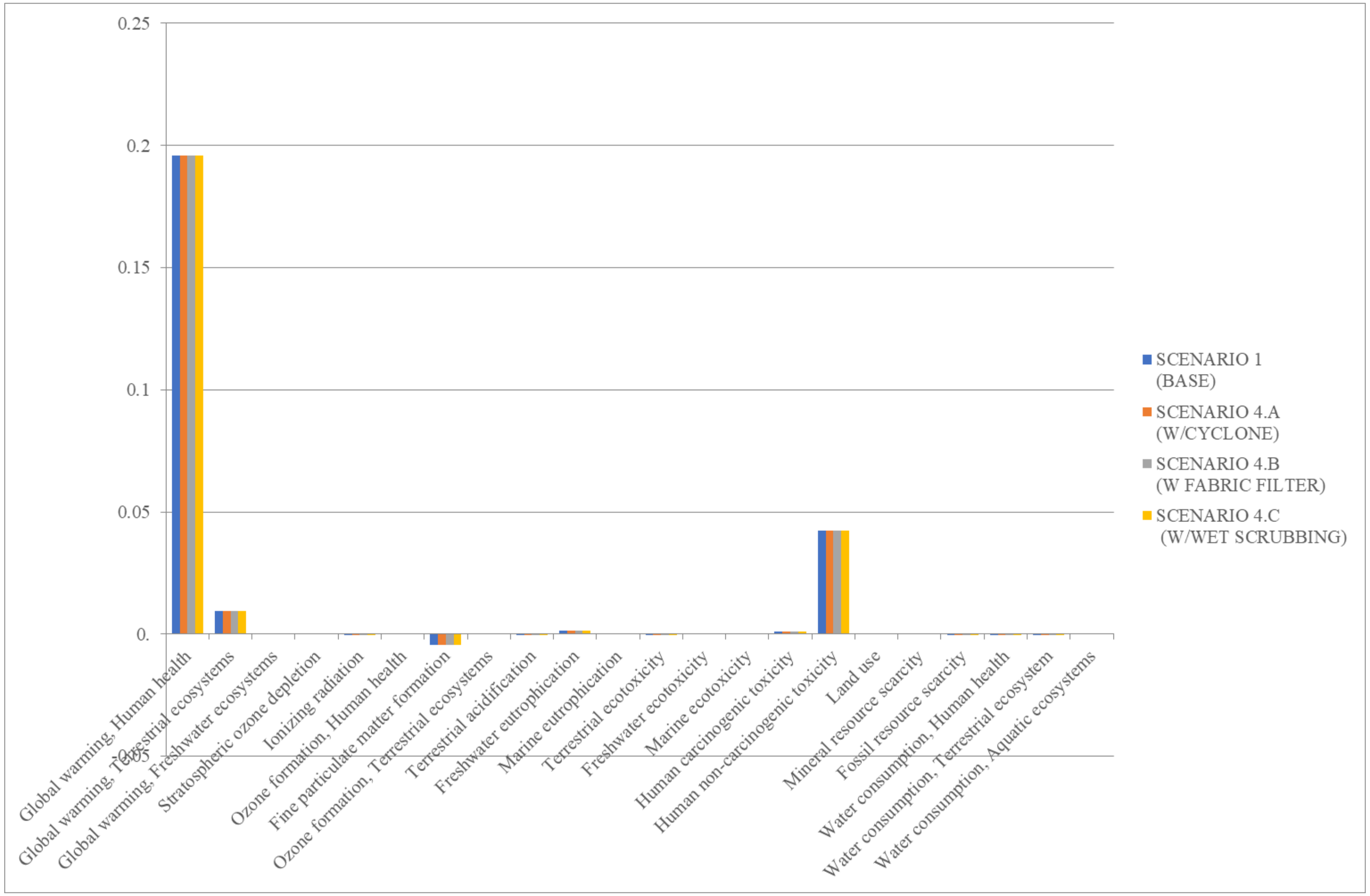


Figure D. 2 Mid-point normalization results for mechanical treatment scenarios.

Table D. 4 Mid-Point Normalization Results for Mechanical Treatment Scenarios

Label	**Scenario 1**	**Scenario 4.a**	**Scenario 4.b**	**Scenario 4.c**
Global warming, Human health	0.1959	0.1959	0.1959	0.1959
Global warming, Terrestrial ecosystems	0.0096	0.0096	0.0096	0.0096
Global warming, Freshwater ecosystems	2.61E-07	2.61E-07	2.61E-07	2.61E-07
Stratospheric ozone depletion	2.44E-06	2.44E-06	2.44E-06	2.44E-06
Ionizing radiation	-7.73E-07	-7.57E-07	-7.72E-07	-7.73E-07
Ozone formation, Human health	1.15E-05	1.15E-05	1.15E-05	1.15E-05
Fine particulate matter formation	-0.0046	-0.0045	-0.0046	-0.0046
Ozone formation, Terrestrial ecosystems	4.48E-05	4.48E-05	4.48E-05	4.48E-05
Terrestrial acidification	-3.74E-06	-3.49E-06	-3.72E-06	-3.74E-06
Freshwater eutrophication	0.0015	0.0015	0.0015	0.0015
Marine eutrophication	4.17E-07	4.17E-07	4.17E-07	4.17E-07
Terrestrial ecotoxicity	-4.38E-08	-4.17E-08	-4.36E-08	-4.38E-08

Freshwater ecotoxicity	8.96E-05	8.96E-05	8.96E-05	8.96E-05
Marine ecotoxicity	1.8E-05	1.8E-05	1.8E-05	1.8E-05
Human carcinogenic toxicity	0.001	0.001	0.001	0.001
Human non-carcinogenic toxicity	0.0424	0.0424	0.0424	0.0424
Land use	1.97E-05	1.98E-05	1.97E-05	1.97E-05
Mineral resource scarcity	4.6E-09	5.84E-09	4.69E-09	4.6E-09
Fossil resource scarcity	-0.0001	-0.0001	-0.0001	-0.0001
Water consumption, Human health	-3.48E-05	-3.46E-05	-3.48E-05	-3.48E-05
Water consumption, Terrestrial ecosystem	-2.62E-06	-2.6E-06	-2.61E-06	-2.62E-06
Water consumption, Aquatic ecosystems	1.3E-10	1.3E-10	1.3E-10	1.3E-10

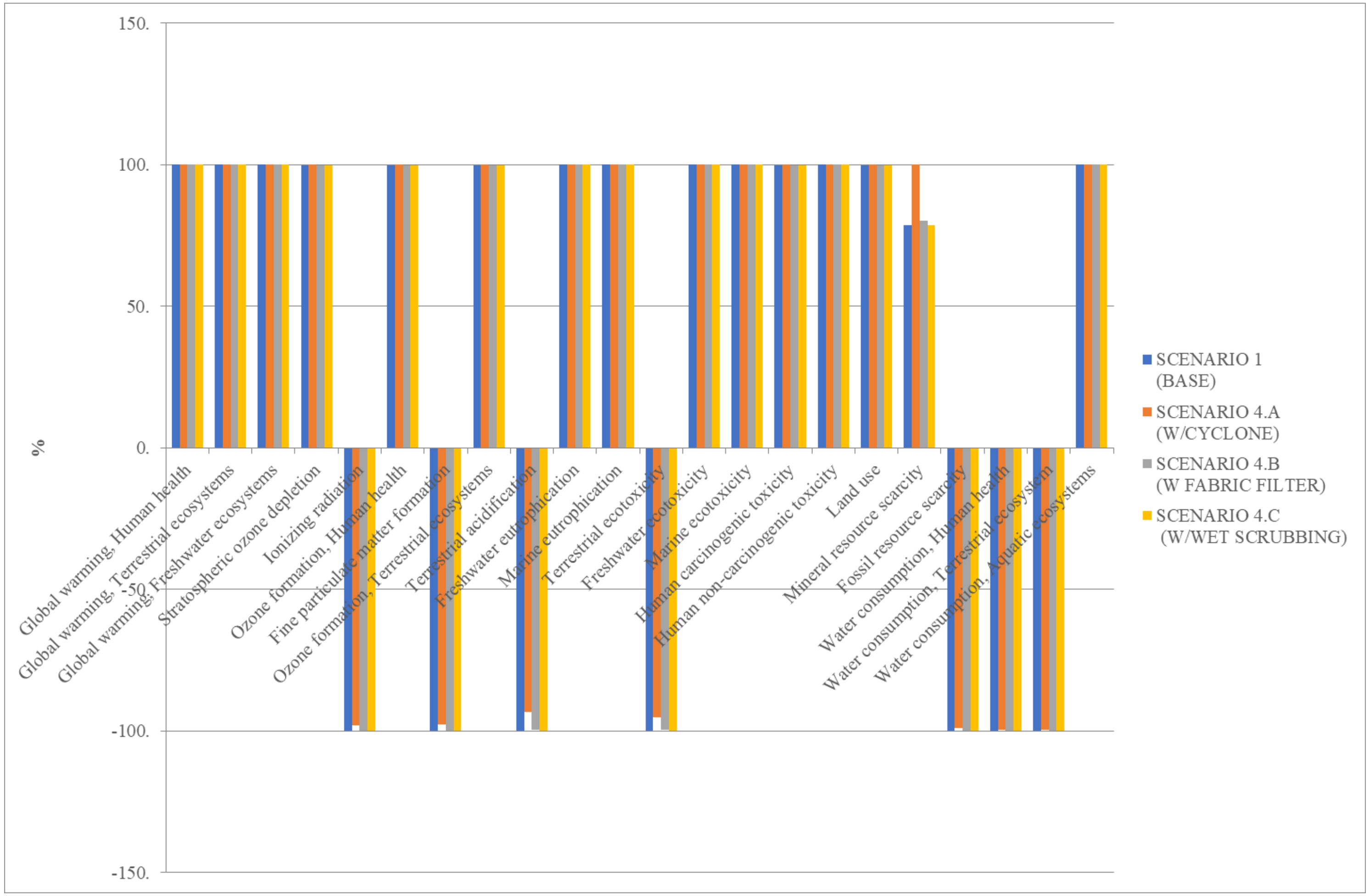


Figure D. 3 Comparative characterization results for mechanical treatment scenarios.

Table D. 5 Comparative Characterization Results for Mechanical Treatment Scenarios

Label	**Scenario 1**	**Scenario 4.a**	**Scenario 4.b**	**Scenario 4.c**
Global warming, Human health	99.9918	100	99.9924	99.9918
Global warming, Terrestrial ecosystems	99.9918	100	99.9924	99.9918
Global warming, Freshwater ecosystems	99.9918	100	99.9924	99.9918
Stratospheric ozone depletion	99.8741	100	99.8836	99.874
Ionizing radiation	-100	-98	-100	-100
Ozone formation, Human health	99.7989	100	99.814	99.7987
Fine particulate matter formation	-100	-98	-100	-100
Ozone formation, Terrestrial ecosystems	99.8788	100	99.8879	99.8787
Terrestrial acidification	-100	-93	-99	-100
Freshwater eutrophication	99.987	100	99.9879	99.987
Marine eutrophication	99.9924	100	99.993	99.9924
Terrestrial ecotoxicity	-100	-95	-100	-100

Freshwater ecotoxicity	99.9924	100	99.993	99.9924
Marine ecotoxicity	99.9923	100	99.9929	99.9923
Human carcinogenic toxicity	99.6877	100	99.7112	99.6874
Human non-carcinogenic toxicity	99.9896	100	99.9904	99.9896
Land use	99.7717	100	99.7889	99.7715
Mineral resource scarcity	78.7668	100	80.3593	78.7465
Fossil resource scarcity	-100	-99	-100	-100
Water consumption, Human health	-100	-100	-100	-100
Water consumption, Terrestrial ecosystem	-100	-99	-100	-100
Water consumption, Aquatic ecosystems	99.9899	100	99.9907	99.9899

Table D. 6 Data of Influencing Input Parameter Analysis of Mechanical Treatment Scenarios Based on GWHH

Input Parameters	**Scenario 1**	**Scenario 4.a**	**Scenario 4.b**	**Scenario 4.c**
Electricity_Desulphurization	0.003	0.003	0.003	0.003
Electricity_AD	0.001	0.001	0.001	0.001
Total municipal solid waste_Mechanical treatment	0.0005	0.0005	0.0005	0.0005
Heat_Landfill	0.0003	0.0003	0.0003	0.0003
Organic waste_AD	3.03E-06	3.03E-06	3.03E-06	3.03E-06
Electricity_Landfill	-8.55E-06	-8.38E-06	-8.54E-06	-8.55E-06
Electricity_Mechanical treatment	-8.67E-06	-8.50E-06	-8.66E-06	-8.67E-06
Heat_AD	-8.23E-06	-1.12E-05	-1.12E-05	-1.13E-05

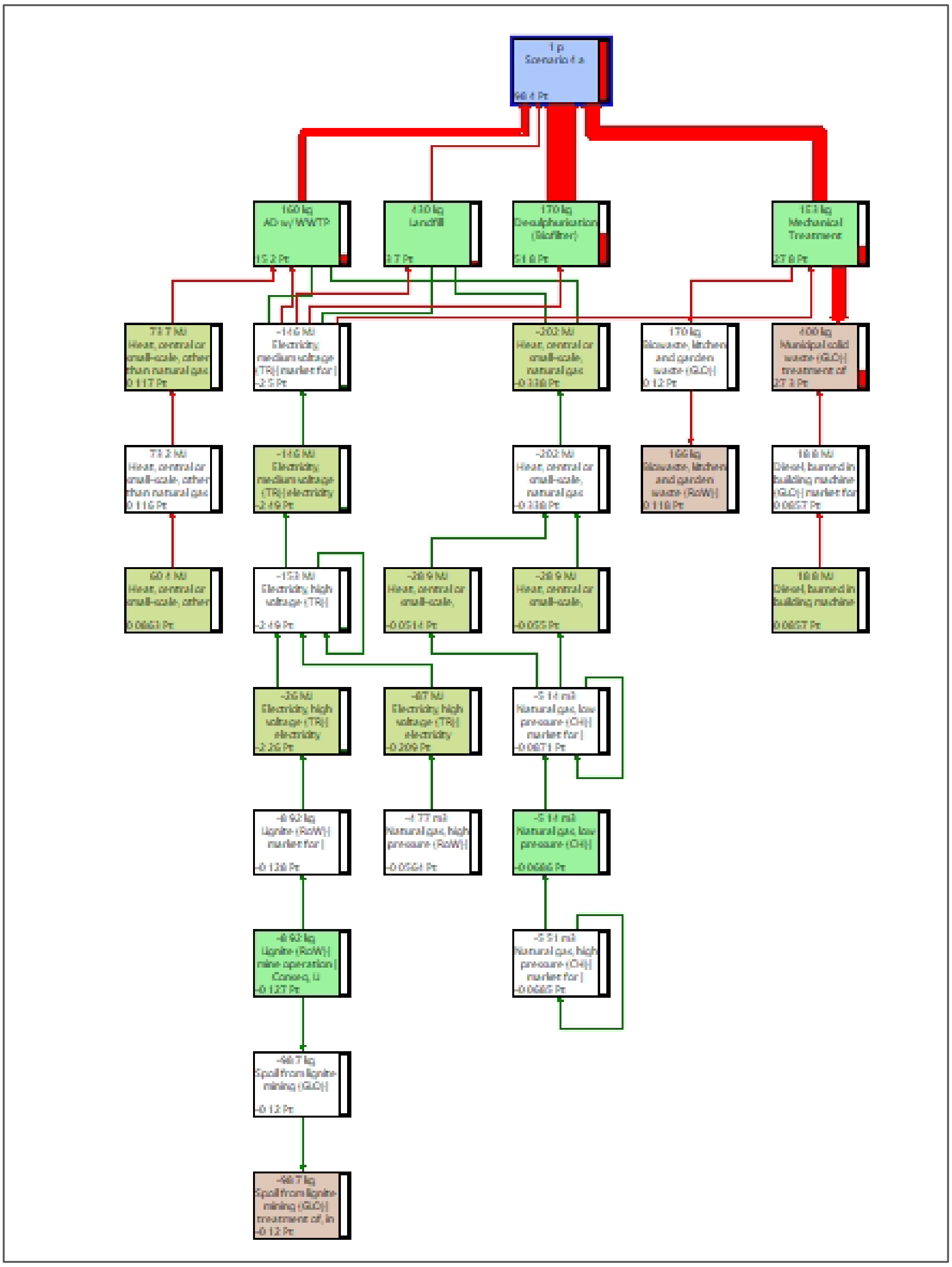


Figure D. 4 Network analysis results of Scenario 4.a.

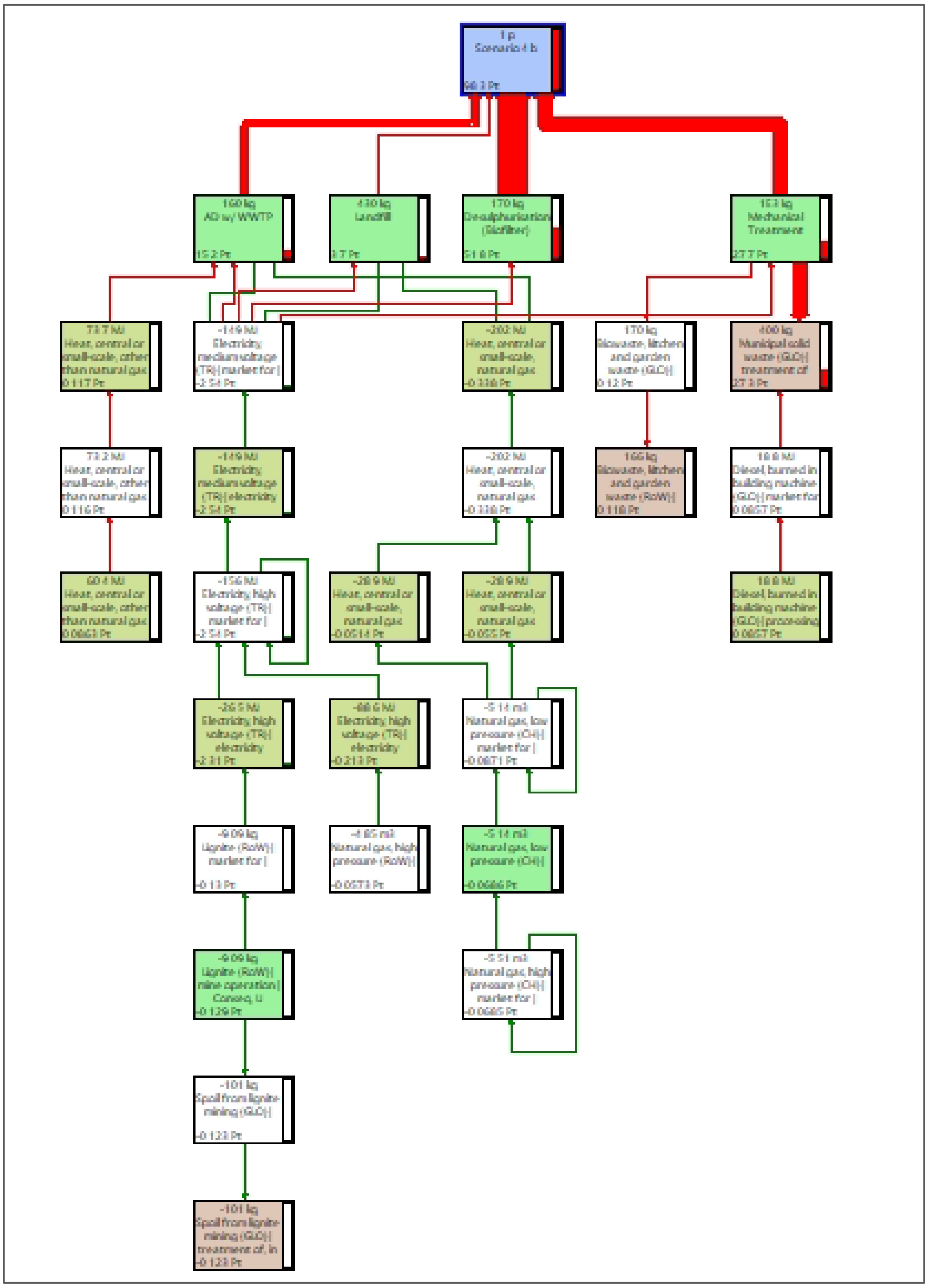


Figure D. 5 Network analysis results of Scenario 4.b.

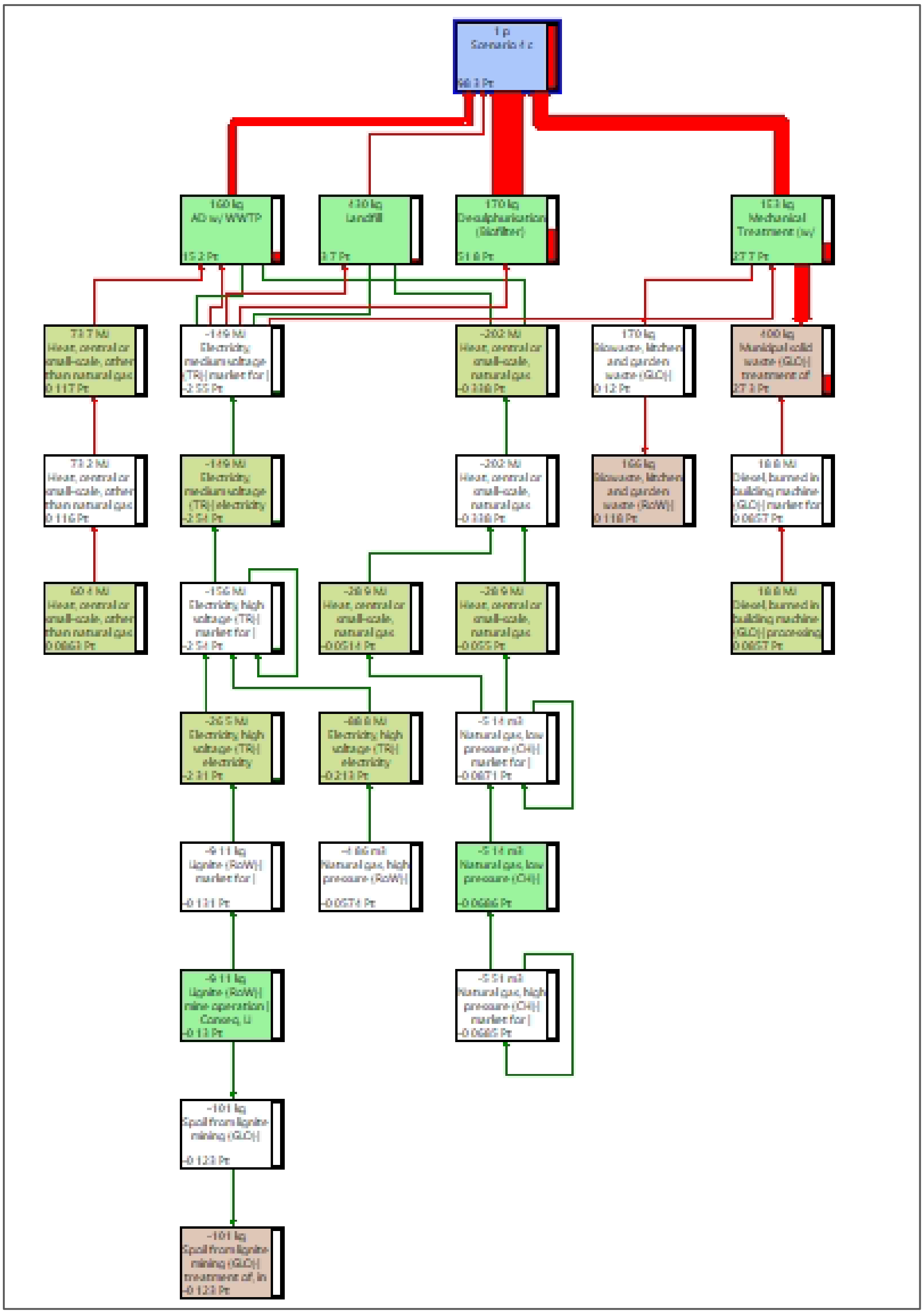


Figure D. 6 Network analysis results of Scenario 4.c.

E. Sensitivity Analysis Results

Table E. 1 Comparative End- Point Results for Effect of Variation in Electricity Type.

Label	**Scenario 3.c (Module 1)**	**Scenario 3.c (Module 2)**	**Scenario 3.c (Module 3)**
Human health	93.8283	93.8943	93.8939
Ecosystems	4.5013	4.4876	4.4876
Resources	-0.02	-0.02	-0.02

Table E. 2 Comparative End- Point Results for Effect of Bulking Agent in Composting Unit.

Label	**Scenario 2.a**	**Scenario 2.a (added miscanthus chopped)**	**Scenario 2.a (added wood chips)**
Human health	92.7366	92.7139	92.7618
Ecosystems	4.2372	4.2482	4.269
Resources	-0.03	-0.02	-0.02

Table E. 3 Comparative End- Point Results for Effect of Emissions Level to Soil in Composting Unit

Label	**Scenario 2.a**	**Scenario 2.a (w/ 5% rise in emissions)**	**Scenario 2.a (w/ 10% rise in emissions)**	**Scenario 2.a (w/ 15% rise in emissions)**
Human Health	93.9256	93.9279	93.9303	93.9326
Ecosystems	4.488	4.488	4.488	4.488
Resources	-0.02	-0.02	-0.02	-0.02

Table E. 4 Comparative End- Point Results for Effect of Loss of Methane in Desulphurization

Label	**Scenario 1**	**Scenario 1 (w/methane loss)**	**Scenario 3.a**	**Scenario 3.a (w/methane loss)**	**Scenario 3.b**	**Scenario 3.b (w/methane loss)**	**Scenario 3.c**	**Scenario 3.c (w/methane loss)**	**Scenario 3.d**	**Scenario 3.d (w/methane loss)**
Human health	93.8282	93.5818	93.7966	93.1802	93.7565	93.3533	116.562	115.9455	93.7968	91.951
Ecosystems	4.5014	4.4893	4.501	4.4709	4.5006	4.4809	4.7436	4.7135	4.501	4.4109
Resources	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.07	0.07	-0.02	-0.02

F. Characterization and Normalization Factors for ReCipe2016

Table F. 1 Recipe2016 Midpoint to Endpoint Characterization Factors (Huijregts et al., 2017)

Midpoint to Endpoint Characterization Factor	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Human Health				
Global Warming - Human health	DALY/kg CO2 eq.	8.12E-08	9.28E-07	1.25E-05
Stratospheric ozone depletion - Human health	DALY/kg CFC11 eq.	2.37E-04	5.31E-04	1.34E-03
Ionizing Radiation - Human health	DALY/kBq Co-60 emitted to air eq.	6.80E-09	8.50E-09	1.40E-08
Fine particulate matter formation - Human health	DALY/kg PM2.5 eq.	6.29E-04	6.29E-04	6.29E-04
Photochemical ozone formation - Human health	DALY/kg NOx eq.	9.10E-07	9.10E-07	9.10E-07
Toxicity - Human health (cancer)	DALY/kg 1,4-DCB emitted to urban air eq.	3.32E-06	3.32E-06	3.32E-06
Toxicity - Human health (non-cancer)	DALY/kg 1,4-DCB emitted to urban air eq.	2.28E-07	2.28E-07	2.28E-07

Table F. 2 Recipe2016 Midpoint to Endpoint Characterization Factors (Huijregts et al., 2017) (cont'd)

Midpoint to Endpoint Characterization Factor	Unit	Individualistic	Hierarchic	Egalitarian
Water consumption - human health	Daly/m3 consumed	3.10E-06	2.22E-06	2.22E-06
Terrestrial Ecosystems				
Global Warming - Terrestrial ecosystems	Species.year/kg CO2 eq.	5.32E-10	2.80E-09	2.50E-08
Photochemical ozone formation - Terrestrial ecosystems	Species.year/kg NOx eq.	1.29E-07	1.29E-07	1.29E-07
Acidification - Terrestrial ecosystems	Species.year/kg SO2 eq.	2.12E-07	2.12E-07	2.12E-07
Toxicity - Terrestrial ecosystems	species*yr/kg 1,4-DBC emitted to industrial soil eq.	1.14E-11	1.14E-11	1.14E-11
Water consumption - terrestrial ecosystems	species.yr/m3 consumed	0.00E+00	1.35E-08	1.35E-08
Land use - occupation and transformation	Species/(m2·annual crop eq)	8.88E-09	8.88E-09	8.88E-09
Freshwater Ecosystems				
Global Warming - Freshwater ecosystems	Species.year/kg CO2 eq.	1.45E-14	7.65E-14	6.82E-13

Table F. 3 Recipe2016 Midpoint to Endpoint Characterization Factors (Huijregts et al., 2017) (cont'd)

Midpoint to Endpoint Characterization Factor	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Eutrophication - Freshwater ecosystems	Species.year/kg P to freshwater eq.	6.71E-07	6.71E-07	6.71E-07
Toxicity - Freshwater ecosystems	species·yr/kg 1,4-DBC emitted to freshwater eq.	6.95E-10	6.95E-10	6.95E-10
Water consumption -aquatic ecosystems	species.yr/m3 consumed	6.04E-13	6.04E-13	6.04E-13
Marine Ecosystems				
Toxicity - Marine ecosystems	species·yr/kg 1,4-DBC emitted to sea water eq.	1.05E-10	1.05E-10	1.05E-10
Eutrophication - Marine ecosystems	Species.year/kg N to marine water eq.	1.70E-09	1.70E-09	1.70E-09
Resources				
Mineral resource scarcity	USD2013/kg Cu	1.59E-01	2.31E-01	2.31E-01

Table F. 4 Recipe2016 Midpoint to Endpoint Characterization Factors (Huijregts et al., 2017) (cont'd)

Midpoint to Endpoint Characterization Factor	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Fossil resource scarcity		**Endpoint characterization factors**		
Crude oil	USD2013/kg	0.46	0.46	0.46
Hard coal	USD2013/kg	0.03	0.03	0.03
Natural gas	USD2013/Nm3	0.30	0.30	0.30
Brown coal	USD2013/kg	-	-	0.03
Peat	USD2013/kg	-	-	0.03

Table F. 5 Recipe2016 Endpoint Normalization Scores (Huijregts et al., 2017)

Endpoint Normalization Scores	Unit	Individualistic	Hierarchic	Egalitarian
Human Health				
Global Warming - Human health	DALY per person in 2010	8.73E-04	7.42E-03	7.25E-02
Stratospheric ozone depletion - Human health	DALY per person in 2010	1.55E-05	3.19E-05	9.44E-05
Ionizing Radiation - Human health	DALY per person in 2010	3.19E-06	4.08E-06	9.78E-06
Fine particulate matter formation - Human health	DALY per person in 2010	1.00E-02	1.61E-02	1.61E-02
Photochemical ozone formation - Human health	DALY per person in 2010	1.80E-05	1.80E-05	1.80E-05
Toxicity - Human health (cancer)	DALY per person in 2010	3.29E-06	3.42E-05	9.80E-04
Toxicity - Human health (non-cancer)	DALY per person in 2010	3.39E-07	2.08E-04	1.48E-02
Water consumption - human health	DALY per person in 2010	1.96E-04	1.96E-04	2.91E-04

Table F. 6 Recipe2016 Endpoint Normalization Scores (Huijregts et al., 2017) (cont'd)

Endpoint Normalization Scores	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Terrestrial Ecosystems				
Global Warming - Terrestrial ecosystems	Species.year per person in 2010	5.72E-06	2.24E-05	1.45E-04
Photochemical ozone formation - Terrestrial ecosystems	Species.year per person in 2010	2.24E-06	2.24E-06	2.24E-06
Acidification - Terrestrial ecosystems	Species.year per person in 2010	8.42E-06	8.42E-06	8.42E-06
Toxicity - Terrestrial ecosystems	Species.year per person in 2010	3.62E-04	8.19E-04	8.82E-04
Water consumption - terrestrial ecosystems	Species.year per person in 2010	0.00E+00	3.48E-06	3.48E-06
Land use - occupation and transformation	Species.year per person in 2010	6.23E-04	6.23E-04	6.23E-04
Freshwater Ecosystems				
Global Warming - Freshwater ecosystems	Species.year per person in 2010	1.56E-10	6.11E-10	3.95E-09
Eutrophication - Freshwater ecosystems	Species.year per person in 2010	4.90E-07	4.90E-07	4.90E-07

Table F. 7 Recipe2016 Endpoint Normalization Scores (Huijregts et al., 2017) (cont'd)

Endpoint Normalization Scores	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Toxicity - Freshwater ecosystems	Species.year per person in 2010	8.74E-09	1.75E-08	2.02E-07
Water consumption -aquatic ecosystems	Species.year per person in 2010	6.16E-10	6.16E-10	6.16E-10
Marine Ecosystems				
Toxicity - Marine ecosystems	Species.year per person in 2010	9.24E-10	4.56E-09	2.59E-04
Eutrophication - Marine ecosystems	Species.year per person in 2011	6.12E-09	6.12E-09	6.12E-09
Resources				
Mineral resource scarcity	USD2013 per person in 2010	3.08E+04	2.77E+04	2.77E+04
Fossil resource scarcity	USD2013 per person in 2010	2.91E+02	2.91E+02	2.91E+02

Table F. 8 Recipe2016 Midpoint Normalization Scores (Huijregts et al., 2017)

Midpoint Normalization Scores	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Human Health				
Global Warming - Human health	kg CO2 eq. per person in 2010	1.08E+04	7.99E+03	5.80E+03
Stratospheric ozone depletion - Human health	kg CFC11 eq. per person in 2010	6.53E-02	6.00E-02	7.04E-02
Ionizing Radiation - Human health	kBq Co-60 emitted to air eq. per person in 2010	4.70E+02	4.80E+02	6.99E+02
Fine particulate matter formation - Human health	kg PM2.5 eq. per person in 2010	1.60E+01	2.56E+01	2.56E+01
Photochemical ozone formation - Human health	kg NOx eq. per person in 2010	2.06E+01	2.06E+01	2.06E+01
Toxicity - Human health (cancer)	kg 1,4-DCB emitted to urban air eq. per person in 2010	9.90E-01	1.03E+01	2.95E+02

Table F. 9 Recipe2016 Midpoint Normalization Scores (Huijregts et al., 2017) (cont'd)

Midpoint Normalization Scores	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Toxicity - Human health (non-cancer)	kg 1,4-DCB emitted to urban air eq. per person in 2010	5.09E+01	3.13E+04	2.22E+06
Water consumption - human health	m3 consumed per person in 2010	2.67E+02	2.67E+02	2.67E+02
Terrestrial Ecosystems				
Global Warming - Terrestrial ecosystems	kg CO2 eq. per person in 2010	1.08E+04	7.99E+03	5.80E+03
Photochemical ozone formation - Terrestrial ecosystems	kg NOx eq. per person in 2010	1.77E+01	1.77E+01	1.77E+01
Acidification - Terrestrial ecosystems	kg SO2 eq. per person in 2010	4.10E+01	4.10E+01	4.10E+01
Toxicity - Terrestrial ecosystems	kg 1,4-DBC emitted to industrial soil eq. per person in 2010	6.73E+03	1.52E+04	1.64E+04

Table F. 10 Recipe2016 Midpoint Normalization Scores (Huijregts et al., 2017) (cont'd)

Midpoint Normalization Scores	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Water consumption - terrestrial ecosystems	m3 consumed per person in 2010	2.67E+02	2.67E+02	2.67E+02
Land use - occupation and transformation	m2·annual crop eq per person in 2010	6.17E+03	6.17E+03	6.17E+03
Freshwater Ecosystems				
Global Warming - Freshwater ecosystems	kg CO2 eq. per person in 2010	1.08E+04	7.99E+03	5.80E+03
Eutrophication - Freshwater ecosystems	kg P to freshwater eq. per person in 2010	6.50E-01	6.50E-01	6.50E-01
Toxicity - Freshwater ecosystems	kg 1,4-DBC emitted to freshwater eq. per person in 2010	1.26E+01	2.52E+01	2.90E+02
Water consumption -aquatic ecosystems	m3 consumed per person in 2010	2.67E+02	2.67E+02	2.67E+02
Marine Ecosystems				
Toxicity - Marine ecosystems	kg 1,4-DBC emitted to sea water eq. per person in 2010	8.80E+00	4.34E+01	2.46E+06

Table F. 11 Recipe2016 Midpoint Normalization Scores (Huijregts et al., 2017) (cont'd)

Midpoint Normalization Scores	**Unit**	**Individualistic**	**Hierarchic**	**Egalitarian**
Eutrophication - Marine ecosystems	kg N to marine water equivalents per person in 2010	4.62E+00	4.62E+00	4.62E+00
Resources				
Mineral resource scarcity	kg Cu-eq per person in 2010	1.93E+05	1.20E+05	1.20E+05
Fossil resource scarcity		**Endpoint characterization factors**		
Crude oil	oil-eq per person in 2010	569.90	569.90	569.90
Hard coal	oil-eq per person in 2010	0.40	0.40	0.40
Natural gas	oil-eq per person in 2010	381.51	381.51	381.51
Brown coal	oil-eq per person in 2010	31.46	31.46	31.46
Peat	oil-eq per person in 2010	-	-	-