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Name : İlayda
Surname : Sipahi
E-Mail : ilayda.sipahi@metu.edu.tr
Date : 16.09.2021
Signature : ________________________

TRANSPORTATION AND RECYCLING EFFECTS ON THE HOUSEHOLD TEXTILE WASTE OF ESKISEHIR USING LCA

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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BY

İLAYDA SİPAHİ

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FOR
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Approval of the thesis:

TRANSPORTATION AND RECYCLING EFFECTS ON THE HOUSEHOLD TEXTILE WASTE OF ESKISEHIR USING LCA

submitted by **İLAYDA SİPAHİ** in partial fulfillment of the requirements for the degree of **Master of Science in Environmental Engineering, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Bülent İçgen
Head of the Department, **Environmental Engineering** ________________

Assist. Prof. Dr. Zöhre Kurt
Supervisor, **Environmental Engineering, METU** ________________

Examining Committee Members:

Prof. Dr. İpek İmamoğlu
Environmental Engineering, METU ________________

Asst.Prof.Dr. Zöhre Kurt
Environmental Engineering, METU ________________

Prof. Dr. Ayşegül Aksoy
Environmental Engineering, METU ________________

Assoc. Prof. Dr. Selim Sanin
Environmental Engineering, Hacettepe University ________________

Asst.Prof.Dr. Mustafa Erkayaoğlu
Mining Engineering., METU ________________

Date: 16.08.2021

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name : İlayda Sipahi

Signature :

ABSTRACT

TRANSPORTATION AND RECYCLING EFFECTS ON THE HOUSEHOLD TEXTILE WASTE OF ESKISEHIR USING LCA

Sipahi, İlayda
Master of Science, Environmental Engineering
Supervisor : Assist. Prof. Dr. Zöhre Kurt

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Textile is a material that could be diversified the most, therefore considerations of textile waste recycling/ reuse and the effects of its landfill should be carefully considered. In this thesis, transportation and recycling effects on the household textile waste of Eskişehir was investigated by using Life Cycle Assessment (LCA). Disregarding consumer using stage, the entire life cycle of waste produced from cotton was evaluated. LCA inventory was included for occupation of land, water consumption, chemical consumption, energy consumption, emission to air and water and transportation network. LCA analysis was performed using SimaPro 9.1.0.8 faculty to assess global warming potential (GWP) and single score result. According to the results, the GWP of 4190 tons/year pure cotton household textile waste in Eskişehir was estimated to be 57340 tonnes/year CO_2eq from the beginning of the cotton production until the landfilling. The distance of transportation of the initial material of cotton did not have a significant effect on single score or GWP of the cotton household waste. However, changing the transportation length of the household cotton waste had an impact of the results. The minimum environmental effects were observed with 301.68 tonnes/year CO_2eq reduction when all the household textile waste is recycled in a relocated recycling facility next to the landfill. Sensitivity analysis showed that the GWP caused from reinstating the sorting facility of the city next to the landfill is equivalent to 92.7 kgkm truck transportation load. This effect could be reduced via increasing the recycling rate by approximately 2%. The study indicated that if all the pure cotton textile waste could be recycled, 40% CO_2eq emission reduction could be achieved compared to the current situation in Eskişehir. The overall results of this study clearly demonstrated that increasing the rate of recycling was the most effective changes for Eskişehir.

Keywords: Household Textile Waste, Life Cycle Assessment, Recycling, Cotton, Transportation

ÖZ

ESKİŞEHİRDEKİ TÜKETİCİ SONRASI TEKSTİL ATIKLARINA GERİ DÖNÜŞÜM VE ULAŞIM ETKİLERİNİN YDA İLE İNCELENMESİ

Sipahi, İlayda
Yüksek Lisans, Çevre Mühendisliği
Tez Yöneticisi: Dr.Öğretim Üyesi Zöhre Kurt

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Tekstil atığı çeşitlendirilebilen bir malzeme olduğundan geri dönüşüm/yeniden kullanım ve düzenli depolanma durumundaki etkiler dikkatle değerlendirilmelidir. Bu çalışmada Eskişehir'deki tüketici sonrası tekstil atıklarına geri dönüşüm ve ulaşımın etkileri Yaşam Döngüsü Analizi (YDA) metodolojisi ile araştırılmıştır. Çalışma kapsamında pamuktan üretilmiş tekstil atığı incelenmiş olup tüketici kullanımı dışında pamuğun üretiminden tekstil atığının yönetimine kadar tüm yaşam döngüsü değerlendirilmiştir. YDA envanteri; arazi, su, kimyasal ve enerji kullanımı, hava/su emisyonları ve ulaşım dahil olacak şekilde hazırlanmıştır. YDA sonuçları KIP ve son nokta etkileri ile değerlendirilmiş ve hesaplamalar ReCiPe 2016 Midpoint/Hierarchist metotları ile yapılmıştır. YDA aracı olarak (SimaPro 9.1.0.8 faculty) kullanılmıştır. Sonuçlar neticesinde Eskişehir'de depolanan 4190 ton/yıl pamuktan üretilmiş tekstil atığının KIPi üretimin başlangıcından depolanması dahil olacak şekilde yaklaşık olarak 57340 ton/yıl CO_2eq bulunmuştur. Farklı tedarik zincirlerine ait ulaşım opsiyonlarının yüksek geri dönüşüm oranlarında kayda değer bir etkisi görülmemiştir. Geri dönüşüme ait ulaşım opsiyonlarının ise yüksek geri

dönüşüm oranlarındaki etkisi yüksektir. Bu doğrultuda en iyi senaryo olan yeni bir geri dönüşüm tesisi kurulması opsiyonu ile ful geri dönüşüm durumunda 301.68 ton/yıl CO_2eq azaltımı sağlanabilir. Hassasiyet analizi mevcut durumdaki düzenli depolama sahasına kurulabilecek bir ayrıştırma tesisinin azaltacağı 92.7 kgkm karayolu taşımacılığı yükünün düşüreceği KIP etkisinin mevcut durumdaki geri dönüşüm oranının yaklaşık olarak %2'lik artışla da karşılanabileceğini göstermiştir. Eskişehir'deki tüketici sonrası pamuklu atıkların tamamının geri dönüşümü durumunda KIP etkisinin %40 CO_2eq azaltılabileceği hesaplanmıştır. Bu çalışma Eskişehirde arttırılabilecek geri dönüşüm oranının, ulaşım ağlarında yapılabilecek bir değişiklikten çok daha etkili olduğunu açıkça göstermiştir.

Anahtar Kelimeler: Tüketici Sonrası Tekstil Atığı, Yaşam Döngüsü Analizi, Geri Dönüşüm, Pamuk, Ulaşım

To my precious family

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CHAPTER 1

INTRODUCTION

Sorting of recyclable or reusable waste from landfills all over the world is crucial, since landfilling destroys the potential products or raw materials, it causes various environmental impacts, it is not sustainable (Chen and Gao, 2020; Riba et al., 2020; Sauve and Acker, 2020; Shirvanimoghaddam et al., 2020; Wang et al., 2020b; Degenstein et al., 2021). Considering both the landfilling ratio and the benefits to be obtained by recycling or reusing regarding the entire life cycle of the waste, textile is one of the most remarkable waste that should be prioritized to be sorted before ends up in the landfills (Quaghebeur et al., 2013; Degenstein et al., 2021; Sanchis-Sebastiá et al., 2021).

Considering the amount of produced textile waste, it is the 3-11% of the overall produced waste in Turkey (Akinci et al., 2012; Yılmaz and Abdulvahitoğlu, 2019). 50% of this textile waste is estimated as household textile waste (Altun, 2012; Buyukaslan et al., 2015). Besides, the amount of produced household textile waste is increasing day by day (Degenstein et al., 2021; Sanchis-Sebastiá et al., 2021). Furthermore, since textile industry is one of the most polluting industries in the world, the benefits to be obtained by recycling or reusing of the household textile waste is very notable (Moazzem et al., 2021b). Thus, to understand the life cycle of household textile waste is crucial in the path of reducing not only the amount of landfilled household textile waste but also its environmental impacts (Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017; Moazzem et al., 2018).

Up to date, no study was reported investigating sustainable household textile waste management strategies analyzed with LCA in Turkey. Therefore, this thesis is focusing on the different aspects of household textile waste of Eskişehir. This city is deemed appropriate for such a study for the following reasons. Eskişehir, is one of the highest household textile waste producers with an average of 14500 tons to 15000 tons annually in Turkey. Similarly, this city has one the most interested public when it comes to recycling and where realistic waste management transportation data can be collected (Hasan, 2004; Ari and Yilmaz, 2016; Erdil, 2019; Ağaçsapan and Çabuk, 2020; Wang et al., 2020a). Considering high public awareness, waste management transportation system in Eskişehir and the amount of specially for the wasted pure cotton household textile waste, it is crucial to carry out such a study in Eskişehir as the results of this study could be implemented in different regions in Turkey on the way of zero waste (Tinmaz and Demir, 2006; Akinci et al., 2012; Erdil, 2019; Resmi Gazzette, no: 28142, Date: 12/07/2019; Taşkın and Demir, 2020; Moazzem et al., 2021b). The following thesis is focusing on the household textile waste produced in Eskisehir province of Turkey that contains pure cotton.

Approximately 4190 tons of pure cotton household textile is wasted in the landfills annually in Eskişehir (Banar et al., 2009; Altun, 2012; Buyukaslan et al., 2015; Ari and Yilmaz, 2016; Yılmaz and Abdulvahitoğlu, 2019). Landfilling pure cotton material is a waste of raw materials since it can be easily recycled and reused (Payne, 2015; Schmidt et al., 2016; Wang et al., 2020b). Since cotton production process is one of the most important steps of textile production process in terms of environmental impacts, the environmental benefits to be obtained by recycling or reusing of cotton is very remarkable (Kalliala and Nousiainen, 1999; Semba et al., 2020). Besides, textile industry is among the sectors which have priorities in Europe’s new sustainable growth strategy ˈˈThe European Green Dealˈˈ (Braun et al., 2021). Hence, such a study can be drawn as a framework for household textile waste compatible with ˈˈThe European Green Dealˈˈ (Whicher et al., 2018; Braun et al., 2021).

This study aims to investigate the transportation and recycling effects on the household textile waste of Eskisehir using LCA.

More specific objectives are

1) *Assessing the environmental effects of landfilled pure cotton household textile waste of Eskişehir*
2) *Assessing the 50% recycling, whole recycling and reusing effects on the pure cotton household textile waste of Eskişehir*
3) *Assessing the different transportation options effects of source materials on the current situation, on the 50% recycling situation and on the whole recycling situation of the pure cotton household textile waste of Eskişehir*
4) *Assessing the different transportation options effects of recycling on the current situation, 50% recycling situation and whole recycling situation of the pure cotton household textile waste of Eskişehir*
5) *Assessing the optimum recycling rates versus reduced truck transportation load effects on the pure cotton household textile waste of Eskişehir*

1.1 Overview of the Study

This study contains 5 chapters. In Chapter 2; the relation between the waste management, sustainable development, zero waste and The European Green is introduced. Later, the importance of sorting textile waste before ends up in the landfills, the reason to be prioritized for sorting the textile waste are mentioned. Following this, landfilling, recycling and reusing of textile waste is introduced. In this direction, a comprehensive literature review about the LCA study focusing on textile waste is conducted. Finally, LCA definition, LCA software's and methods and the textile waste studies related with LCA is provided.

In Chapter 3; a roadmap for the structure of the LCA methodology introduced. Firstly, the structure of the LCA methodology is created to fulfill the gaps and recommendations based on the specific objectives of the study. Disregarding consumer using stage, the entire life cycle of household textile waste produced from cotton for landfilling, recycling and reusing is evaluated within the scope of this study. Life cycle analysis was performed by using SimaPro 9.1.0.8 faculty. Calculations are conducted with the ReCiPe 2016 Midpoint Hierarchist impact assessment method to assess Global Warming Potential and ReCiPe 2016 Endpoint Hierarchist impact assessment method to assess single score result. LCA inventory was prepared according to literature review, Ecoinvent database and conducted interviews with 13.30.01, 38.11.01, 13.10.12 and 13.99.04 NACE code companies and with environmental management department of the Eskişehir Municipality and with the site visit conducted to Eskişehir 2nd class Sanitary Landfill.

In Chapter 4; LCA scenarios and their results were provided. In this direction, goal, and scope of the LCA study, LCA inventory of the scenarios which are prepared with the collected data, impact assessment result and their interpretations and lastly sensitivity analysis results and their interpretations were given.

In Chapter 5; conclusions, limitations of the study and future recommendations were discussed. The details of the conducted interviews, site visits and all the midpoint results belonging to each scenario are given in the appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 Sustainable Development, Zero Waste and The European Green Deal

The concept of sustainable development emerged as a compromise between continuous economic growth and nature conservation in the 1970s, when current (linear economy) economic development policies were not sufficient for an ecologically sustainable system and social justice system all over the world and different definitions were made for sustainable development (Murray et al., 2017). The best-known definition of sustainable development was made by The World Commission on Environment and Development in 1987 which is defined as; development that meets the needs of today without compromising the ability to meet the needs of future generations (Agarwal, 2018; Djuric Ilic et al., 2018). Many conferences, agreements and declarations were published on international platforms and as a result, a decision was made to create a series of sustainable development principles in The United Nations on Sustainable Development conference held in Rio in 2012 (Murray et al., 2017). With the mentioned principles, it is aimed to create a set of universal goals that address the urgent environmental, political and economic problems facing our world and 17 goals, known as the UN Sustainable Development Goals, entered into force in January 2016 (UNDP, 2016). Above mentioned sustainability goals and their aims summarized from (UNDP, 2016) Table 2.1 below.

Table 2.1 UN Sustainable Development Goals (UNDP, 2016)

No Poverty: Aims to ensure social protection for the poor and vulnerable society, improve access to fundamental services such as food, clean drinking water and sanitation and support society damaged by extreme climate events and other economic, social, and environmental problems and disasters.
Zero Hunger: Aims to end all forms of hunger and malnutrition by 2030 and ensure that all people, especially children, have sufficient nutrition throughout the year.
Good Health and Well-Being: Aims to ensure that everyone has access to general healthcare, safe and accessible medicines, and vaccines, and to support vaccine research and development.
Quality Education: Aims to ensure that all girls and boys complete free primary and secondary education, provide equal access to affordable vocational education, eliminate gender and wealth inequalities, and provide access to quality higher education.
Gender Equality: Aims to eliminate all forms of discrimination against women and girls, not only the basic human rights, but also the empowerment of women and girls, which are critical to accelerate sustainable development.
Clean Water and Sanitation: Aims to invest in infrastructure, build sanitary facilities and promote hygiene at all levels to ensure that everyone has access to safe and accessible drinking water.
Affordable and Clean Energy: Aims to invest clean energy sources such as solar, wind and thermal to ensure that everyone has access to accessible energy by 2030.
Decent Work and Economic Growth: Aims to provide full and productive employment and decent work for all women and men by 2030.
Industry: Innovation, and Infrastructure; aims to ensure equal access to knowledge and to address digital inequality in terms of promoting innovation and entrepreneurship.
Reduced Inequalities: Aims to improve the regulation and monitoring of financial markets and institutions, and to direct development aid and foreign investments to the regions where they are most needed.
Sustainable Cities and Communication: Aims to make cities safe and sustainable, provide safe and accessible housing, invest in public transport, create public green spaces, and improve urban planning and management in a participatory and inclusive way.

Table 2.1 (continued)

Responsible Consumption and Production: Aims to ensure the efficient management of our natural resources, to change our toxic waste and pollutant disposal methods to sustainable applications, to encourage recycle and reducing practices in waste management, and to create more sustainable consumption patterns.
Climate Action: Aims to reduce greenhouse gas emissions and stop global warming.
Life Below Water: Aims to conserve natural water resources such as; oceans and seas
Life on Land: Aims to protect and restore terrestrial ecosystems such as forests, wetlands, and mountains.
Peace Justice and Strong Institutions: Aims to significantly reduce all forms of violence and work with governments and societies to find lasting solutions to conflict and insecurity.
Partnerships for the Goals: Aims to increase international cooperation by supporting national plans to achieve all goals.

Following the establishment of sustainable development goals, it was understood that it was not possible to reach the above-mentioned principles with the current linear economy (Pires and Martinho, 2019). So an alternative approach has been sought in the international arena and a new production model which is called circular economy concept has emerged (Zaman and Lehmann, 2011; Ghisellini et al., 2016). The circular economy approach is expressed as the recycling of waste materials and regaining the recycled material in the economy (Murray et al., 2017). As a matter of fact, it is aimed to prevent waste formation by transforming the element defined as waste in the linear economy into a resource in the circular economy (Djuric Ilic et al., 2018; Pires and Martinho, 2019). Hereby, ''zero waste concept'' and zero waste regulations have emerged as an economic and administrative tool that can be used to support the circular economy concept, based on environmental point of sustainable development principles (Djuric Ilic et al., 2018; Zelenika et al., 2018) (Pires and Martinho, 2019). After mentioning the principles of sustainable development and the emergence of zero waste, the details of the zero-waste concept are explained below.

There are various definitions and diverse applications for zero waste (Iqbal et al., 2020). Referring to Turkey’s zero waste regulation, zero waste approach is defined as a means to protect the environment and human health and all resources by preventing / reducing waste generation in production, consumption and service processes, giving priority to reuse by collecting the waste generated separately at the source and reducing the amount of waste by ensuring recycling and / or recovery applications instead of disposal applications (Resmi Gazzette, no: 28142, Date: 12/07/2019). Another definition˸˸*The conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health* ˸˸which is quite similar with the previous ones made by Zero Waste International Alliance (ZWIA, 2018b). Based on these definitions, the zero-waste hierarchy (ZWIA, 2018a) given in Figure 2.1 was created to implement the ideal waste management for the zero waste systems and strategies. Hierarchy aims to prevent waste generation, to minimize waste where prevention is not possible, to prioritize reuse, to ensure efficient use of resources, to separate collection of waste at source, to ensure establishment of an effective collection system (Van Ewijk and Stegemann, 2016; Fortuna and Castaldi, 2018). In line with the correct implementation of this hierarchy, it is stated that the possibility to reach the zero waste targets increases (Song et al., 2015).

Figure 2.1 Zero waste hierarchy 7.0. (Modified From; ZWIA, 2018a)

In line with sustainable development goals, zero waste and circular economy model, The European Green Deal which is the key policy for transforming the European Union industry to carbon neutral by 2050 was launched as a proposal in 2019 (Pianta and Lucchese, 2020; Bieroza et al.,2021; Johnson et al., 2021; Kougias et al., 2021; Ringel et al., 2021). In this direction, a circular economy action plan has been prepared for the implementation of this policy (Whicher et al., 2018). In this direction, the industries that can be adapted to the circular economy more easily during the transformation to carbon neutral have been determined as food and drink, textiles, high value manufacturing, oil and gas, chemicals and energy (Whicher et al., 2018; Braun et al., 2021). In addition, it is expected that the carbon emission reductions to be obtained from the adaptation to circular economy of these sectors will be higher as they are among the most polluting sectors (Whicher et al., 2018; Braun et al., 2021).

2.2 The Importance of Sorting Waste Before Ends Up in the Landfills

Sorting of recyclable or reusable waste before ends up in the landfills all over the world is crucial, since landfilling causes various environmental impacts and it is the least preferable waste management method (Chen and Gao, 2020; Sauve and Acker, 2020; Wang et al., 2020b). Landfilling destroys the potential products or raw materials (Riba et al., 2020; Shirvanimoghaddam et al., 2020; Degenstein et al., 2021), it occupies huge areas and it is not sustainable (Assamoi and Lawryshyn, 2012; Sauve and Acker, 2020; Wang et al., 2020b). Due to the lack of sorting of recyclable or reusable waste, the amount of landfilled valuable waste is increasing the concerns (Barr and Gilg, 2005; Pluskal et al., 2021; Gutierrez-Gomez et al., 2021). By sorting that waste and directing it to recycling and reusing; recyclable or reusable waste can be turned into a product or a raw material (Sandin and Peters, 2018; Pluskal et al., 2021). Hereby, the necessity to produce a new product or a raw material can be avoided by recycling or reusing (Friedrich and Trois, 2013; Wang et al., 2020b; Esteve-Turrillas and de la Guardia, 2017; Fan et al., 2019). In this way, environmental impacts caused both by the production and landfilling can be reduced (Assamoi and Lawryshyn, 2012; Wang et al., 2020b). The reduction in environmental impacts can be considered as environmental benefits (Sandin and Peters, 2018; Pluskal et al., 2021). For this reason, recyclable or reusable waste should be sorted and directed to the recycling and reusing (Bovea et al., 2010; Pluskal et al., 2021).

2.3 The Importance of Sorting Textile Waste Before Ends Up in the Landfills

The amount of landfilled waste type and the environmental benefits to be obtained by directing it to recycling or reusing are very important for prioritizing the waste type to be sorted (Bovea et al., 2010; Akinci et al., 2012; Chen and Gao, 2020; Zheng et al., 2020). For this reason, firstly the landfilled waste should be characterized (Quaghebeur et al., 2013; Gutierrez-Gomez et al., 2021). Every year, approximately 11 billion tons of waste is being sent to landfills in the World (Ferdous et al., 2021). Since, sorting of waste is not done properly, more than 50% of this landfilled waste are recyclable or reusable waste (Ferdous et al., 2021). This recyclable or reusable landfilled waste consists of paper textile, plastic, glass, wood waste etc. which are approximately 31% of landfilled sites (Assamoi and Lawryshyn, 2012). The rate of these waste types may vary according to countries, regions, and cities (Akinci et al., 2012; Bukhari et al., 2018; Qasim et al., 2020). In this direction, textile is one of the most common type of landfilled waste constituting an average of 3-10 % of landfills by mass (Tarantini et al., 2009; Bovea et al., 2010; Akinci et al., 2012; Quaghebeur et al., 2013; Yılmaz and Abdulvahitoğlu, 2019; Mäkelä et al., 2020; Degenstein et al., 2021; Sanchis-Sebastiá et al., 2021). Besides, the amount of produced textile waste is increasing day by day (Degenstein et al., 2021; Sanchis-Sebastiá et al., 2021). Thus, landfilling of textile waste specially is a growing environmental concern (Mazibuko et al., 2019). Furthermore, since the textile industry is one of the most polluting industries in the world, the benefits to be obtained by recycling or reusing them is very notable (Moazzem et al., 2021b).

2.4 Household Textile Waste Management Processes for Landfilling, Recycling and Reusing

Textile waste is mostly managed by landfilling (Degenstein et al., 2021; Muñoz-Torres et al., 2021). Recycling and reusing are other waste management methods and these methods are considered sustainable (Roy et al., 2020). In the landfilling method, the textile waste thrown into the municipal waste bins by the users (Corsten et al., 2013). Then they are collected and transported to the landfills (Corsten et al., 2013). It is buried here and is expected to decompose by capturing gas according to landfill type (Strähle and Hauk 2017). However, synthetic fibers do not decompose (Strähle and Hauk 2017). Since landfilling occupies large areas and causes environmental air emissions it has environmental impacts (Assamoi and Lawryshyn, 2012; Sauve and Acker, 2020; Wang et al., 2020b). If long distances are covered for the landfilling also has environmental impacts (Moazzem et al., 2018; Moazzem et al., 2021b). In this direction main environmental impacts for landfilling are caused from land occupation and air emissions and from transportation (Assamoi and Lawryshyn, 2012; Friedrich and Trois, 2013; Sauve and Acker, 2020; Wang et al., 2020b; Moazzem et al., 2021b).

In the recycling, collected household textile waste before ends up in the landfills are transported to textile sorting facilities to sort them according to color and fiber types (Schmidt et al., 2016; Riba et al., 2020). This process can be done automatically or manually (Dahlbo et al., 2017). Later, sorted textile waste is sent to recycling (Castellani et al., 2015). Recycling can be carried out in two ways as mechanical and chemical methods (Shen et al., 2010; Schmidt et al., 2016). Mechanical recycling is the more commonly applied method (Sandin and Peters, 2018; Fidan et al., 2021). Mechanical recycling consists of cutting and shredding processes (Esteve-Turrillas and de la Guardia, 2017). As a result of cutting and shredding processes, textile waste turns into fibers. Then the recycled fibers continue to textile production from yarn production (Moazzem et al., 2021b). In mechanical recycling, pure fiber types can be upcycled (Payne, 2015). In other words, a fabric produced from pure cotton can be mechanically recycled to produce a fabric again. The situation is slightly different for the blended fibers. A fabric produced from blended fibers such as cotton and polyester mixture can be mechanically recycled to produce insulation materials, carpet, rugs etc. (Payne, 2015; Moazzem et al., 2021b). This is called downcycling (Payne, 2015). For recycling electricity and heat consumptions cause environmental impacts (Esteve-Turrillas and de la Guardia, 2017). For recycling process main environmental impacts caused from electricity and heat consumptions and from transportation for textile sorting and recycling (Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017; Semba et al., 2020).

In the reusing, non-usable textile waste can be collected by charity organizations, municipalities and so forth, and can be repaired by tailoring activities (Dahlbo et al., 2017). Afterwards, it can be sent to needy people living nearby to the textile waste collected area or it can be sent to needy people in overseas countries (Koligkioni et al., 2018; Moazzem et al., 2018; Semba et al., 2020). Another alternative, people can repair their non-usable textile waste by tailoring activities, and they can use it again (Schmidt et al., 2016; Sandin and Peters, 2018). For reusing electricity and heat consumptions cause environmental impacts (Schmidt et al., 2016). If long distances are covered for the textile waste reusing also has environmental impacts (Dahlbo et al., 2017; Semba et al., 2020). For reusing process main environmental impacts are caused from electricity and heat consumptions and from the transportation for textile waste collection to conduct reusing (Schmidt et al., 2016; Dahlbo et al., 2017; Semba et al., 2020).

2.5 Benefits of Textile Reusing, Recycling

It is important to understand the environmental benefits of sorting the household textile waste before ends up in the landfills and directing it to recycling and reusing as evaluating the entire life cycle, as there are environmental impacts caused from each step (Moazzem et al., 2018). Especially, textile production process requires intensive use of resources such as electricity, chemicals, water and causes environmental emissions (Yilmaz et al., 2005; de Oliveira Neto et al., 2019; Moazzem et al., 2018). Besides, if the production steps are conducted in or supplied from different regions or countries, transportation distance can be too long which can cause the environmental impacts (Shen, 2014; Turker and Altuntas, 2014;

Moazzem et al., 2018). Since landfilling destroys the products or raw materials and occupies large areas it also causes environmental impacts (Assamoi and Lawryshyn, 2012; Sauve and Acker, 2020; Wang et al., 2020b). If recycled fibers and reused textiles can be replaced with a new fiber or a textile product, the need to produce a new fiber or textile product can be avoided (Bovea et al., 2010; Bodin, 2016; Liu et al., 2020; Degenstein et al., 2021; Moazzem et al., 2021b). Hereby, the environmental impacts caused from production can be reduced which can lead to environmental benefits (Moazzem et al., 2021b). In addition, if recycling or reusing transportation network is shorter than the need to supply of a new textile product, the environmental impacts caused from the transportation of a new textile supply can be reduced (Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017; Koligkioni et al., 2018; Subramanian et al., 2020; Moazzem et al., 2021b). Moreover, if the textile waste can be sorted before ends up in the landfills and can be managed by recycling or reusing, environmental impacts caused from landfilling can be reduced too (Assamoi and Lawryshyn, 2012; Esteve-Turrillas and de la Guardia, 2017). The processes that can be replaced in the production step with recycling and reusing are shown in Figure 2.2 below. However, while examining the entire life cycle of landfilling, recycling and reusing, possible changes in transportation network and the prevented landfill stage are not displayed.

Figure 2.2. General flow diagram of the textile production, recycling and reusing process (transportation and landfilling stages are not displayed) (Schmidt et al., 2016)

2.6 Life Cycle of Textile

Textile starts its life cycle with production. Production can be conducted in or supplied from different regions or countries (Shen, 2014; Turker and Altuntas, 2014; Moazzem et al., 2018). Later, continuous with distribution of textile products to the consumer and finally, it completes its life cycle with end-of- life treatment which is generally landfilling (Peters et al., 2015; Bick et al., 2018; Moazzem et al., 2018). If these wastes are landfilled, the life cycle of textile waste ends up with landfilling. If recycling or reusing methods are applied at the end of life, textile waste can restart on its life cycle. However, since recycling or reusing also has a lifespan, recycled or reused textile waste eventually ends their life cycles and are disposed in the landfills too (Sandin and Peters, 2018; Wiedemann et al., 2021). In the conducted studies, the loss rate on recycling has been accepted between 10% and 20% (Schmidt et al., 2016; Dahlbo et al., 2017; Moazzem et al., 2021b). It is therefore assumed that a product has 10 times to 8 times recycling lifespan (Dahlbo et al., 2017; Moazzem et al., 2021b). There are different interpretations for reusing lifespan (Dahlbo et al., 2017; Sandin and Peters, 2018). While some studies do not evaluate the reusing lifespan without considering the amount of loss which is send to landfills, some studies assumed that 60-80% of a product can be reused which means a product can be reused 6 to 8 times (Intini and Kühtz, 2011; Schmidt et al., 2016; Sandin and Peters, 2018). In addition, user preferences such as buying a new product rather than using second-hand regarding reuse are also a significant criterion while evaluating the lifespan of the reusing. Thus, there are generally limitations regarding the reusing (Sandin and Peters, 2018). As a summary, the general flow diagram of textile life cycle is given in Figure 2.3 below.

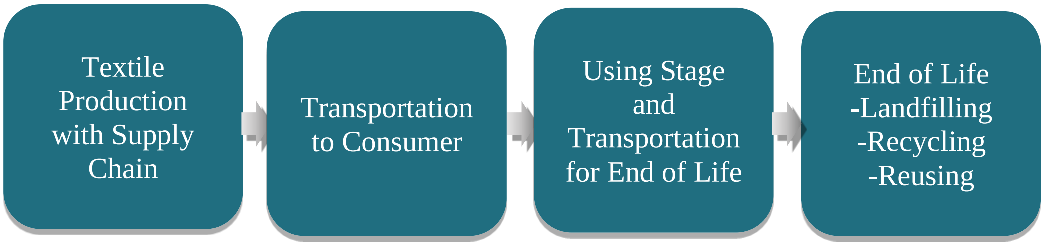

Figure 2.3. General flow diagram of the textile life cycle (Modified From; (Moazzem et al., 2018).

2.7 Studies Focusing on Textile Waste

Since the importance of sorting the household textile waste before ends up in the landfills and directing them to recycling or reusing is growing in many countries, many studies have been conducted focusing on different aspects of sustainable textile waste management (Sandin and Peters, 2018; Hole and Hole, 2019; Yousef et al., 2019; Moazzem et al., 2021b). Some studies investigated the effective collection systems of textile waste to increase recycling or reusing rate (Tarantini et al., 2009; Nørup et al., 2019; Yousef et al., 2019; Subramanian et al., 2020). As an example, a study conducted in France focused to boost the collection of textile waste by increasing public awareness to raise the reusing rate (Subramanian et al., 2020). Some studies investigated the reductions in environmental impacts by recycling or reusing instead of landfilling (Moazzem et al., 2021b). There are also studies which aimed to investigate how to optimize recycling or reusing to increase environmental benefits by shortened transportation networks of recycling or reusing (Koligkioni et al., 2018; Semba et al., 2020; Muñoz-Torres et al., 2021). So, there have been different textile waste studies with different aims, but all of them targeted to investigate the sustainable household textile waste management strategies to increase environmental benefits (Sandin and Peters, 2018).

2.8 LCA Studies Focusing on Textile Waste

In order to measure environmental benefits that can be obtained by recycling or reusing, life cycle assessment "LCA" is one of the commonly used tool (Feo and Malvano, 2009; Roy et al., 2020). It can measure the environmental impacts and it can provide a good framework for evaluating the best waste management strategies. Therefore, it is defined as a decision-making tool (Feo and Malvano, 2009; Sauve and Acker, 2020).

Many studies are conducted to measure the environmental benefits to be obtained by recycling or reusing with LCA tool (Sandin and Peters, 2018; Hole and Hole, 2019; Nørup et al., 2019; Moazzem et al., 2021b). As an example, environmental benefits of reusing compared to incineration of textile waste was examined in Finland to choose the best waste management option and which particular country prohibited the landfilling of textile waste in 2015 (Dahlbo et al., 2017). Similar studies by using LCA tool were also conducted for Japan, Denmark, Australia, and Northern Europe (Schmidt et al., 2016; Koligkioni et al., 2018; Semba et al., 2020; Moazzem et al., 2021a). However, these studies need to be addressed in detail. It is worth noting that each study has a different LCA methodology (Muthu, S. 2015; Moazzem et al., 2021b). LCA methodologies of these studies were determined according to their goals and scope, their limitations, their inventory studies, their impact assessment methodologies, and sensitivity analysis. In addition to these, their gaps and recommendations are also investigated (Sandin and Peters, 2018).

LCA goals of these studies are to evaluate environmental benefits to be obtained by sorting the household textile waste before ends up in the landfills or incineration and directing them to recycling or reusing by creating different scenarios (Koligkioni et al., 2018; Moazzem et al., 2021b). For example, in Japan, the carbon emission reduction of discharged household textile waste by different incineration, recycling, and reusing scenarios are examined. The results indicated that there would be a maximum 70% CO_2eq reduction in total GWP through the reuse of discharged 6.03 $\times 10^8$ kg of used clothing which was selected as the best option between recycling and reusing. The study also investigated the effects of transportation distance. The different transportation networks created with new scenarios which are based on the following questions: “what happens if reusing is done in different countries?” “What happens if reusing is done in Japan?” and “What happens if it is incinerated in Japan” (Semba et al., 2020). Their analysis showed that, reuse is provided in overseas countries less effect than incineration conducted in Japan” (Semba et al., 2020).

Another LCA study focusing on textile waste was conducted in Denmark. In this study, following questions were investigated: “What happens if currently incinerated textile waste in Denmark is reused in Denmark again with 5% landfilling ?”, “What happens if currently incinerated textile waste in Denmark is reused in the Europe with a 30 % landfilling” ?, “What happens if currently incinerated textile waste in Denmark is reused with 10% landfilling in overseas countries”?, “what happens if half of the currently incinerated textile waste in Denmark is reused in Denmark?” and “What happens if energy savings is increased in the current incineration system”. Their analysis showed that reuse even with a less reusing ratio and overseas transportation showed higher benefits than the current situation of Denmark. Besides, it has been concluded that, reusing in overseas countries with less landfilling ratio is more beneficial than reusing in Europe with higher landfilling ratio. Incineration with more energy recovery has increased the environmental savings. Thus, they stated that; incineration with more energy recovery and reusing are much more efficient than landfilling (Koligkioni et al., 2018).

In the studies related with LCA studies focusing on textile waste, it was seen that even if recycling is provided in the overseas countries, it has lass effects than local landfilling (Esteve-Turrillas and de la Guardia, 2017). So, they concluded that the main environmental effects are caused from the production steps and landfilling and those effects can be minimized mainly by recycling which is also supported by other studies (Esteve-Turrillas and de la Guardia, 2017). It can be concluded from the studies which are compared the landfilling and recycling that even if 50 % of textile waste is recycled instead of landfilling, it is quite beneficial under any circumstances (Sandin and Peters, 2018). Most beneficial option is reusing (Semba et al., 2020).

LCA scope of these studies generally covered the textile life cycle from consumer to the end of textile life (Dahlbo et al., 2017; Koligkioni et al., 2018; Semba et al., 2020). Only a few studies define their LCA scopes from production to the end of textile life (Bodin, 2016; Schmidt et al., 2016). LCA system boundaries of the production to the end of textile life studies mostly covered the transportation network both for supply chains of new textile products and end of life treatment (Esteve-Turrillas and de la Guardia, 2017; Dahlbo et al., 2017). Since the supply chain of textile or end of life treatment transportation networks can vary a lot, usually assumptions have been made instead of using real data (Turker and Altuntas, 2014; Shen, 2014; Bodin, 2016; Schmidt et al., 2016; Moazzem et al., 2018; Moazzem et al., 2021b). Textile using stage is excluded in most of the studies as this stage is not expected to affect the benefits to be obtained by recycling or reusing (Schmidt et al., 2016; Moazzem et al., 2021b). LCA scope details of the production to the end of life studies are mostly focused on cotton and polyester fibers as they are mostly used fiber types (Sandin and Peters, 2018). Usually either only cotton or polyester or both fabrics are studied (Payne, 2015; Sandin and Peters, 2018). Since the agricultural activities of cotton production process is one of the most important steps of textile production process in terms of environmental impacts, the environmental benefits to be obtained by recycling or reusing of cotton were higher in these studies (Kalliala and Nousiainen, 1999; Semba et al., 2020). Limited number of studies focused on different fiber types such as wool or viscose (Schmidt et al., 2016; Sandin and Peters, 2018; Esteve-Turrillas and de la Guardia, 2017).

LCA limitations of these studies vary. One of the common limits in these studies is about recycling of blended fibers. So that generally pure fiber types have been examined with a few exceptions (Sandin and Peters, 2018). (Sandin and Peters, 2018). Another limitation of textile studies is the uncertainty of the replacement rates of recycled fibers or reused products with the new ones. (Sandin and Peters, 2018). For the replacement rate of recycled fibers, most studies assumed that recycling is upcycling and can be achieved with approximately 10% loss or similar rates (Corsten et al., 2013; Castellani et al., 2015; Schmidt et al., 2016). In some studies, it is assumed that recycling can be done without loss (Castellani et al., 2015; Sandin and Peters, 2018). There are also limitations in the conducted studies regarding the reusing as both user preferences such as the desire to buy a new product rather than using second-hand ones and the condition of the product to be reused are shown as important parameters on the reusing. However, some studies only make the assessment of environmental effects of 100% reusing disregarding these limitations (Sandin and Peters, 2018). Another study compared the replacement rates of reusing according to users' preferences such as buying a new product and using second-hand. It was assumed that, reuse replacement rate can decrease from 100% to 60-80% according to user preferences (Intini and Kühtz, 2011). As scenarios based on reusing has more limitations and assumptions, recycling scenarios are considered more realistic than reusing (Sandin and Peters, 2018). Another limitation while assessing the potential environmental impact reduction from production to the end-of- life scope is the definition of household textile waste . They are defined as "apparel" or "garment" instead of "a t-shirt", "a dress", or "jeans" etc. (Moazzem et al., 2021b; Schmidt et al., 2016). However, during the production of a t-shirt, a dress, jeans etc. the consumption and type of chemicals, energy and water may vary. Different dyes and different chemicals can be used in each product. On the other hand, these differences may not change the general results a lot due to the wide scope of LCA study defined from production to the end-of life (Baydar et al., 2015; Schmidt et al., 2016; Moazzem et al., 2021b). In order to ignore this limitation, the consumptions are generally considered as 1 kg of fabric production data as the consumptions of fabric do not differ much (Peters et al., 2015). As the scope expands, covering these details makes the LCA study very complicated especially for the textile industry (Moazzem et al., 2018; Luo et al., 2021). However, every detail can be increased the error probability in the LCA studies (Moazzem et al., 2018; Sandin and Peters, 2018).

LCA inventory studies, impact assessment categories and the LCA software and methods of these studies are as follows: Inventory studies are mostly conducted by using Ecoinvent database and the data obtained from related literature (Moazzem et al., 2021a). The most commonly assessed environmental impact category is global warming potential by considering energy consumption (Zamani et al., 2015; Sandin and Peters, 2018). Many studies stated that; the use of chemicals, water, land and emission to air and water during the cotton production, and in other steps of textile production, use of land and emission to air in landfilling process, are the main reasons of the environmental impacts and they were calculated in their LCA studies as references (Baydar et al., 2015; Moazzem et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b). However, these consumptions and emissions cause the environmental effects are not presented in their inventory studies (Esteve-Turrillas and de la Guardia, 2017). Furthermore, although the environmental benefits of recycling and reusing are also occurred as they can be replaced with a new fiber or a textile product and as they can avoid the landfilling process, most of these studies did not show the main consumptions and emissions of textile production, recycling, reusing and landfilling steps separately in the given references (Koligkioni et al., 2018; Dahlbo et al., 2017; Moazzem et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b). However, it is very important to show the main consumptions and emissions of all the textile production, transportation, landfilling, recycling and reusing steps in terms of understanding the reasons of the obtained efficiency by avoiding these consumptions and emissions as they are the main reason of environmental impacts (Esteve-Turrillas and de la Guardia, 2017). Gabi and SimaPro LCA softwares are commonly used LCA softwares (Laurent, Clavreul et al., 2014). The LCA calculation methods can vary (Laurent, Clavreul et al., 2014). ReCiPe midpoint and CML baseline are the commonly used calculation methods (Yuan et al., 2013; Zhang et al., 2015; Peters et al., 2015).

LCA sensitivity analysis of these studies are different. Some studies conducted their sensitivity analysis, based on the different replacement rates, different recycling ratios or different transportation distances modes in order to control the uncertainty of replacement rates, recycling ratios and the effects of transportation distances and modes (Schmidt et al., 2016; Koligkioni et al., 2018; Moazzem et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b). In a study in which different transportation modes were examined, airway and sea transportation were compared. Transportation effects on the entire life cycle of textile were interpreted. It was seen that the transportation network was not much remarkable on the entire life cycle of textile recycling. However, the airway effect was found relatively higher than sea transportation (Moazzem et al., 2018). In another study in which different recycling ratios were examined, it was stated that, increasing the recycling rate is one of the most important key factors to obtain more environmental benefits (Moazzem et al., 2021b). There are also studies which do not consider any textile limitations or uncertainties mentioned above (Dahlbo et al., 2017; Semba et al., 2020; Bodin, 2016).

LCA gaps and recommendations which are pointed out in these studies can be summarized accordingly: It is recommended to conduct more household textile waste studies covering the entire life cycle of textile waste (Schmidt et al., 2016; Sandin and Peters, 2018). Detailed inventory studies involving the real data transportation network specially for the textile sorting and landfilling, recycling and reusing should be conducted (Sandin and Peters, 2018; Taşkın and Demir, 2020). Besides, it is recommended to focus on different impact categories rather than global warming potential (Moazzem et al., 2021a). Additionally, it is recommended to include not only the energy consumption but also the occupation of land, water consumption, chemical consumption, energy consumption, emission to air and water for the inventory studies regarding the related textile production and recycling, reusing and landfilling as they are the main reasons of environmental impacts (Esteve-Turrillas and de la Guardia, 2017). Also, the importance of indicating the inventories for each step separately was emphasized (Esteve-Turrillas and de la Guardia, 2017; Sandin and Peters, 2018). For further studies, it is recommended to focus on regional cases (Tinmaz and Demir, 2006; Akinci et al., 2012). For regional studies, it is recommended to investigate firstly the provinces close to recycling facilities and where the recycling and reuse rate can be increased easily with public awareness since it is one of the most important factor to increase recycling or reusing (Hasan, 2004; Erdil, 2019; Wang et al., 2020a). As such, if improvements are made in these regions, the different regions can also be encouraged (Erdil, 2019).

2.9 Textile Production Processes

In general, textile production has a very complex and difficult applications (Moazzem et al., 2018). The applied processes vary according to each fiber, fabric and end product types (Baydar et al., 2015). For this reason, it is not possible to standardize textile production (Moazzem et al., 2018). Production generally consists of six main steps which are virgin material production, fiber production, yarn production, fabric production, wet process and make up process (Hasanbeigi and Price, 2012; Alkaya and Demirer, 2014; Moazzem et al., 2018; Braun et al., 2021). During the production, all these steps can be conducted or supplied from different regions or countries (Shen, 2014; Turker and Altuntas, 2014; Baydar et al., 2015)

(Moazzem et al., 2018; Fidan et al., 2021). In the scope of this study, woven textile made from cotton is examined. In this direction, the general flow diagram of the cotton woven textile production steps are given in Figure 2.4 below and it is followed by explanation of the production steps.

Figure 2.4 General flow diagram of the textile production process made from cotton (Bodin, 2016).

Step 1: Virgin Material Production of Cotton

According to fiber literature, cotton is one of the most widely used natural fiber (Moazzem et al., 2018). Virgin material production of cotton consists of planting, fertilizing, irrigation, harvesting steps (Yilmaz et al., 2005; Atis, 2006; Baydar et al., 2015). Afterwards, harvested cotton is sent to textile production facilities for fiber production which is detailed in the next sectio (Bodin, 2016). During this step, main environmental impacts are caused from occupation of land, water consumption, fertilizer and pesticide consumption and direct emissions to air and water (Hall et al., 1996; Freney, 1997; Kirchmann et al., 1998; Kalliala and Nousiainen, 1999; Atis, 2006; Van Der Velden et al., 2014; Baydar et al., 2015) (Esteve-Turrillas and de la Guardia, 2017).

Step 2: Fiber Production

After the harvesting of cotton, the ginning process is applied for fiber production (Baydar et al., 2015). The main function of the ginning process is the conversion of cotton to a salable product for the textile industry. Earlier, the only purpose of the ginning process was to separate the fibers from the seed, yet nowadays advance cotton ginning is used for cleaning and drying of fibers (Van Der Sluijs, 2015; Bodin, 2016). During this step, main environmental impacts are caused from heat and electricity consumption (Palamutcu, 2010; Esteve-Turrillas and de la Guardia, 2017).

Step 3: Yarn Production

Yarn can be defined as a structure in which fibers hold each other by friction or twisting activity and it has a thin and elongated form (Koç and Kaplan, 2007). Fibers from which yarns are produced are divided into two as filament and staple according to their length (Van Der Velden et al., 2014). If the yarn is produced from staple fibers, it is called spun yarn, if not it is called as continuous filament yarn (Koç and Kaplan, 2007). To give an example some apparel products, such as only slippery sportswear, are made entirely of filament yarns the process in which these fibers are transformed into suitable yarns for the textile industry is called spinning and spinning process is consist from opening, carding, combing, roving and spinning steps (Moazzem et al., 2018; Ozturk et al., 2020). Also different spinning methods are available to produce several yarn structures in the various properties such as open-end and ring spinning (Koç and Kaplan, 2007). During this step, main environmental impacts are caused from heat and electricity consumption (Palamutcu, 2010; Van Der Velden et al., 2014; Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017; Moazzem et al., 2018).

Step 4: Woven Fabric Production

Yarns produced in the previous step are used as raw materials for woven fabric production (Alkaya and Demirer, 2014). Yarns are exposed to constantly variable tension and friction during the yarn production step (Ozturk et al., 2020). As such, they can be eroded and mauled. Since the movements repeated on the same parts during the weaving process can cause damage to the yarn surface too (Palamutcu, 2010). For this reason, in order to increase the resistance of the yarns, sizing is performed before the weaving application (Alkaya and Demirer, 2014; Van Der Velden et al., 2014). Natural starch and its derivatives constitute most of the sizing agents currently used in the textile industry (Alkaya and Demirer, 2014; Reddy et al., 2014). Afterwards, the weaving process is performed by connecting the yarns to each other in a weaving machine (Alkaya and Demirer, 2014). Weaving is a process that consumes a large amount of electrical energy (Palamutcu, 2010; Van Der Velden et al., 2014; Ozturk et al., 2020). Besides, sizing chemicals and water are other main consumptions during the fabric production (Palamutcu, 2010; Alkaya and Demirer, 2014; Esteve-Turrillas and de la Guardia, 2017; Moazzem et al., 2018).

Step 5: Wet Processing

Wet process is a process that can change even for the same fiber type (Moazzem et al., 2018). The procedures to be applied may vary according to the demand (Bonaldi, 2018). Wet processes in textile production is one of the most water demanded steps which consists of pre-treatment, finishing and dyeing processes (Moazzem et al., 2018; Samanta et al., 2019). Wet processes form the basis of textile production as key resources are consumed in this step (Choudhury, 2017). For instance, the materials used in the sizing process should then be removed by desizing which is a pre-treatment process (Palamutcu, 2010; Van Der Velden et al., 2014; Ozturk et al., 2020). As a result of desizing, the biological oxygen demand load can increase approximately at the range of 50% in wastewater (Madhav et al.,2018). The main purpose of the wet processes is to improve some of the features to make the product more attractive and salable (Alkaya and Demirer, 2014). For this reason, there can be so many sub-processes under the wet process (Moazzem et al., 2018). Detailed descriptions of the wet process and detailed information on auxiliary chemicals can be found in Best Available Techniques Reference Document (BREF) (European Commission, 2003). Water, chemicals for desizing, bleaching and dyeing and energy are the main consumptions for the wet processing (Palamutcu, 2010; Choudhury, 2017; Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017; Moazzem et al., 2018; Ozturk et al., 2020; Palamutcu, 2010). During this step, main environmental impacts are caused from water, heat, electricity consumptions and chemical consumption for desizing, bleaching and dyeing. Besides it causes from treated water emissions occurred from wet process. (Palamutcu, 2010; Van Der Velden et al., 2014; Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017; Moazzem et al., 2018).

Step 6: Make-Up Process

Make-up process is the last step before transportation and distribution to the final consumer (Moazzem et al., 2018). Sub-processes belonging to the make-up process can be variable according to customer demand. However, cutting, ironing and sewing can be classified as main processes. For these applications, electricity and steam consumption are the main resource consumptions (Schmidt et al., 2016).

2.10 Life Cycle Assessment's History and Explanation

As mentioned above, some regulations such as zero waste have emerged as an economic and administrative tool that can be used to support the circular economy concept, based on environmental point of sustainable development principles and those tools and principles are being formed with science-based studies such as environmental impact assessment practices that can be implemented by industries, institutions, organizations etc. (Feo and Malvano, 2009). There are various tools and methods to analyze the environmental impact assessment for the industries to build sustainability management strategy. Life Cycle Analysis tool can be given as an example of these methods which is also used in the scope of this study in order to select the most effective waste management applications for the woven household textile waste made from cotton (Feo and Malvano, 2009; Roy et al., 2020; Sauve and Acker, 2020).

The actual emergence of the LCA concept started in the 1960s when environmental deterioration, and resources scarcity started becoming a concern (Guinée and Heijungs, 2017). LCA studies initially focused on packaging applications and concentrated primarily on energy use and some emissions and it was firstly used in the US and Northern Europe which was firstly applied with uncoordinated, non-standardized ways (Bjørn et al., 2017). Later, LCA started to take place in the scientific community with international cooperation and coordination, and experienced methodological developments in the 1970s, 1980s and 1990s. After the strengthening of the methodological framework, LCA applications started to increase rapidly in the production industry and in the other industrial processes with academic collaboration and standards (Guinée and Heijungs, 2017). Finally, the framework and principles of the LCA were described and defined by International Standardization Organization (ISO) in 2006 as follow; LCA is a technique that involves the determination and evaluation of the environmental impacts of a product during its entire life cycle by creating an input and output inventory of production processes, and the interpretation of the results of the inventory analysis and impact assessment stages (ISO, 2006a). This assessment technique can include all impacts to air, water and soil (Bjørn et al., 2017). These impacts can be identified and measured as both direct (emissions generated during the production phase and energy used, etc.) and indirect (raw material supply, distribution of the product, use by the consumer and disposal, etc.) impacts (Cleary, 2010). As a summary LCA is a system that includes all environmental stages of a product or process from obtaining raw material from nature until all wastes return to nature (Moazzem et al., 2018).

Besides the provided information about LCA, there are also different features to refer to. To use its features correctly, it is important to determine what purpose the LCA study will be used for because it has a wide range of usage area (Moazzem et al., 2018). For example, thanks to the comprehensive and holistic evaluation that can be performed with LCA, it enables comparison of the environmental impacts caused by modifications to the products or processes. Thus, LCA can also provide support in decision-making processes (Feo and Malvano, 2009; Sauve and Acker, 2020).

LCA study framework to be performed on the above-mentioned applications areas are divided into 4 stages according to the ISO 14040 standard. These stages are given as follows respectively; (Stage 1)-goal and scope definition, (Stage 2)-life cycle inventory (LCI; Stage 3)-life cycle impact assessment (LCIA) and (Stage 4)-life cycle interpretation as shown in Figure 2.5 (ISO, 2006a; Laurent, Bakas, et al., 2014; Laurent, Clavreul, et al., 2014; Luo et al., 2021). These steps explained in detail in the following sections.

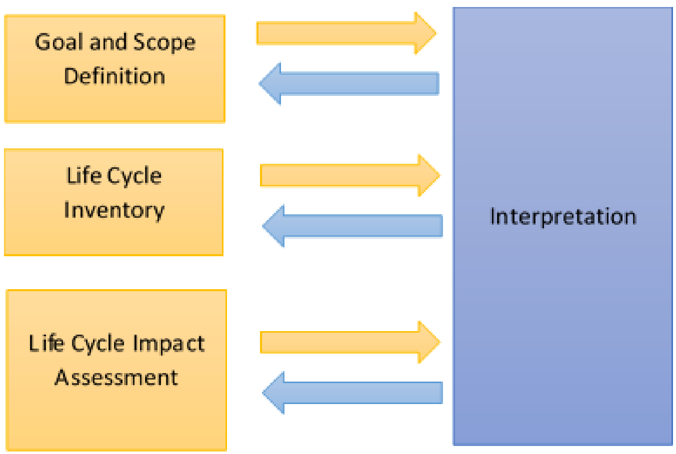

Figure 2.5 Life cycle assessment framework (Modified From; ISO, 2006a).

2.10.1 Goal and Scope Definition of LCA

In the first step of the LCA study, the goal and scope should be defined (ISO, 2006a). For the goal definitions, the target audience of the study, decisions to be supported by the LCA study and the scope of these decisions should be clearly determined (Bjørn et al.,2017). For the scope definitions, the following issues should be determined (Çokaygil, 2005).

- System boundaries of the study should be determined. This means which processes will be included and excluded. For example, while transport and distribution of a textile product can be included, packaging of this product can be excluded within the system boundary (Moazzem et al., 2018).
- Environmental impact categories to be examined should be selected. (Laurent, Bakas, et al., 2014; Laurent, Clavreul, et al., 2014; Luo et al., 2021). This phase should also be completed to guide the data collection process which is explained detailed in the next section (ISO, 2006a). Frequently used impact categories in LCA studies are global warming, stratosperic ozone depletion, acidification, Eutrophication and photochemical oxidation (USEPA, 2006).
- Functional unit of the study should be determined (ISO, 2006a). This means, defining the product or process with a numeric reference value such as 1 kg textile product (Laurent, Bakas, et al., 2014; Laurent, Clavreul, et al., 2014; Luo et al., 2021). Related data for 1kg textile product such as input materials, energy, water, output materials, emissions and waste are collected in line with the functional unit (Moazzem et al., 2018).

2.10.2 Life Cycle Inventory (LCI)

In the second stage of the LCA study, inventory analysis is included (ISO, 2006a). Inventory analysis covers all inputs and outputs of processes such as raw material, electricity, heat, fuel and steam energy consumption and all kinds of outputs such as wastewater, air emissions and solid waste (USEPA,2006). In line with the determined functional unit in the previous section, units of collected inputs and outputs can be defined as "weight" for raw material supply and material production, "kWh" for electricity generation, "MJ" for heat energy production, "km" for transportation (Feo and Malvano, 2009; Laurent, Bakas, et al., 2014; Laurent, Clavreul, et al., 2014; Sauve and Acker, 2020; Fidan et al., 2021; Luo et al., 2021).

The quality of the data to be collected in this stage is very important for obtaining reliable results (ISO, 2006a; Sauve and Acker, 2020).Therefore, the most time-consuming part of the LCA study can be called inventory analysis (Bjørn et al., 2017). In addition, the data of the processes applied in practice may not always be available (Schmidt et al.,2016). Therefore, different data sources may be needed for inventory analysis (Moazzem et al., 2018) such as electronic databases, literature data, laboratories, factories or other institutions data and collected data from measurements (Christensen et al., 2020).

2.10.3 Life Cycle Impact Assessment (LCIA)

In the third stage of the LCA study, life cycle impact assessment is included (ISO, 2006a). At this stage, possible environmental impacts of emissions identified during the inventory analysis process on human health and environmental values are evaluated (Bodin, 2016). Some questions about environmental impacts of a product or service can be answered at this stage. For example, what are the effects of x tons of carbon dioxide or y tons of methane emitted into the atmosphere? Which one has the greater effect? What are the effects of these on local and global environmental problems? (Christensen et al., 2020). Classification and characterization results belonging to evaluated environmental impacts should be shown in line with the standards (ISO, 2006b). Besides, normalization, grouping and weighting results which are optional elements according to standards can be shown too (ISO, 2006b).

2.10.4 Interpretation

In the life cycle interpretation step, the results are reviewed and identified the significant issues based on the life cycle impact assessment results (Moazzem et al., 2018). Besides, this is the step where the results are analyzed and considered in the light of the uncertainties of the applied data and the assumptions that have been made and documented throughout the study (Bjørn et al., 2017). These uncertainties are tried to be answered with sensitivity analysis (Laurent, Bakas, et al., 2014; Laurent, Clavreul, et al., 2014; Luo et al., 2021). In this step the following subjects can be covered.

- Important environmental issues based on the life cycle assessment results (ISO, 2006a).
- Evaluation of methodology and results in terms of holism, sensitivity and consistency (Çokaygil, 2005).
- Controlling of the results in line with the requirements defined in the goals and scope stage (ISO, 2006a).

2.10.5 LCA Softwares, Methods, Environmental Impact Categories and Databases

There are different developed LCA modelling and reporting softwares (Laurent, Clavreul, et al., 2014). To choose the suitable software for the LCA studies, it is necessary to consider some issues such as the database of the software or ease of use (Bjørn et al., 2017). There are different softwares for LCA tools like SimaPro, Gabi, Umberto, OpenLCA (Laurent, Clavreul, et al., 2014; Moazzem et al., 2021b). This software varies especially according to the industrial databases they contain (Emami et al., 2019; Turk et al., 2020; Ferrari et al., 2021). As a result of the conducted literature review for this study, it is observed that SimaPro and GaBi are used more widely in generic LCA studies (Laurent, Clavreul, et al., 2014). SimaPro software, which has a very common usage area and having a database suitable for many sectors which is the Ecoinvent database (Laurent, Clavreul, et al., 2014). There are different calculation methodologies developed for impact assessment such as ReCiPe, CML, ILCD (Yuan et al., 2013; Zhang et al., 2015; Peters et al., 2015). These methods can vary according to the midpoint impact categories they include such as global warming, land use or fossil resource depletion and according to the regions in which they are calculated such as Global scale or European Scale or according to scope of calculations such as midpoint or endpoint calculations (Yuan et al., 2013; Lamnatou and Chemisana, 2015; Zhang et al., 2015; Fréon et al., 2017; Lamnatou et al., 2018; Luo et al., 2021; Moazzem et al., 2021b). For example, while calculation can be made on a European scale with the CML method, calculations can be made on a global scale with the ReCiPe method or land use effect belonging to midpoint impact categories can be calculated with ReCiPe midpoint method, however, it is not calculated separately in CML method (Yuan et al., 2013; Lamnatou and Chemisana, 2015; Zhang et al., 2015; Fréon et al., 2017; Lamnatou et al., 2018; Luo et al., 2021; Moazzem et al., 2021b). Finally, while the commonly used midpoint effects which are given in Section 2.10.1 can be calculated in each method which is helpful for the comprehensive comparison between the processes, endpoint effects can be calculated with ReCiPe method which is helpful to make conciseness comparison as it is calculated by including different environmental impact categories (Dong and Ng, 2014; Zamani et al., 2015; Lamnatou et al., 2018; Sandin and Peters, 2018).

After calculating the endpoint impacts, a single holistic result including each endpoint impacts can be obtained which is referred to as single score results (Dong and Ng, 2014; Huijbregts et al., 2017). In this direction, the link between the midpoint impact categories and endpoint results which are calculated by ReCiPe method is given in Table 2.2 below.

Table 2.2 Midpoint impact categories, endpoint protection areas and the link between them (Modified from Huijbregts et al., 2017)

Categorized Midpoint Impacts	**Damage Pathway**	**Endpoint Area of Protection**
Global Warming*	Increase in Malnutrient	Human Health
Water Consumption*		
Human Carcinogenic Toxicity*	Increase in Various Types of Cancer	
Ionizing Radiation*		
Stratospheric Ozone Depletion*		
Ionizing Radiation*	Increase in Other Diseases/Causes	
Stratospheric Ozone Depletion*		
Human Non-Carcinogenic Toxicity		
Global Warming*		
Fine Particulate Matter Formation	Increase in Respiratory Disease	
Ozone Formation, Human Health		
Global Warming*	Damage to Freshwater Species	Ecosystems
Freshwater Eutrophication		
Freshwater Ecotoxicity		
Water Consumption*		
Global Warming*	Damage to Terrestrial Species	
Water Consumption*		
Ozone Formation, Terrestrial Ecosystems		
Terrestrial Acidification		
Terrestrial Ecotoxicity		
Land Use		
Marine Ecotoxicity	Damage to Marine Species	
Mineral Resource Scarcity	Increased Extraction Costs	Resources
Fossil Resource Scarcity	Oil/Gas/Coal Energy Cost	

* Impact Categories with More Than One Pathway

CHAPTER 3

DATA COLLECTION AND LCA METHODOLOGY

In this chapter, a roadmap for LCA methodology and data collection of this study is introduced step by step.

3.1 Roadmap for LCA Methodology and Data Collection

This study aims to investigate the environmental effects of transportation and recycling on the household textile waste of Eskişehir by using LCA methodology. Based on the specific objectives of the study, firstly, the structure of the LCA methodology is created to fulfill the gaps and recommendations given in the literature. In this direction, the functional unit of LCA is determined as 1 kg woven household textile waste produced from pure cotton. Disregarding the consumer using stage, the entire life cycle of household textile waste produced from cotton is decided in order to be evaluated within the scope of the LCA as it is recommended to conduct more household textile waste studies from production to end of life (Sandin and Peters, 2018; Taşkın and Demir, 2020). Since cotton is a valuable raw material and consumes so many resources, household textile waste fiber type is selected as cotton (Kalliala and Nousiainen, 1999; Alkaya and Demirer, 2014; Semba et al., 2020). LCA inventory is determined to be prepared according to occupation of land, water consumption, chemical consumption, energy consumption, emission to air and water and transportation network regarding the related textile production, recycling, reusing and landfilling as they are the main reasons of environmental impacts (Schmidt et al., 2016; Moazzem et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b). Also, all production, recycling, reusing and landfilling process inventories are prepared separately as it is recommended in the literature (Esteve-Turrillas and de la Guardia, 2017; Sandin and Peters, 2018). Transportation network specially for the sorting and recycling is determined to be prepared according to real data as it is one of the gaps in the previous LCA studies focusing on textile waste (Sandin and Peters, 2018; Taşkın and Demir, 2020). Lastly the life span of the recycling is assumed as maximum 10 times by considering the 10% landfilling rate in each recycling (Sandin and Peters, 2018; Schmidt et al., 2016). The same life span is assumed also for reusing (Sandin and Peters, 2018).

LCA analysis is chosen to be performed by using SimaPro 9.1.0.8 faculty with the ReCiPe 2016 Midpoint and Hierarchist impact assessment method to assess global warming potential to compare the obtained landfilling of 1 kg pure cotton household textile waste results with the literature, to be certain of the accuracy of the results, and to make comprehensive interpretation (Dong and Ng, 2014). Furthermore, to assess single score results in order to make conciseness comparison between the specific objective of this study as it gives a single holistic result by calculating different environmental impact categories. (Zamani et al., 2015; Sandin and Peters, 2018; Dong and Ng, 2014). In this regard, while examining the environmental benefits in terms of GWP and single score, higher environmental efficiency in terms of single score is expected (Dong and Ng, 2014; Huijbregts et al., 2017). Afterwards, the LCA methodology roadmap is drawn as per each objective of this study as it is outlined below.

1) *Assessing the environmental effects of landfilled pure cotton household textile waste of Eskişehir:* Firstly, the amount of landfilled and recycled pure cotton household textile waste in Eskişehir was investigated in the literature. It was determined in the literature as it is detailed in Section 3.3. that the amount of landfilled pure cotton household textile waste is 4190 ton/year (Altun, 2012; Buyukaslan et al., 2015; Ari and Yilmaz, 2016; Yılmaz and

Abdulvahitoğlu, 2019; Ağaçsapan and Çabuk, 2020). Although the household textile waste recycling rate of Turkey is found to be approximately 10% in the literature, there is no specific household textile waste recycling amount or ratio for Eskişehir (Altun, 2012; Buyukaslan et al., 2015; Ari and Yilmaz, 2016). For this reason, it is assumed that 10% of 4190 ton/year landfilled pure cotton household textile waste of Eskişehir is considered to be recycled. In another word, it is considered that, 90% of 4190 ton/year pure cotton household textile waste is being landfilled and 10% of 4190 ton/year pure cotton household textile waste is being recycled. On the other hand, the effects of 10% recycling of this textile waste with 10% loss are negligible when compared to 90% landfilling (Moazzem et al., 2021b). Consequently, the amount and management methods of the pure cotton household textile waste of Eskişehir are expressed as landfilled 4190 ton/year pure cotton household textile waste in this study. However, all assessments are aimed to be performed including 10% recycling rate. In this direction, this assessment is aimed to be conducted by creating the following question: "What is the global warming potential and single score result of landfilled 4190 ton/year pure cotton textile waste of Eskişehir from the beginning of production to landfilling including recycling"? From production to landfilling processes including recycling are obtained from the following references (Schmidt et al., 2016; Moazzem, et al., 2021a; Moazzem, et al., 2021b).

2) *Assessing the 50% recycling, whole recycling and reusing effects on the pure cotton household textile waste of Eskişehir:* The environmental effects of recycling is aimed to be assessed by creating the following question; "What would the global warming potential and single score result changes be, if landfilled 4190 tons/year pure cotton household textile waste in Eskişehir would be sorted and directed to 50 % recycling, whole recycling or reusing"? Although the main purpose of this study is focused on recycling, GWP and

single score results of reusing are also aimed to be examined to show the changes. However, the environmental effects of transportation for reusing and different reusing ratios are not included. The reason for this is that: there are so many limitations in the conducted studies regarding the reusing as both user preferences such as the desire to buy a new product rather than using second-hand and the condition of the product to be reused are shown as important parameters on the reusing (Schmidt et al., 2016). Furthermore, scenarios based on reusing have more limitations and assumptions. Recycling scenarios are considered more realistic than reusing (Sandin and Peters, 2018). Therefore, this study focused on recycling. Recycling and reusing processes are obtained from the following references (Schmidt et al., 2016; Dahlbo et al., 2017; Esteve-Turrillas and de la Guardia, 2017; Koligkioni et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b).

3) *Assessing the different transportation options effects* ***of source material*** *on the current situation, on the 50% recycling situation and on the whole recycling situation of the pure cotton household textile waste of Eskişehir:* It is aimed to calculate the global warming potential and single score result changes of different transportation networks of the source material on the current situation, 50% recycling situation and whole recycling situation of pure cotton household textile waste of Eskişehir. To this aim, firstly the supply chain of textile products offered to the consumers in Eskişehir was investigated. In line with the literature review given in Section 3.6, it is accepted that 50% of textile products supplied from China and 50 % supplied from Turkey to consumers in Eskişehir which is one of the current situation conditions. In this direction, this assessment is aimed to be conducted by creating the following question: "What would the global warming potential and single score result changes be on current situation, 50% recycling situation and whole recycling situation if the textile products are supplied

from 100% China and 100% from Turkey"? While evaluating the effects of different transportation options of the source material, loads are aimed to be included.

4) *Assessing the different transportation options effects* ***of recycling*** *on the current situation, 50% recycling situation and whole recycling situation of the pure cotton household textile waste of Eskişehir:* It is aimed to calculate the global warming potential and single score result changes of different transportation networks of the recycling on the current situation, 50% recycling situation and whole recycling situation of pure cotton household textile waste of Eskişehir. To this aim, firstly the transportation network for current recycling system of Eskişehir was investigated. In line with the conducted interview given in Section 3.7, it is obtained that collected household textile waste in Eskişehir is firstly sent to Bursa by truck for sorting it and transported to Uşak by truck for recycling. In this direction, this assessment is aimed to be conducted by creating the following question: "What would the global warming potential and single score result changes be on current situation, 50% recycling situation and whole recycling situation if a new sorting facility is built in Eskişehir and if a new sorting and recycling facility are both built in Eskişehir"? While evaluating the effects of different transportation options of the recycling, loads are aimed to be included.
5) *Assessing the recycling rates versus reduced truck transportation load effects on the pure cotton household textile waste of Eskişehir:* When the landfilling rate of household textile waste is higher, effects arising from production to landfilling processes are more than the effects arising from recycling processes (Schmidt et al., 2016; Dahlbo et al., 2017). As the production to landfilling processes are avoided or replaced with recycling processes, the effects arising from production to landfilling are decreased and recycling processes and their effects come to fore in case of higher recycling rate

(Schmidt et al., 2016; Dahlbo et al., 2017). For example, supplying the source material can be avoided or replaced by recycling. Thus, if the recycling rate is higher, process contribution and environmental effects of transportation of source materials can be decreased (Schmidt et al., 2016; Dahlbo et al., 2017; Esteve-Turrillas and de la Guardia, 2017; Koligkioni et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b). This means that, even if supplying of source material transportation load is reduced, significant environmental benefits are not expected at high recycling rates. However, if transportation load of recycling is reduced, significant environmental benefits are expected specially at high recycling rates. With this explanation in mind, building a new sorting and recycling facility options in Eskişehir can induce more reduction specially on higher recycling rates. Nevertheless, the effects of reducing truck transportation load on different recycling rates is still uncertain. Besides, similar environmental benefits might be achieved by increasing the recycling rates instead of reducing truck transportation load by building a new sorting or recycling facility in Eskişehir case. In this regard, it is aimed to perform a sensitivity analysis to find optimum recycling rates versus reduced truck transportation load to achieve similar environmental benefits. For this assessment, it is decided to increase the recycling rate over the current situation conditions (it is expressed as current situation scenario in section 4.3.1) and over the new sorting facility case which is replaced with existing sorting facility on the current situation conditions (it is expressed as scenario 10 in section 4.3.1). All the details of the different scenarios are given in Section 4.3.1. In this direction, this assessment is aimed to be conducted by creating the following questions: “What is the sensitivity of different recycling rates to truck transportation load of recycling”? “Is there any recycling rate that provide similar environmental benefits which can be obtained by reducing truck transportation load of recycling"? The details of the sensitivity analysis are given in Section 4.2.7.

To carry out these assessments, firstly data collection is conducted. In this direction, the amount of landfilled cotton household textile waste of Eskişehir is obtained from the literature and given in Section 3.3. The amount of main consumptions and emissions for cotton textile production, landfilling, recycling and reusing stages among the land use, water consumption, chemical consumption, energy consumption, emission to air and emission to water are collected and given in Section 3.4 and 3.5. Data are obtained from the literature, Ecoinvent database and conducted interviews with 13.30.01, 38.11.01, 13.10.12, 13.99.04 NACE code companies and site visits to Eskişehir 2nd class Sanitary Landfill. Different sources are used to create diversity in data sources.

The distances and transportation modes for the current textile supply chain network offered to Eskişehir consumer is obtained from the literature review and given in the Section 3.6. The distances and transportation modes of the landfilling, current recycling, and reusing transportation network of Eskişehir and new recycling transportation network scenario are given in Section 3.7 and 3.8. These data are obtained by conducted interviews with the Environmental management department of The Eskişehir Municipality. The details of all collected data are explained under the relevant sections.

3.2 Amount of Landfilled Textile Waste of Turkey

When focusing on the amount and the details of landfilled textile waste in the World and Turkey, especially household textile waste attracts attention. Studies have shown that more than 87 % of household textile waste in the world ends up in landfills (Moazzem et al., 2021b). Looking at different examples, 10 million tons of household textile waste is discharged in the landfills each year in North America, 12 million tons of household textile waste discharged in the landfills in the USA (Shirvanimoghaddam et al., 2020). Considering the amount of produced textile waste, it is the 3-11% of the overall produced waste in Turkey (Akinci et al., 2012; Yılmaz and Abdulvahitoğlu, 2019). 50% of this textile waste is estimated as household textile waste (Altun, 2012; Buyukaslan et al., 2015). Nearly 90 % of textile waste ends up in landfills, 10% is sent to recycling and reusing is negligible (Altun, 2012; Buyukaslan et al., 2015). Regarding the amount, one million tons of textile waste is being sent to landfill in Turkey every year. 500 thousand tons of this textile waste is estimated to be household textile waste (Buyukaslan et al., 2015). It is predicted that 29% of these landfilled household textile waste is produced from pure cotton and 24% from pure polyester (Altun, 2012). In other words, approximately 145 thousand tons of pure cotton products and 112 thousand tons of pure polyester products are wasted in Turkey each year (Altun, 2012). It means that landfilled textile waste made of pure fibers material is a waste of raw materials since it can be easily recycled (Payne, 2015). Besides, these wastes can be reused instead of landfilling (Schmidt et al., 2016; Wang et al., 2020b). However, recycling rate is around 10%, and reuse is almost negligible in Turkey (Altun, 2012; Buyukaslan et al., 2015). The waste that is prioritized to be sorted has been selected as household textile waste made from cotton in this study regarding the waste amounts in the landfills and the benefits to be obtained by recycling and reusing.

3.3 The Importance of Eskişehir and Current Situation of Pure Cotton Household Textile Waste of Eskişehir

Public awareness is one of the most important elements in the proper management of recyclable or reusable waste (Hasan, 2004; Wang et al., 2020a). The public, who is aware of recyclable or reusable waste can take more active role to cooperate with the government officials and municipalities to success the proper waste management (Xue et al., 2010; Cao et al., 2016). In this regard, when recycling or reusing campaigns are carried out by the authorities, the successes achieved in the sorting of these wastes in provinces with high public awareness can be higher than other regions (Xue et al., 2010; Cao et al., 2016). Based on this perspective, Eskişehir is one of the provinces of Turkey with the highest public awareness about recycling and reusing (Ari and Yilmaz, 2016). Besides, since Eskişehir is one of the provinces in the middle of Turkey, some studies focused on Eskişehir to be a waste transfer or management place by considering the waste management transportation network (Ağaçsapan and Çabuk, 2020). In this respect, detailed inventory studies involving the real data transportation network specially for the sorting and waste management of Eskişehir can serve as a guide for further studies (Taşkın and Demir, 2020). Considering high public awareness and waste management transportation system in Eskişehir, it is crucial to carry out such a study in Eskişehir as the results of this study could be implemented in different regions in Turkey on the way of zero waste (Tinmaz and Demir, 2006; Akinci et al., 2012; Erdil, 2019; Resmi Gazzette, no: 28142, Date: 12/07/2019; Taşkın and Demir, 2020).

When focusing on the generated waste amount in Eskişehir, it is estimated that an average of 275,000 thousand to 300,000 thousand tons of municipal solid waste is produced annually and discharged in the landfills (Yılmaz and Abdulvahitoğlu, 2019; Ağaçsapan and Çabuk, 2020). Between 3% to 5% of these produced and discharged municipal solid wastes are thought to be household textile waste (Banar et al., 2009; Yılmaz and Abdulvahitoğlu, 2019). In other words, approximately 14500 tons of household textile waste is discharged in the landfills annually in Eskişehir. Considering 29% of these landfilled household textile waste are produced from pure cotton, nearly 4190 tons pure cotton wasted in the landfills in Eskişehir (Altun, 2012; Buyukaslan et al., 2015; Ari and Yilmaz, 2016). Although the produced textile waste recycling rate of Turkey is found to be approximately 10% in the literature there is no specific household textile waste recycling ratio for Eskişehir (Altun, 2012; Buyukaslan et al., 2015; Ari and Yilmaz, 2016).

3.4 Data Collection for Textile Production

Firstly, main consumptions and emissions of the cotton textile production data are introduced in Section 2.9. In the following step, the amount of main consumptions and emissions for cotton textile production data are obtained from related literature, Ecoinvent database and a conducted interview with a company is given a 13.30.01 NACE code instead of declaring the company name whose field of business activity is; Textile Finish, Bleaching and Dyeing Services of Fabrics and Textile Products which are also given in Appendix C. In this direction the amount of main consumptions and emission of the textile production steps are collected for Step 1: Virgin material production, Step 2: Fiber production, Step 3: Yarn production, Step 4: Fabric production, Step 5: Wet process and Step 6: Make-up process. Different sources are used to create diversity in data sources. Details about the obtained data of each production step are explained under the relevant sections.

3.4.1 Step 1: Virgin material production data

Virgin material production data are obtained from related literature and Ecoinvent database. The data obtained from both related literature and Ecoinvent database are used by taking their averages. The data only obtained from Ecoinvent is used directly. In this direction, virgin material production data and their references are given in Table 3.1 below.

Table 3.1 Step 1: Virgin material production data

1 kg Virgin Material Production (Cotton Harvesting)	Cotton	References
Main Consumptions	**Values**	
Occupation of land (m^2)	1.6 m^2	(Ecoinvent V3, 2020)
Water	[a]0.4 m^3 ±2	(Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)
Cotton seeds	[a]0.004 kg ±1.46	(Atis, 2006; Ecoinvent V3, 2020)
Fertilizers (inorganic)	[a]0.161 kg ±3	(Atis, 2006; Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)
Fertilizer (organic)	[a]0.1 kg ±3.2	(Kalliala and Nousiainen, 1999; Atis, 2006)
Pesticides	[a]$3.6x10^{-3}$ ±4.12	(Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020; Atis, 2006; Kalliala and Nousiainen, 1999)
Direct Emissions		
Emission to air caused from agriculture	[a]0.8 kg ±1.4	(Kirchmann et al., 1998;Freney, 1997;Hall et al., 1996;Ecoinvent V3, 2020; Esteve-Turrillas and de la Guardia, 2017;Kalliala and Nousiainen, 1999)
Water emissions caused from agriculture	[a]0.42 kg ±2.8	(Kalliala and Nousiainen, 1999; Ecoinvent V3, 2020)

[a]Average Values of Literature and Ecoinvent Database.

3.4.2 Step 2: Fiber production data

Fiber production data are obtained from related literature and Ecoinvent database. The data in which obtained. In this direction, fiber production data and their references given in Table 3.2 below.

Table 3.2 Step 2: Fiber production data

1 kg Fiber Production	Cotton	References
Main Consumptions	**Values**	
Virgin Material	[a]2 kg	(Ecoinvent V3, 2020)
Heat	[a]$1.32X10^{-5}$ MJ ±1.08	(Ecoinvent V3, 2020) (Esteve-Turrillas and de la Guardia, 2017),
Electricity	[a]0.02 kwh ±0.4	(Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)

[a]Average Values of Literature and Ecoinvent Database.

3.4.3 Step 3: Yarn production data

Yarn production data are obtained from related literature and the Ecoinvent database. The data obtained from both related literature and Ecoinvent database are used by taking their averages. The data only obtained from Ecoinvent is used directly. In this direction, yarn production data and their references are given in Table 3.3 below.

Table 3.3 Step 3: Yarn production data

1 kg Yarn Production	**Cotton**	**References**
Main Consumptions	**Values**	
Fiber	1.15 kg	(Ecoinvent V3, 2020)
Heat	[a]3.8 MJ ±2	(Palamutcu, 2010; Van Der Velden et al., 2014; Ozturk et al., 2020; Ecoinvent V3, 2020)
Electricity	[a]2.34 kwh ±2.2	(Palamutcu, 2010; Van Der Velden et al., 2014; Ozturk et al., 2020; Ecoinvent V3, 2020)

[a]Average Values; Calculated by taking the averages from the given references.

3.4.4 Step 4: Fabric production data

Consumed heat and electricity data are used by taking the average of obtained data from a conducted interview with a 13.30.01 NACE code company for fabric production and obtained data from the literature. The rest are obtained from related literature and Ecoinvent database. The data which is obtained from both related literature and Ecoinvent database are used by taking their averages. The data only obtained from Ecoinvent is used directly. In this direction, fabric production data and their references are given in Table 3.4 below.

Table 3.4 Step 4: Fabric production data

1 kg Fabric Production	**Cotton**	**References**
Main Consumptions	**Values**	
Water	[a]0.03 m^3 ±1.15	(Esteve-Turrillas and de la Guardia, 2017;Ecoinvent V3, 2020)
Yarn	[a]1.15 kg ±1.4	(Schmidt et al., 2016; Ecoinvent V3, 2020)

Table 3.4 (continued)

Sizing Agents	0.04 kg	(Ecoinvent V3, 2020)
Heat	[b]2.263 MJ ±1	(Palamutcu, 2010), Real Data
Electricity	[b]0.5 kwh ±0.5	(Palamutcu, 2010), Real Data

[a]Average Values of Literature and Ecoinvent Database. [b] Average Values of Real Data and Ecoinvent Database

3.4.5 Step 5: Wet process data

Consumed heat and electricity data are used by taking the average of obtained data from a conducted interview with a 13.30.01 NACE code company for wet process obtained data from the literature. The rest are obtained from related literature and Ecoinvent database, The data which are obtained from both related literature and Ecoinvent database are used by taking their averages. In this direction, wet process data and their references are given in Table 3.5 below.

Table 3.5 Step 5: Wet process data

Wet Process	Cotton	References
Main Consumptions	**Values**	
Water	[a]0.182 m^3 ±2.4	(Kalliala and Nousiainen, 1999; Baydar et al., 2015; Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)

Table 3.5 (Continued)

Chemicals	[a] 0.4523 kg ±4.08	(Kalliala and Nousiainen, 1999; Baydar et al., 2015; Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)
Electricity	[b]0.7 kwh ±1.5	(Kalliala and Nousiainen, 1999; Baydar et al., 2015), Real Data
Heat	[b]46.21 MJ ±11.15	(Kalliala and Nousiainen, 1999; Baydar et al., 2015), Real Data
Direct Emissions After Treatment		
Wastewater emissions caused from fiber to finishing	[a]0.016 m^3±2	(Kalliala and Nousiainen, 1999; Baydar et al., 2015; Ecoinvent V3, 2020)

[a]Average Values of Literature and Ecoinvent Database. [b] Average Values of Real Data and Ecoinvent Database

3.4.6 Step 6: Make-Up process data

Make-up process data are obtained from Ecoinvent database. In this direction, make-up process data and their references are given in Table 3.6.

Table 3.6 Step 6: Make-Up process data

Make-up Process (Cutting, sewing, ironing)	**Cotton Data Sources**	**References**
Main Consumptions	**Values**	
Fabric	1.15 kg	(Ecoinvent V3, 2020),
Heat	0.015 MJ	(Ecoinvent V3, 2020)
Electricity	0.4 kwh	(Ecoinvent V3, 2020)

3.5 Data Collection for Landfilling, Recycling and Reusing

Firstly, main consumptions and emission of the landfilling, recycling and reusing are introduced in Section 2.4. Later on, the amount of main consumptions and emissions for landfilling, recycling and reusing data are obtained from the related literature, Ecoinvent database and conducted interviews with a company given a 38.11.01 NACE code instead of declaring the company's name whose field of business activity is; Collection of non-hazardous wastes (garbage, recyclable materials, textile wastes, etc.) (excluding construction and demolition wastes, debris such as brush, scraps, rubble) which is a textile sorting facility located in Bursa Province , with a company given a 13.10.12 NACE code instead of declaring the company's name whose field of business activity is; (Twisting and spinning cotton fiber) which is a textile recycling facility located in Uşak Province and with a with a company given a 13.99.04 NACE code instead of declaring the company name whose field of business activity is; (Manufacture of textile scraps (for filling beds, quilts, pillows etc.) which is another textile recycling company located in Uşak Province. Lastly a site visit is conducted to Eskişehir 2nd class Sanitary Landfill by obtaining the necessary permissions. Different sources are used to create diversity in data sources. Details about the obtained data of each production step are explained under the relevant sections.

3.5.1 Data Collection for Landfilling

Landfilling process is detailed in Section 2.4 is carried out as follows: Textile waste disposed into the municipal waste by the users (Corsten et al., 2013). Then they are collected and transported to the landfills (Corsten et al., 2013). It is buried here and is expected to decompose by capturing gas according to landfill type (Strähle and Hauk 2017). In this direction, a similar study that has accepted that the main consumption and emissions of the landfilling of cotton textile waste are air emissions and occupation of land is taken as a reference (Moazzem et al., 2021b).

To learn about the type of landfilling,a site visit is conducted to Eskişehir 2nd class Sanitary Landfill. In this direction, it has been learned that there is a gas collection system. So, air emission data originating from the landfilling of cotton textile waste is obtained for the facilities with a gas collection system from the Ecoinvent database. Average occupation of land by 1 kg textile waste data is obtained from the conducted site visit to Eskişehir 2nd class Sanitary Landfill and from Ecoinvent database and their average values are taken. Site visit permission is given in Appendix A and a conducted interview during the site visit given in Appendix B. In this direction, landfilling data and their references are given in Table 3.7 below.

Table 3.7 Landfilling data

1 kg Cotton Textile Waste Landfilling		**References**
Main Consumptions	**Values**	
Occupation of land (m^2)	^{b} 0.96 m^2	(Ecoinvent V3, 2020), Real Data
Direct Outputs		
Emission to air caused from textile landfilling	0.16 kg	(Ecoinvent V3, 2020)

^{b} Average Values of Real Data and Ecoinvent Database

The photograph taken during the site visit is given in Figure 3.1 below.

Figure 3.1 Some pictures taken during the site visits in the landfills (taken by the Ilayda Sipahi)

3.5.2 Data Collection for Recycling

Recycling process which is detailed in Section 2.4 is carried out as follows: Collected waste are transported to the sorting facilities to sort them according to color and fiber types (Riba et al., 2020). This process can be done automatically or manually (Dahlbo et al., 2017). Later, sorted textile waste is being sent to recycling (Castellani et al., 2015). Recycling can be carried out in two ways, as mechanical and chemical methods (Shen et al., 2010; Schmidt et al., 2016). Mechanical recycling is the more commonly applied method (Sandin and Peters, 2018; Fidan et al., 2021). Mechanical recycling consists of cutting and shredding processes (Esteve-Turrillas and de la Guardia, 2017). As a result of cutting and shredding processes, textile waste turns into fibers. Then the recycled fibers continue to textile production from yarn production (Moazzem et al., 2021b). In mechanical recycling, pure fiber types can be upcycled (Payne, 2015).

To learn how the cotton household textile waste of Eskişehir is recycled in reality, interviews with a company given a 38.11.01 NACE code instead of declaring the company’s name whose field of business activity is: Collection of non-hazardous wastes (garbage, recyclable materials, textile wastes, etc.) (excluding construction and demolition wastes, debris such as brush, scraps, rubble) which is a textile sorting facility located in Bursa Province with a company given a 13.10.12 NACE code instead of declaring the company’s name whose field of business activity is: (Twisting and spinning cotton fiber) which is a textile recycling facility located in Uşak Province and with a company given a 13.99.04 NACE code instead of declaring the company's name whose field of business activity is: (Manufacture of textile scraps (for filling beds, quilts, pillows etc.) which is another textile recycling company located in Uşak Province are conducted.

For textile sorting: 38.11.01 NACE code textile sorting company stated that they perform manual sorting (Appendix E). In this direction, similar studies which are also assessed by a manual sorting system with no remarkable main consumptions and emissions are taken as a reference (Schmidt et al., 2016; Fidan et al., 2021).

For recycling: 13.10.12 and 13.99.04 NACE code textile recycling companies stated that they perform mechanical recycling with cutting and shredding process and they can recycle the pure cotton textile wastes with the same quality of original ones which are given inAppendix F. In this direction, similar studies which have also assessed mechanical recycling are taken as a reference (Schmidt et al., 2016; Esteve-Turrillas and de la Guardia, 2017).

As a result, the amount of main consumptions and emissions for recycling (cutting and shredding processes) data are obtained from related literature and Ecoinvent database and their average values are taken which are given with the references in Table 3.8 below.

Table 3.8 Recycling data

1 kg Textile Waste Recycling (Cutting and Shredding Process)	Recycling (Cutting and Shredding Process)	References
Main Consumptions	**Values**	
Electricity	[a]0.208 kwh	(Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)
Heat	[a]0.18 MJ	(Esteve-Turrillas and de la Guardia, 2017; Ecoinvent V3, 2020)

[a]Average Values of Literature and Ecoinvent Database.

3.5.3 Data Collection for Reusing

Reusing process which is detailed in Section 2.4 is carried out as follows: In the reusing, non-usable textile waste can be collected by charity organizations, municipalities etc. and can be repaired by tailoring activities (Dahlbo et al., 2017). Afterwards, it can be sent to needy people living nearby to the textile waste collected area or it can be sent to needy people in countries that may be overseas (Koligkioni et al., 2018; Moazzem et al., 2018; Semba et al., 2020). Another alternative, people can repair their non-usable textile waste by tailoring activities, and the people can use it again (Schmidt et al., 2016; Sandin and Peters, 2018). For reusing, it can be said that main consumptions are caused from tailoring activities (Schmidt et al., 2016). In this direction, a similar study which accepted that the amount of main consumption of reusing is similar with the make-up process, which is the last step of textile production is taken as a reference (Schmidt et al., 2016).

In fact, the amount of the main consumptions data of reusing obtained from the Ecoinvent database is the same as the make-up process step of textile production.

Reusing process data and their references are given in Table 3.9 below.

Table 3.9 Reusing data

Reusing (Make-Up Process) =Step 6		References
Main Consumptions	**Values**	
Electricity	0.4 kwh	(Ecoinvent V3, 2020)
Heat	0.015 MJ	(Ecoinvent V3, 2020)

3.6 Data Collection For Current Transportation Network of Textile Supply Chain of Textile Products Offered to Eskişehir Consumer

Turkey has an important place in textile production and cotton production and their export, but most of the textile products offered to consumers in Turkey is produced in China (Ozturk, 2005; Alkaya and Demirer, 2014; Pulat et al., 2009). Turkey is the world's sixth largest apparel producer and tenth largest textile exporter (Talay et al., 2018). It has the capacity to produce in many different textile manufacturing processes such as yarn production, woven or knitted fabric production etc. (Palamutcu, 2010; Alkaya and Demirer, 2014). There are 35 thousand to 50 thousand companies which operate in these fields (Palamutcu, 2010; Alkaya and Demirer, 2014) (Turker and Altuntas, 2014; Shen, 2014). Apart from this, it has an important place in the cotton production and consumption as the world’s seventh cotton producer and fourth in the cotton consumption (Alkaya and Demirer, 2014). Those textile products produced in Turkey are mostly exported to Europe (Talay et al., 2018). Although, Turkey has a production and export capacity in textile, products offered to customers in Turkey not only are produced in Turkey but also imported from other countries (Shen, 2014; Turker and Altuntas, 2014; Yilmaz and Karaalp-Orhan, 2015; Erduman et al., 2020). When the details of the products offered to the customers in Turkey are examined, products such as apparel generally belonging fast fashion brands like H&M, Puma, Mango, Zara, etc. as it is all over the world (Shen, 2014; Turker and Altuntas, 2014; Shirvanimoghaddam et al., 2020). Products such as home textiles like towels, curtains belong to local manufacturers (Palamutcu, 2010). When the supply chains of these fast fashion brands are examined, nearly 13 % of the textile production and raw material supply are conducted in Turkey, Bangladesh and so forth, 42 % are conducted in China which is the largest manufacturer and supplier of these brands (Shen, 2014; Turker and Altuntas, 2014; Chen et al., 2017). In this direction when the supply chain of textile products offered to consumers in Turkey is considered, there are both local and imported products in Turkey (Yilmaz and Karaalp-Orhan, 2015; Nakiboglu and Bulgurcu, 2021). By looking at the import and domestic production data of textile products produced in Turkey, the import dependency ratio of Turkey is found as 0,2440 which means a part of locally produced domestic textile consumption is imported also (Necla, 2017). In other words, there is an import of up to 30% in the supply of some textile raw materials such as cotton or yarn even if those textile products are manufactured and finished in Turkey (Erduman et al., 2020). When we look at the foreign trade statistics of the Turkish Statistical Institute, those textile requirements are mostly imported from China by shipping (TURKSTAT, 2021). In the light of the above-mentioned information, the current ratio of textile products offered to Turkish consumers is nearly 50% produced in China and 50% produced in Turkey. Within the scope of this study it is not worthed to go into details of the other countries where few supplies are also originated from Vietnam, Bangladesh etc. which are other nearby regions of China which is the main supplier of Turkey (Turker and Altuntas, 2014; Chen et al., 2017; TURKSTAT, 2021). There are similar LCA studies in which textile supply chain assumptions made based on a country or a region in which main imports are conducted (Schmidt et al., 2016; Dahlbo et al., 2017; Moazzem et al., 2021b).

If the production journey of textile which is supplied from China to Turkey is examined in more detail; Xinjiang is the most famous region in China where cotton is mostly produced and supplied to textile production facilities (Liang et al., 2020; Mi et al., 2020; Li et al., 2021b). In this direction, the cotton harvested in the Xinjiang region is generally shipped from Xinjiang port to Shanghai port (Lin and Bai, 2020). It is then distributed to textile manufacturing facilities located in Jiangsu by truck transportation (Li et al., 2021a). Following this, finished textile products are brought back to Shanghai port by truck transportation and supplied to Istanbul Port by shipping (Zhang et al., 2017; Erdil, 2019; Li et al., 2021a; TURKSTAT, 2021). Finally, it is assumed that the textile products arriving at the Istanbul port are transported by truck to the Eskişehir consumer. In this direction, a website called SEARATES is used to calculate the total sea transportation. So, the distance of cotton transportation conducted from Xinjiang Port to Shanghai Port is found as 986,26 sea miles given in Figure 3.2 and the distance of textile products transportation conducted from Shanghai Port to İstanbul Port is found as 7893,87 sea miles given in Figure 3.3 which is nearly 8880 sea miles (986,26 sea miles + 7894,87= 8880,13) in total. The same website is used in another study to find sea transportation distance (Herrero and Xu, 2017). Truck transportation is calculated from Google Earth. The distance of cotton transportation for textile manufacturing is conducted from Shanghai Port to Jiangsu province which is found as 325 km by truck transportation. Likewise, the distance of manufactured textile products transportation which are sent back from Jiangsu province to the Shanghai Port is also 325 km by truck given in Figure 3.4. Therefore, the total truck transportation distance within China is found to be 650 km (325x2=650km). Finally, the distance of truck transportation conducted from Istanbul port to the Eskişehir consumer is found as 350 km given in Figure 3.5. There are other studies in which transportation distances are calculated using Google Earth as well (Herrero and Xu, 2017; Fidan et al., 2021).

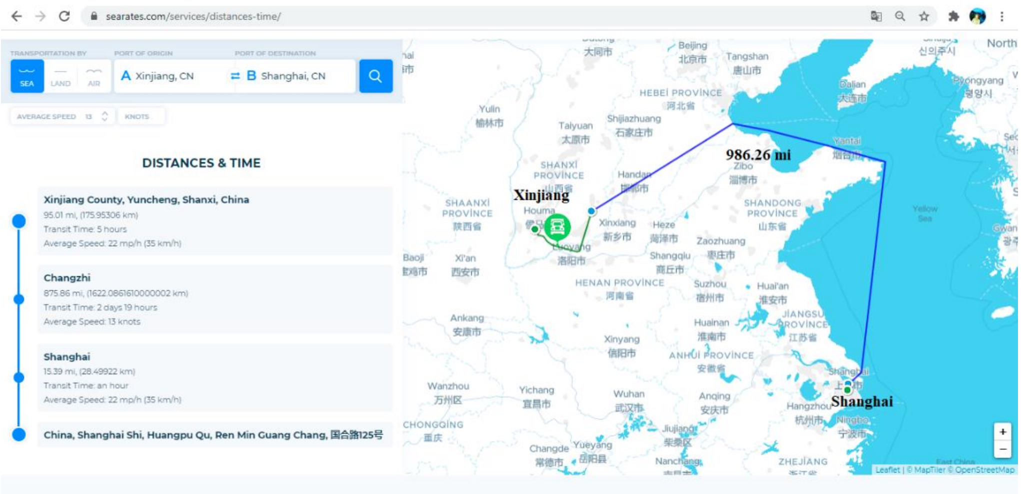

Figure 3.2. Sea transportation between Xinjiang Port and Shanghai Port

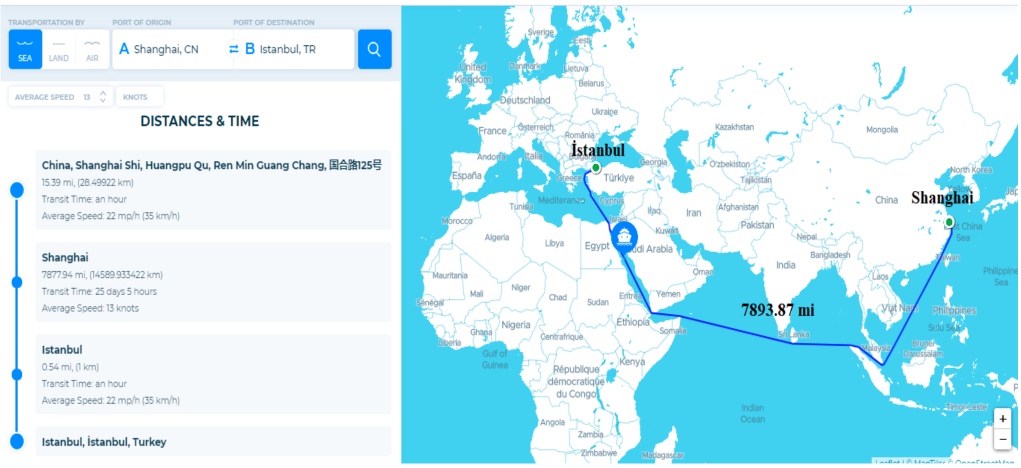

Figure 3.3. Sea transportation between Shanghai Port to İstanbul Port

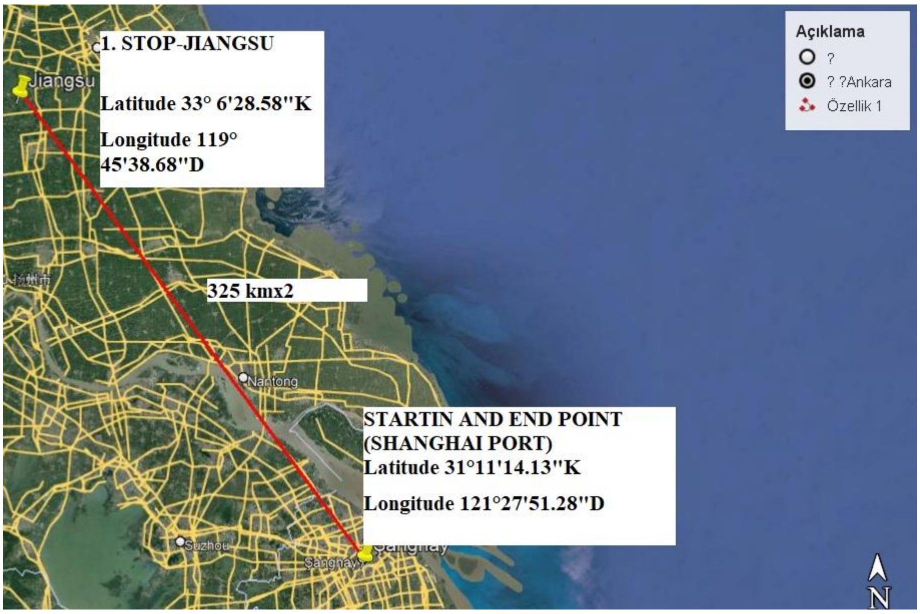

Figure 3.4. Truck transportation between Shanghai Port and Jiangsu Province

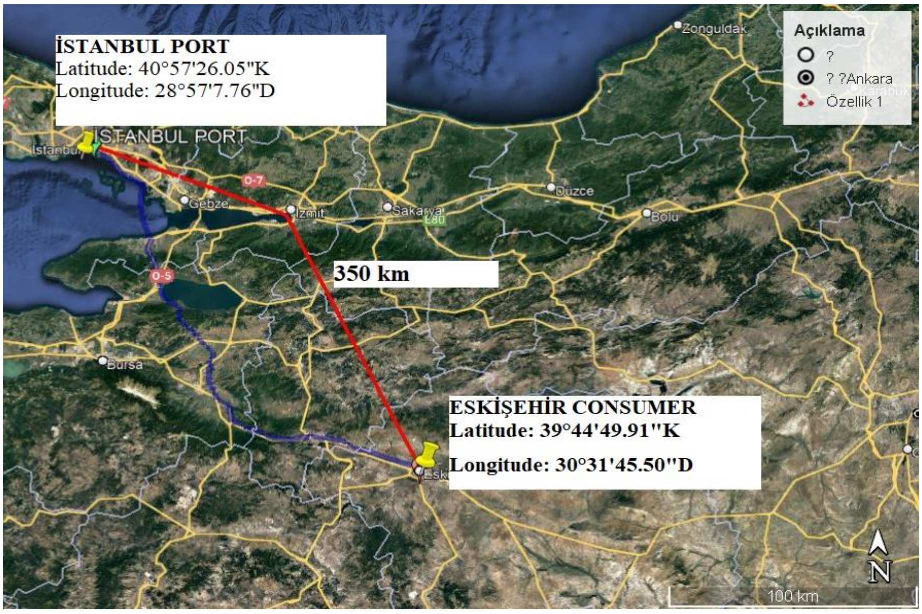

Figure 3.5. Truck transportation from İstanbul Port to Eskişehir consumer

If the production journey of textile which is supplied within Turkey is examined in more detail; southeastern part of Turkey is one of the most famous regions for the cotton production (Görmüş and Yücel, 2002; Yazar et al., 2002; Alganci et al., 2014). In this direction, cotton generally harvested in the Adana province of Turkey is then distributed by truck transportation from Adana to textile manufacturing facilities which are general located in Marmara region of Turkey such as İstanbul, Bursa, Lüleburgaz (Ozturk, 2005; Uludag et al., 2006; Alkaya and Demirer, 2015; Fidan et al., 2021). According to literature review, cotton is accepted commodity to be produced in Adana and it is accepted to be distributed by truck transportation to Bursa for textile manufacturing for this study. Finally, it is assumed that the textile products are transported from Bursa to the Eskişehir consumer by truck transportation. In this direction, truck transportations are calculated from Google Earth which are found as 800 km from Adana to Bursa, 200 km from Bursa to Eskişehir. Transportation network of the products 100% supplied from Turkey is given in following Table 3.6.

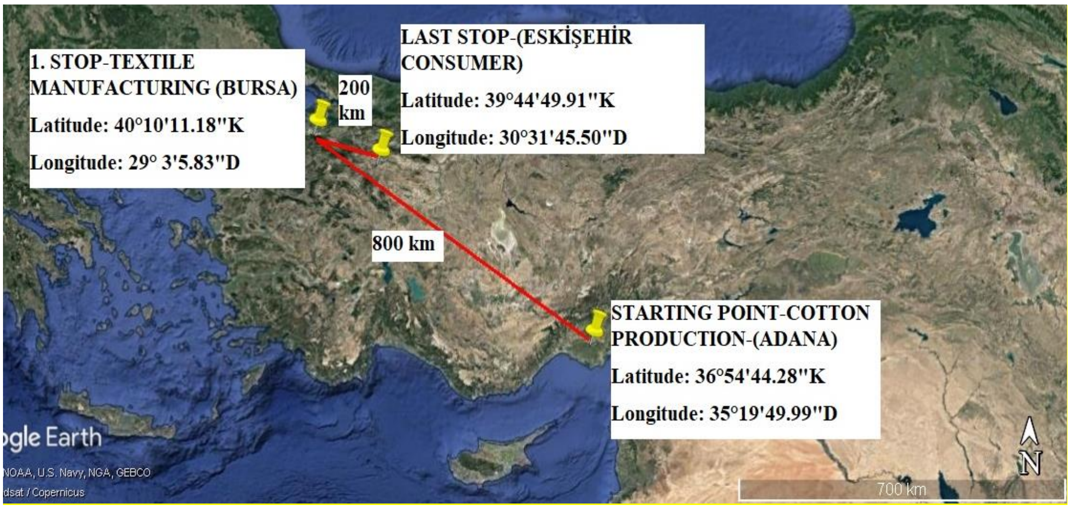

Figure 3.6. Truck transportation between Adana, Bursa and Eskişehir provinces

In this direction, current transportation networks of the products which are 50% produced in Turkey and 50% produced in China are calculated by taking half of the transportation network of China and Turkey. In this regard, the data related to distances and transportation modes for current textile supply chain of textile products offered to Eskişehir consumer is given in Table 3.10 below.

Table 3.10 Current textile supply chain of textile products offered to Eskişehir consumer

Transportation for 50% Produced in China 50%Produced in Turkey
Shipping From China to İstanbul Port: 8880 miles/2=4440 sea miles
Truck Transportation within China: 650 km/2=325 km
Truck Transporation from İstanbul Port to Eskişehir: 350 km/2= 175 km
Truck Transportation from Adana to Bursa: 800 km/2=400 km
Truck Transportation from Bursa to Eskişehir: 200/2= 100 km
Total Transportation: 4440 sea miles+1000 km truck transportation

3.7 Data Collection For Current Transportation Network of Landfilling, Reycling and Reusing in Eskişehir and the Supply Chain of Recycled Product to Eskişehir Consumer

To learn the distances and transportation modes of the current landfilling, recycling, and reusing transportation network of Eskişehir, an interview is conducted with the Environmental Management Department of the Eskişehir Municipality by obtaining the necessary permission given in Appendix A and the details of the interview given in Appendix B.

For landfilling: Environmental Management Department of the Eskişehir Municipality stated that the maximum distance from which the wastes are collected and brought to the Eskişehir 2nd Class sanitary landfill is 50 km.

For recycling: Environmental Management Department of the Eskişehir Municipality stated that, textile waste is collected from an area 50 km then it is transported to Bursa for sorting it according to fiber types and colors. Later, it is transported to Uşak for recycling it.

For reusing: Environmental Management Department of the Eskişehir Municipality stated that: there is no collection for a reusing system, but people can bring their belongings to the charity organizations of the municipalities.

In this direction, current transportation networks for landfilling are found as 50 km by truck as per the interview. Current transportation system for recycling is calculated as follows: Textile collection system in Eskişehir is taken as 50 km by truck as per the interview, Transportation for textile sorting from Eskişehir to Bursa calculated with Google Earth and found as 200 km. Transportation for textile recycling from Bursa to Uşak calculated with Google Earth and found as 450 km by truck. The distance and networks of current recycling system is given in following Figure 3.7. Since the reusing depends on the preferences of people, the distance to bring people's textile wastes from different parts of the cities to the charity organizations of municipalities is assumed to be the same as the textile collection distance in Eskişehir which is 50 km by passenger car. Furthermore, although the main purpose of this study is focused on recycling, reusing is also aimed to be examined just to show the changes in case of landfilled household textile waste would be sorted and directed to reusing which is also explained in the 2. specific objective of this study detailed in Section 3.1.

Figure 3.7. Transportation network for current recycling system with existing sorting and recycling facility

While evaluating the supply chain of recycled products, it is assumed that new recycled fibers are sent back to Bursa for recycled textile manufacturing. So, in case of evaluating current recycling network of Eskisehir, as recycling is conducted in Uşak, recycled fibers are sent from Uşak to Bursa for recycled product manufacturing which is 450 km as given in Figure 3.7. Later, finished recycled textile products are offered from Bursa to Eskişehir consumers which is 200 km as given in Figure 3.7. The reason to choose Bursa is that: Since Bursa is chosen as the textile manufacturing place in the textile supply chain of Turkey, the same location is chosen for the textile products produced from recycled fibers.

In this direction, the data related to transportation network for current landfilling, recycling and reusing system of Eskişehir and the supply chain of recycled product to the Eskişehir consumer is given in

Table 3.11 below.

Table 3.11 Transportation network data of current landfilling, recycling and reusing system of Eskişehir and the current supply chain of recycled product to Eskişehir consumer

Transportation for Landfilling in Eskişehir	Transportation for Current Recycling System of Eskişehir	Transportation for Reusing in Eskişehir
Waste Collection: 50 km	Household textile waste Collection in Eskişehir: 50 kgkm	Waste Collection: 50 km
Landfilling: 50 km	Textile Waste Sorting from Bursa to Eskişehir: 200 km	
	Textile Recycling from Bursa to Uşak 450 km	
	Recycled Product Supply to Eskişehir Consumer	
	Recycled Fiber From Uşak to Textile Manufacturing to Bursa: 450 km	
	Transportation from Bursa Manufacturing to Eskişehir Consumer: 200 km	
Total Truck Transportation Distance: 100 km	**Total Truck Transportation Distance: 1350 km**	**Total Passenger Car Transportation Distance: 50 km**

3.8 Data Collection for Changing Transportation Network of Recycling

To assess the different transportation options effects of recycling on the current situation, 50% recycling situation and whole recycling situation of the pure cotton household textile waste of Eskişehir, created new scenarios are as follows:

1) What would the new transportation network of recycling be, if a new sorting facility is built near the landfilling facility of Eskişehir: Textile collection is 50 km by truck. Transportation for textile sorting from Eskişehir-to-Eskişehir 2nd Class sanitary landfill is 50 km by truck. Transportation for textile recycling from Eskişehir to Uşak is 220 km. Transportation for recycled textile production from recycled fibers from Uşak to Bursa is 450 km. Lastly, transportation to offer the finished recycled textile products to Eskişehir consumers from Bursa to Eskişehir is 200 km. Transportation for recycling system with new sorting and existing recycling facility is given in Figure 3.8 below.

2) What would the new transportation network of recycling be, if a new sorting and recycling facility are both built near the landfilling facility of Eskişehir: Textile collection is 50 km by truck. Transportation for textile sorting and recycling from Eskişehir-to-Eskişehir 2nd Class sanitary landfill is 50 km by truck. Transportation for recycled textile production from recycled fibers from Eskişehir to Bursa is 200 km. Lastly, transportation to offer finished recycled textile products to Eskişehir consumers from Bursa to Eskişehir is 200 km. Transportation for recycling system with new sorting and new recycling facility is given in Figure 3.9 below.

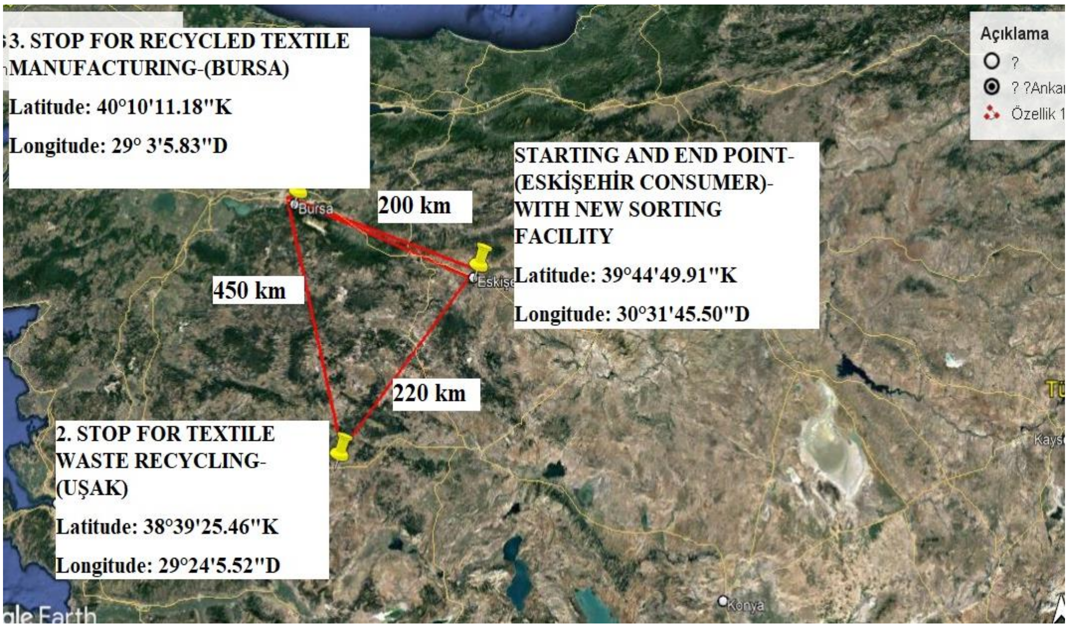

Figure 3.8. Transportation network for recycling system with new sorting and existing recycling facility

Figure 3.9. Transportation network for recycling system with new sorting and new recycling facility

CHAPTER 4

LCA SCENARIOS AND THEIR RESULTS

In this chapter, LCA scenarios and their results are given. In this direction, goal, and scope of the LCA study, LCA inventory of the processes which are prepared with the collected data, impact assessment result and their interpretations and lastly sensitivity analysis results and their interpretations are given.

4.1 Goal and Scope Definition of LCA

The goal of the LCA: The goal of the LCA study is to investigate the objectives of this study with their specific questions which are listed below. Details on how all these questions are created are given in Section 3.1 where the LCA roadmap is drawn.

1) *Assessing the environmental effects of landfilled pure cotton household textile waste of Eskişehir:* "What is the global warming potential and single score result of landfilled 4190 ton/year pure cotton textile waste of Eskişehir from the beginning of production to landfilling including recycling"?
2) *Assessing the 50% recycling, whole recycling and reusing effects on the pure cotton household textile waste of Eskişehir:* "What would the global warming potential and single score result changes be, if landfilled 4190 tons/year pure cotton household textile waste in Eskişehir would be sorted and directed to 50 % recycling, whole recycling or reusing"?
3) *Assessing the different transportation options effects of source materials on the current situation, on the 50% recycling situation and on the whole*

recycling situation of the pure cotton household textile waste of Eskişehir: "What would the global warming potential and single score result changes be on current situation, 50% recycling situation and whole recycling situation if the textile products are supplied from 100% China and 100% from Turkey"?

4) *Assessing the different transportation options effects of recycling on the current situation, 50% recycling situation and whole recycling situation of the pure cotton household textile waste of Eskişehir:* "What would the global warming potential and single score result changes be on current situation, 50% recycling situation and whole recycling situation if a new sorting facility and is built in Eskişehir and new sorting and recycling facility are both built in Eskişehir"?
5) *Assessing the recycling rates versus reduced truck transportation load effects on the pure cotton household textile waste of Eskişehir:* "What is the sensitivity of different recycling rates to truck transportation load of recycling"? "Is there any recycling rate that provide similar environmental benefits which can be obtained by reducing truck transportation load of recycling"?

Scenarios: Scenarios are created to prepare life cycle inventory processes to investigate the objectives of this study with their specific questions. In this direction created scenarios are given in Table 4.1 below with their color codes. With this color codes in mind, process inventories and results related with each scenarios are displayed with same colors in the rest of this study.

Table 4.1 Scenarios of the LCA study with their color codes

Scenarios with their numbers and explanations
Current Situation: 90% Landfilling, 10% Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 1 for the 1st Assessment: 50 % recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 2 for the 1st Assessment: Whole Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 3 for the 1st Assessment: Whole Reusing: Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 4 for the 2nd Assessment: 90% Landfilling, 10% Recycling Transportation of Source Material: 100% of textile products supplied from China Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 5 for the 2nd Assessment: 90% Landfilling, 10% Recycling Transportation of Source Material: 100% of textile products supplied from Turkey Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 6 for the 2nd Assessment: 50% Recycling Transportation of Source Material: 100% of textile products supplied from China Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 7 for the 2nd Assessment: 50% Recycling Transportation of Source Material: 100% of textile products supplied from Turkey Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 8 for the 2nd Assessment: Whole Recycling Transportation of Source Material: 100% of textile products supplied from China Transportation of Recycling: Based on existing sorting and recycling facility
Scenario 9 for the 2nd Assessment: Whole Recycling Transportation of Source Material: 100% of textile products supplied from Turkey Transportation of Recycling: Based on existing sorting and recycling facility

Table 4.1 (continued)

Scenario 10 for the 3rd Assessment: 90% Landfilling, 10% Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on new sorting and existing recycling facility
Scenario 11 for the 3rd Assessment: 90% Landfilling, 10% Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on new sorting and new recycling facility
Scenario 12 for the 3rd Assessment: 50% Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on new sorting and existing recycling facility
Scenario 13 for the 3rd Assessment: 50% Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on new sorting and new recycling facility
Scenario 14 for the 3rd Assessment: Whole Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on new sorting and existing recycling facility
Scenario 15 for the 3rd Assessment: Whole Recycling Transportation of Source Material: 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers. Transportation of Recycling: Based on new sorting and new recycling facility

Functional unit: The functional unit of this study is selected as 1 kilogram woven household textile waste made from pure cotton

LCA software and assessment method: LCA analysis is chosen to be performed by using SimaPro 9.1.0.8 faculty with the ReCiPe 2016 Midpoint and Hierarchist impact assessment method to assess global warming potential to compare the obtained landfilling of 1 kg pure household textile waste results with the literature, to be certain of the accuracy of the results, and to make comprehensive interpretation (Dong and Ng, 2014). Furthermore, to assess single score results in order to make conciseness comparison between the specific objective of this study as it gives a single holistic result by calculating different environmental impact categories. (Zamani et al., 2015; Sandin and Peters, 2018; Dong and Ng, 2014). In this regard, while examining the environmental benefits in terms of GWP and single score, higher environmental efficiency in terms of single score is expected (Dong and Ng, 2014; Huijbregts et al., 2017).

Single score result is expressed as the as the sum of the endpoint effects on human health, resources and ecosystem (Dong and Ng, 2014; Huijbregts et al., 2017). While calculating endpoint effects, environmental mechanism of each midpoint impact category on human health, ecosystem and resource scarcity are described in Table 2.2 belonging to Section 2.10.5. In this study, single score results are calculated by including 17 midpoint impact categories as it is offered by ReCiPe method as it is given in following Table 4.2. Although, the included 17 midpoint impact categories and their constant endpoint factors are provided in the following Table 4.2, it is recommended to examine the detailed calculations of each midpoint characterization factors from the ReCiPe 2016 Report (Huijbregts et al., 2017).

Table 4.2 Included midpoint impact categories and their endpoint factors for Hierarchist impact assessment (Modified from Huijbregts et al., 2016)

MIDPOINT TO ENDPOINT	UNIT OF MIDPOINT IMPACT CATEGORIES	Endpoint Factor for Hierarchist Impact Assessment
Human Health		
-Climate Change **Global Warming Potential	yr/kg CO_2 to air	9.3E-07
-Ozone Depletion Ozone Depletion Potential	yr/kg CFC11 to air	5.3E-04
-Ionizing Radiation Ionizing Radiation Potential	yr//kBq Co-60 to air	8.5E-09
-Fine Particulate Matter Formation Fine Particulate Matter Potential	yr/kg PM2.5 to air	6.3E-04
-Photochemical Ozone Formation Ozone Formation Potential: human health	yr/kg NOx to air	6.3E-04
-Cancer Toxicity Human Carcinogenic Toxicity Potential	yr/kg 1,4-DCB to air	6.3E-04
-Non-Cancer Toxicity Human Non-Carcinogenic Toxicity Potential	yr/kg 1,4-DCB to air	6.7E-09
-Water Use **Water Consumption Potential	yr/kg 1,4-DCB to air	2.2E-06
Ecosystem quality: terrestrial		
-Climate Change **Global Warming Potential	species.yr/kg CO_2 to air	2.8E-09
-Photochemical Ozone Formation Ozone Formation Potential: Terrestrial	species.yr/kg NOx to air	1.3E-07

Table 4.2 (continued)

-Acidification Terrestrial Acidification Potential	species.yr/kg SO2 to air	2.1E-07
-Toxicity Terrestrial Ecotoxicity Potential	species.yr/kg 1,4- DCB to industrial soil	5.4E-08
-Water Use **Water Consumption Potential	species.yr/m3 water consumed	5.4E-08
-Land Use Land use potential	species/m2 annual crop land	8.9E-09
Ecosystem quality: fresh water		
-Climate Change **Global Warming Potential	species.yr/kg CO_2	7.7E-14
Eutrophication Freshwater Eutrophication Potential	species.yr/kg P to fresh water	6.1E-07
Toxicity Freshwater Ecotoxicity Potential	species.yr/kg 1,4- DCB to fresh water	7.0E-10
Water Use **Water Consumption Potential	species.yr/kg 1,4- DCB to fresh water	6.0E-13
Ecosystem quality: marine		
Toxicity Marine Toxicity Potential	species.yr/kg 1,4- DCB	1.1E-10
Resource Scarcity		
Fossil Resources Fossil Resource Scarcity Potential	US2013 $/kg crude oil	0.46
Mineral Resource Scarcity Potential	US2013 $/kg Cu	0.23

**Have more than one endpoint effect

Impact Assessment Categories: Global warming potential which is a midpoint effect and single score result which is a total result of endpoint protection areas effects.

Data quality, data collection: Related literature, Ecoinvent database and conducted interviews.

The scope of the LCA study: Disregarding consumer using stage, the entire life cycle of 1-kilogram woven household textile waste made from pure cotton for landfilling, recycling and reusing. System boundaries are given in Table 4.3 below.

Table 4.3 System boundaries of the LCA study

Entire Life Cycle of Landfilled Textile Waste	Entire Life Cycle of Recycling	Entire Life Cycle of Reusing
Transportation of Source Material	Transportation For Recycling	Transportation For Reusing
Textile Production Steps	Recycling (Cutting and Shredding)	Reusing (Make-Up Process)
Transportation To Eskişehir Consumer	Transportation For Recycled Textile Production	10% Landfilling Rate
Transportation For Landfilling	Recycled Textile Production Steps	
Landfilling	Transportation to Eskişehir Consumer	
	10% Landfilling Rate	
Using Stage Is Excluded		

4.1.1 Acceptances and Assumptions

The explanations of the acceptances and assumptions made in this study are given in Table 4.4 below. Each one is referenced based on previous LCA studies focusing on textile waste.

Table 4.4 Acceptances and assumptions of this study

It is assumed that 10% of 4190 ton/year landfilled pure cotton household textile waste of Eskişehir is considered to be recycled based on the Turkish conditions which is detailed with the references in the Section 3.3.
The supply chain of textile products and their transportation distances and modes assumed from related literature which is detailed with the references in the Section 3.6.
Different dyes and different chemicals can be used in each cotton textile products. However, as such details can complicate system boundaries while evaluation entire life cycle of textile waste can increase the error rate of the LCA. So, the consumptions are accepted to be same as 1 kg of woven cotton fabric production data as the consumptions of woven fabric do not differ. So that textile type did not specified as “a t-shirt”, “a dress”, or “jeans” etc. Similar studies conducted with the same acceptance taken as references (Schmidt et al., 2016; Koligkioni et al., 2018; Dahlbo et al., 2017). The detailed literature review given in the Section 2.8.
While evaluating the supply chain of recycled products, it is assumed that new recycled fibers which is detailed in the Section 3.8 are sent back to Bursa for recycled textile manufacturing. Later, finished recycled textile products are sent from Bursa to Eskişehir consumer. The reason to choose Bursa is that: Since Bursa is chosen as the textile manufacturing place in the supply chain of Turkey, the same location is chosen for the textile products produced from recycled fibers.
The life span of the recycling has been accepted as 10 times by considering the 10% landfilling rate in each recycling (Sandin and Peters, 2018; Schmidt et al., 2016). The same rate is used for reusing (Sandin and Peters, 2018). Landfilling rate are considered while creating recycling and reusing processes in the Life Cyle Inventory study of the processes.

4.2 Life Cycle Inventory of the Scenarios

In this section LCA inventory of the processes are prepared separately for the created scenarios to investigate the objectives of this study with their specific questions. Process inventories can be followed by scenario numbers and color codes as it is explained in Table 4.1. All processes are prepared with the collected data and all recycling and reusing processes including 10% landfilling rate.

4.2.1 Current Situation of Pure Cotton Household Textile Waste of Eskişehir

The inventory for current situation of pure cotton household textile waste of Eskişehir including the processes from beginning of the production to landfilling with 10 % recycling rate given in the following Table 4.5. This inventory is prepared for the 1st goal of LCA study given below.

Current Situation: 90% Landfilling, 10% Recycling, 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers, recycling is conducted based on existing sorting and recycling facility.

Table 4.5 The inventory of the processes for current situation from the beginning of the production including 10 % loss rate (Current Situation)

CURRENT SITUATION -90% Landfilling, 10% Recycling -Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers -Transportation Of Recycling: Based on Existing Sorting and Recycling Facility
1-Landfilling Processes - 50 % Produced in China 50%Produced in Turkey
*0.9 x Transportation for 50% Produced in China 50%Produced in Turkey
0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)
*0.9 x Transportation for Landfilling in Eskişehir
0.9 x Landfilling
2-Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility
*0.09 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain **(1350 kgkmx 0.09 = 121.5 kgkm)**
0.09 x Recycling (Cutting and Shredding)
0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.01 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey

* Transportation is calculated by including loads.

4.2.2 50% Recycling of Pure Cotton Household Textile Waste of Eskişehir (Scenario 1)

The inventory for the 50% recycling situation of pure cotton household textile waste of Eskişehir including 10% landfilling rate is given in following Table 4.6. In 50% recycling rate, 50% of environmental effects arise from production to landfilling stages and the rest of 50% are caused by recycling stages. This inventory is prepared for the 2nd goal of LCA study based on the created Scenario 2 given below.

Scenario 1: 50 % recycling, 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers, recycling is conducted based on existing sorting and recycling facility.

Table 4.6 The inventory of the processes for 50% recycling situation including 10 % landfilling loss rate (Scenario 1)

SCENARIO 1 -50 % recycling -Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers -Transportation Of Recycling: Based on Existing Sorting and Recycling Facility
1-Recycling Processes with 10%Landfilling Loss-Based on Existing Sorting and Recycling Facility
*0.45 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain
0.45 x Recycling (Cutting and Shredding)
0.45 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
0.05 x Landfilling Processes - 50 % Produced in China 50%Produced in Turkey
2-Landfilling Processes - 50 % Produced in China 50%Produced in Turkey
*0.5 x Transportation for 50% Produced in China 50%Produced in Turkey
0.5 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)
*0.5 x Landfilling and Landfilling Transportation

* Transportation is calculated by including loads.

4.2.3 Whole Recycling of Pure Cotton Household Textile Waste of Eskişehir (Scenario 2)

The inventory for the entire recycling processes of pure cotton household textile waste of Eskişehir including 10% landfilling rate is given in the following Table 4.7. This inventory is prepared for the 2nd goal of LCA study based on the created Scenario 2 given below.

Scenaro 2: Whole recycling, 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers, recycling is conducted is based on existing sorting and recycling facility.

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Table 4.7 The inventory of the processes for whole recycling situation including 10% landfilling loss rate (Scenario 2)

SCENARIO 2 -Whole recycling -Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers -Transportation Of Recycling: Based on Existing Sorting and Recycling Facility
1-Whole Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility
*0.9 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain
0.9 x Recycling (Cutting and Shredding)
0.9 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.1 x Landfilling Processes - 50 % Produced in China 50%Produced in Turkey

* Transportation is calculated by including loads.

4.2.4 Reusing of Pure Cotton Household Textile Waste of Eskişehir (Scenario 3)

The inventory for reusing processes of pure cotton household textile waste of Eskişehir including 10% landfilling rate is given in the following Table 4.8. This inventory is prepared for the 2nd goal of LCA study based on the created Scenario 3 given below.

Scenario 3: Whole reusing, 50% of textile products supplied from China and 50 % supplied from Turkey to Eskişehir consumers, reusing is conducted is based on existing sorting and recycling facility.

Table 4.8 The inventory of the processes for whole reusing including 10 % landfilling loss rate (Scenario 3)

SCENARIO 3 -Whole Reusing -Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. -Transportation of Recycling: Based on Existing Sorting and Recycling Facility
1-Whole Reusing Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility
*0.9 x Transportation for Reusing in Eskişehir
0.9 x Reusing (Make-Up Process)
*0.1 x Landfilling Processes - 50 % Produced in China 50%Produced in Turkey

* Transportation is calculated by including loads.

4.2.5 Different Transportation Options of the Source Material for the Current Situation, 50% Recycling Situation and Whole Recycling Situation (Scenarios 4, 5, 6, 7, 8, 9)

To prepare the inventory for recycling processes of pure cotton household textile waste of Eskişehir including 10% landfilling rate for different textile supply chain options, firstly the transportation distances and modes of the different textile supply chain options should be given. Different supply chain options and inventories are prepared based on created scenarios given below to assess the 3rd goal of LCA study.

Scenario 4: Current Situation- 100% of textile products supplied from China.
Scenario 5: Current Situation - 100% of textile products supplied from Turkey
Scenario 6: 50% Recycling- 100% of textile products supplied from China
Scenario 7: 50% Recycling- 100% of textile products supplied from Turkey
Scenario 8: Whole Recycling- 100% of textile products supplied from China
Scenario 9: Whole Recycling- 100% of textile products supplied from Turkey

In this direction, current transportation networks of the products which are 50% produced in Turkey and 50% produced in China are calculated by taking half of the transportation network of China and Turkey which is given in Table 3.10 belong to Section 3.6. The transportation networks for other supply chain options which are 100 % supplied from China and 100% supplied from Turkey are given in following Table 4.9.

Table 4.9 Transportation network data of textile supply chain options

Transportation for 100% Produced in China	**Transportation for 100% Produced in Turkey**	**(Current Transportation Network) Transportation for 50% Produced in China 50%Produced in Turkey**
Shipping From China to İstanbul Port: 8880 miles	Truck Transportation from Adana to Bursa: 800 km	Shipping From China to İstanbul Port: 8880 miles/2=4440 sea miles
Truck Transportation within China: 650 km	Truck Transportation from Bursa to Eskişehir: 200 km	Truck Transportation within China: 770 km/2=385 km
Truck Transporation from İstanbul Port to Eskişehir: 350 km		Truck Transporation from İstanbul Port to Eskişehir: 350 km/2= 175 km
		Truck Transportation from Adana to Bursa: 820 km/2=410 km
		Truck Transportation from Bursa to Eskişehir: 300/2= 150 kgkm
Total Transportation: 8,880 sea kgmiles+1,000 km truck transportation	**Total Transportation: 1,000 km truck transportation**	**Total Transportation: 4,440 sea miles+1,000 km truck transportation**

The inventories of the current situation with different supply chain options including 10% landfilling rate are given in following Table 4.10. The lines given as colorless are the steps where the different transportation options are applied.

Table 4.10 The inventory of the current situation processes for different supply chain options (Scenarios 4,5)

SCENARIO 4 -90% Landfilling, 10% Recycling **-Transportation of Source Material: 100% of Textile Products Supplied from China** -Transportation of Recycling: Based on Existing Sorting and Recycling Facility	SCENARIO 5 -90% Landfilling, 10% Recycling **-Transportation of Source Material: 100% of textile products supplied from Turkey** -Transportation of Recycling: Based on Existing Sorting and Recycling Facility
1-Landfilling Processes – 100 % Produced in China	**1-Landfilling Processes – 100 % Produced in Turkey**
*0.9 x Transportation for 100 % Produced in China	*0.9 x Transportation for 100 % Produced in Turkey
0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)	0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)
*0.9 x Transportation for Landfilling in Eskişehir	*0.9 x Transportation for Landfilling in Eskişehir
0.9 x Landfilling	0.9 x Landfilling
2-Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility	**2-Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility**
*0.09 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain	*0.09 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain
0.09 x Recycling (Cutting and Shredding)	0.09 x Recycling (Cutting and Shredding)
0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)	0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.01 x Landfilling Processes- 100 % Produced in China	*0.01 x Landfilling Processes- 100 % Produced in Turkey

* Transportation is calculated by including loads.

The inventories of the 50% recycling situation with different supply chain options including 10% landfilling rate are given in following Table 4.11. The lines given as colorless are the steps where the different transportation options are applied.

Table 4.11 The inventory of the 50% recycling situation processes for different supply chain options (Scenarios 6,7)

SCENARIO 6 -50 % recycling **-Transportation of Source Material: 100% of Textile Products Supplied from China** -Transportation of Recycling: Based on Existing Sorting and Recycling Facility	**SCENARIO 7** -50 % recycling **-Transportation of Source Material: 100% of Textile Products Supplied from Turkey** -Transportation of Recycling: Based on Existing Sorting and Recycling Facility
1-Recycling Processes with 10% Landfilling Loss-Based on Existing Sorting and Recycling Facility	**1-Recycling Processes with 10%Landfilling Loss-Based on Existing Sorting and Recycling Facility**
*0.45 x Transportation for Current Recycling System in Eskişehir	*0.45 x Transportation for Current Recycling System in Eskişehir
0.45 x Recycling (Cutting and Shredding)	0.45 x Recycling (Cutting and Shredding)
0.45 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)	0.45 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.05 x Landfilling Processes – 100 % Produced in China	*0.05 x Landfilling Processes – 100 % Produced in Turkey
2-Landfilling Processes – 100%Produced in China	**2-Landfilling Processes – 100 % Produced in Turkey**
*0.5 x Transportation for 100 % Produced in China	*0.5 x Transportation for 100 % Produced in Turkey
0.5 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)	0.5 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)
*0.5 x Landfilling and Landfilling Transportation	*0.5 x Landfilling and Landfilling Transportation

* Transportation is calculated by including loads.

The inventories of the whole recycling situation with different supply chain options including 10% landfilling rate are given in following Table 4.12. The lines given as colorless are the steps where the different transportation options are applied.

Table 4.12 The inventory of the whole recycling situations processes for different supply chain options (Scenarios 8,9)

SCENARIO 8 -Whole recycling **-Transportation of Source Material: 100% of Textile Products Supplied from China** -Transportation of Recycling: Based on Existing Sorting and Recycling Facility	**SCENARIO 9** -Whole recycling **-Transportation of Source Material: 100% of textile products supplied from Turkey** -Transportation of Recycling: Based on Existing Sorting and Recycling Facility
1-Whole Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility	**1-Whole Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility**
*0.9 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain	*0.9 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain
0.9 x Recycling (Cutting and Shredding)	0.9 x Recycling (Cutting and Shredding)
0.9 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)	0.9 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.1 x Landfilling Processes – 1000 % Produced in China	*0.1 x Landfilling Processes – 1000 % Produced in Turkey

* Transportation is calculated by including loads.

4.2.6 Different Transportation Options of the Recycling for the Current Situation, 50% Recycling Situation and Whole Recycling Siutation (Scenarios 10, 11, 12, 13, 14, 15)

To prepare the inventory for recycling processes of pure cotton household textile waste of Eskişehir including 10% landfilling rate for different transportation options of recycling, firstly the transportation distances and modes of the different recycling options should be given. Different transportation options and inventories are prepared based on created scenarios given below to assess the 4^{4h} goal of LCA study.

Scenario 10: Current Situation- Based on new sorting and existing recycling facility
Scenario 11: Current Situation - Based on new sorting and new recycling facility
Scenario 12: 50% Recycling- Based on new sorting and existing recycling facility
Scenario 13: 50% Recycling- Based on new sorting and new recycling facility
Scenario 14: Whole Recycling- Based on new sorting and existing recycling facility
Scenario 15: Whole Recycling- Based on new sorting and new recycling facility

In this direction, current transportation mode and distance of recycling with existing sorting and recycling facility is 1350 km by truck which is detailed in Section 3.7. If a new sorting facility is built near the landfilling facility of Eskişehir the transportation distance for the recycling system would be 970 km which is detailed in Section 3.8. If a new sorting and recycling facility are both built near the landfilling facility of Eskişehir, the transportation would be 500 km. In this direction firstly the data related to distances and transportation modes for current and new recycling system of Eskişehir is given in Table 4.13 below.

Table 4.13 Transportation network data of current and new recycling system of Eskişehir and the current and new supply chain of recycled product to Eskişehir consumer

Transportation for Current Recycling System in Eskişehir	**New Truck Transportation via Changing Sorting Facility**	**New Truck Transportation via Changing Sorting and Recycling Facility**
Pure Cotton Household Textile Waste Collection in Eskişehir: 50 km	Pure Cotton Household Textile Waste Collection in Eskişehir: 50 km	Pure Cotton Household Textile Waste Collection in Eskişehir: 50 km
Textile Waste Sorting from Bursa to Eskişehir: 200 km	Textile Waste Sorting in Eskişehir Landilling Facility: 50 km	Textile Waste Sorting and Recycling in Eskişehir Landilling Facility: 50 km
Textile Recycling from Bursa to Uşak 450 km	Textile Recycling from Eskişehir to Uşak 220 km	Recycled Fiber from Eskişehir to Bursa for Textile Manufacturing: 200 km
Recycled Product Supply to Eskişehir Consumer	Recycled Product Supply to Eskişehir Consumer	Recycled Product Supply to Eskişehir Consumer
Recycled Fiber from Uşak to Textile Manufacturing to Bursa: 450 km	Recycled Fiber from Uşak to Textile Manufacturing to Bursa: 450 km	Transportation from Bursa Manufacturing to Eskişehir Consumer: 200 km
Transportation from Bursa Manufacturing to Eskişehir Consumer: 200 km	Transportation from Bursa Manufacturing to Eskişehir Consumer: 200 km	
Total Transportation: 1,350 km truck transportation	**Total Transportation: 970 km truck transportation**	**Total Transportation: 500 km truck transportation**

The inventories of the current situation with new sorting facility and new sorting and recycling facility options including 10% landfilling rate are given in following Table 4.14. The lines given as colorless are the steps where the different transportation options are applied.

Table 4.14 The inventory of the current situation processes for different recycling transportation options (Scenarios 10 and 11)

SCENARIO 10	**SCENARIO 11**
-90% Landfilling, 10% Recycling - Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. **-Transportation of Recycling: Based on New Sorting and Existing Recycling Facility**	-90% Landfilling, 10% Recycling - Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. **-Transportation of Recycling: Based on New Sorting and New Recycling Facility**
1-Landfilling Processes - 50 % Produced in China 50%Produced in Turkey	**1-Landfilling Processes - 50 % Produced in China 50%Produced in Turkey**
*0.9 x Transportation for 50% Produced in China 50%Produced in Turkey	*0.9 x Transportation for 50% Produced in China 50%Produced in Turkey
0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)	0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)
*0.9 x Transportation for Landfilling in Eskişehir	*0.9 x Transportation for Landfilling in Eskişehir
0.9 x Landfilling	0.9 x Landfilling
2-Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility	**2-Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility**
*0.09 x Transportation for Recycling Based on New Sorting and Existing Recycling Facility **(970 kgkmx 0.09 = 87.3 kgkm)**	*0.09 x Transportation for Recycling Based on New Sorting and New Recycling Facility **(500 kgkmx 0.09 = 45 kgkm)**
0.09 x Recycling (Cutting and Shredding)	0.09 x Recycling (Cutting and Shredding)
0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)	0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.01 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey	*0.01 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey

* Transportation is calculated by including loads.

The inventories of the 50% recycling situation with new sorting facility and new sorting and recycling facility options including 10% landfilling rate are given in following Table 4.15. The lines given as colorless are the steps where the different transportation options are applied.

Table 4.15 The inventory of the 50% recycling situations processes for different recycling transportation options (Scenarios 12 and 13)

SCENARIO 12	SCENARIO 13
-50 % recycling -Transportation of Source Material: 50% of Textile Products supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. **-Transportation of Recycling: Based on New Sorting and Existing Recycling Facility**	-50 % recycling - Transportation of Source Material: 50% of Textile Products Supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. **-Transportation of Recycling: Based on New Sorting and New Recycling Facility**
1-Recycling Processes with 10% Landfilling Loss-Based on New Sorting and Existing Recycling Facility	**1-Recycling Processes with 10% Landfilling Loss-Based on New Sorting and New Recycling Facility**
*0.45 x Transportation for Recycling Based on New Sorting and Existing Recycling Facility **(970 kgkmx 0.45 = 436.5 kgkm)**	*0.45 x Transportation for Recycling Based on New Sorting and New Recycling Facility **(500 kgkmx 0.45 = 225 kgkm)**
0.45 x Recycling (Cutting and Shredding)	0.45 x Recycling (Cutting and Shredding)
0.45 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)	0.45 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.05 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey	*0.05 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey
2- Landfilling Processes- 50 % Produced in China 50%Produced in Turkey	**2-Landfilling Processes- 50 % Produced in China 50%Produced in Turkey**
*0.5 x Transportation for 50% Produced in China 50%Produced in Turkey	*0.5 x Transportation for 50% Produced in China 50%Produced in Turkey
0.5 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)	0.5 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)
*0.5 x Landfilling and Landfilling Transportation	*0.5 x Landfilling and Landfilling Transportation

* Transportation is calculated by including loads.

The inventories of the whole recycling situation with new sorting facility and new sorting and recycling facility options including 10% landfilling rate are given in following Table 4.18. The lines given as colorless are the steps where the different transportation options are applied.

Table 4.16 The inventory of the whole recycling situation processes for different recycling transportation options (Scenarios 14 and 15)

<u>**SCENARIO 14**</u> -Whole recycling -Transportation of Source Material: 50% of Textile Products supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. **-Transportation of Recycling: Based on New Sorting and Existing Recycling Facility**	<u>**SCENARIO 15**</u> -Whole recycling -Transportation of Source Material: 50% of Textile Products supplied from China and 50 % Supplied from Turkey to Eskişehir Consumers. **-Transportation of Recycling: Based on New Sorting and New Recycling Facility**
1-Whole Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility	**1- Whole Recycling Processes with 10% Landfilling Loss- Based on Existing Sorting and Recycling Facility**
*0.9 x Transportation for Recycling Based on New Sorting and Existing Recycling Facility with Recycled Product Transportation Supply Chain **(970 kgkmx 0.9 = 873 kgkm)**	*0.9 x Transportation for Recycling Based on New Sorting and New Recycling Facility with Recycled Product Transportation Supply Chain **(500 kgkmx 0.9 = 450 kgkm)**
0.9 x Recycling (Cutting and Shredding)	0.9 x Recycling (Cutting and Shredding)
0.9 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)	0.9 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)
*0.1 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey	*0.1 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey

*Transportation is calculated by including loads.

4.2.7 Different Recycling Ratios for Current Situation and Scenario 10

In this section, sensitivity analysis processes are prepared to assess the 5th goal of LCA study. To this aim, the recycling ratios are increased both over the current situation conditions and over the new sorting facility situation which is replaced with existing sorting facility on the current situation conditions (Scenario 10). In this direction, sensitivity analysis is conducted with 15 different recycling ratios. The combination of landfilling and recycling rates applied while increasing the recycling ratios are given in following Table 4.17.

Table 4.17. Combination of applied recycling and landfilling rates for sensitivity analysis

Combination of Applied Recycling and Landfilling Rates			
1	12 % Recycling / 88 % Landfilling	9	45 % Recycling / 55 % Landfilling
2	14 % Recycling / 86 % Landfilling	10	50 % Recycling / 50 % Landfilling
3	20 % Recycling / 80 % Landfilling	11	55 % Recycling / 45 % Landfilling
4	22 % Recycling / 78 % Landfilling	12	60 % Recycling / 40 % Landfilling
5	24 % Recycling / 76 Landfilling	13	65 % Recycling / 35 % Landfilling
6	29 % Recycling, 71 % Landfilling	14	70 % Recycling / 30 % Landfilling
7	35 % Recycling, 65 % Landfilling	15	Whole Recycling
8	40 % Recycling, 60 % Landfilling		

The inventories for the current situation and Scenario 10 with 15 different recycling and landfilling rates combination including 10% landfilling loss are given in following Table 4.18. The lines given as colorless are the steps where the different transportation options are applied. The lines given in black show the ratios applied to the landfilling and recycling processes respectively. The sum of the landfilling, recycling and 10% loss ratios applied in each combination are equivalent to 1 kg of pure cotton household textile waste.

Table 4.18 The inventory of current situation and of the Scenario 10 processes for 15 different recycling and landfilling rates combination

<table>
<tr><td colspan="4"><u>CURRENT SITUATION</u>
-90% Landfilling, 10% Recycling
- Based on Existing Sorting and Recycling Facility</td><td colspan="4"><u>SCENARIO 10</u>
-90% Landfilling, 10% Recycling
-Transportation of Recycling: Based on New Sorting and Existing Recycling Facility</td></tr>
<tr><td colspan="8">Landfilling Ratios</td></tr>
<tr><td>[1]0.88</td><td>[2]0.86</td><td>[3]0.80</td><td>[4]0.78</td><td>[5]0.74</td><td>[6]0.71</td><td>[7]0.65</td><td>[8]0.60</td></tr>
<tr><td>[9]0.55</td><td>[10]0.50</td><td>[11]0. 45</td><td>[12]0.40</td><td>[13]0. 35</td><td>[14]0.30</td><td>[15]0</td></tr>
<tr><td colspan="4">*0.9 x Transportation for 50% Produced in China 50%Produced in Turkey</td><td colspan="4">*0.9 x Transportation for 50% Produced in China 50%Produced in Turkey</td></tr>
<tr><td colspan="4">0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)</td><td colspan="4">0.9 x Production of Textile (Step 1 + Step 2 + Step 3 + Step 4 + Step 5 + Step 6)</td></tr>
<tr><td colspan="4">*0.9 x Landfilling and Landfilling Transportation in Eskişehir</td><td colspan="4">*0.9 x Landfilling and Landfilling Transportation in Eskişehir</td></tr>
<tr><td colspan="8">Recycling Ratios</td></tr>
<tr><td>[1]0.108</td><td>[2]1.126</td><td>[3]0.18</td><td>[4]0.198</td><td>[5]0.234</td><td>[6]0.261</td><td>[7]0.315</td><td>[8]0.36</td></tr>
<tr><td>[9]0.405</td><td>[10]0.45</td><td>[11]0.495</td><td>[12]0.54</td><td>[13]0.585</td><td>[14]0.63</td><td>[15]0.9</td></tr>
<tr><td colspan="4">*0.09 x Transportation for Current Recycling System in Eskişehir with Recycled Product Transportation Supply Chain</td><td colspan="4">*0.09 x Transportation for Recycling Based on New Sorting and Existing Recycling Facility</td></tr>
<tr><td colspan="4">0.09 x Recycling (Cutting and Shredding)</td><td colspan="4">0.09 x Recycling (Cutting and Shredding)</td></tr>
<tr><td colspan="4">0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)</td><td colspan="4">0.09 x Production of Textile (Step 3 + Step 4 + Step 5 + Step 6)</td></tr>
<tr><td colspan="8">Landfilling Loss Ratios</td></tr>
<tr><td>[1]0.012</td><td>[2]0.014</td><td>[3]0.02</td><td>[4]0.022</td><td>[5]0.024</td><td>[6]0.029</td><td>[7]0.035</td><td>[8]0.04</td></tr>
<tr><td>[9]0.045</td><td>[10]0.05</td><td>[11]0.055</td><td>[12]0.060</td><td>[13]0.065</td><td>[14]0.07</td><td>[15]0.1</td></tr>
<tr><td colspan="4">*0.01 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey</td><td colspan="4">*0.01 x Landfilling Processes- 50 % Produced in China 50%Produced in Turkey</td></tr>
</table>

*Transportation is calculated by including loads. The numbers shown above the ratios represent combination numbers.

4.3 Life Cycle Impact Assessment Results and Interpretations for the 1st and 2nd Assessment

In this part of the study current situation, 50% recycling, whole recycling and reusing results are presented and their interpretations are conducted for the first and second assessment of this study given below.

1) *Assessing the environmental effects of landfilled pure cotton household textile waste of Eskişehir:* "What is the global warming potential and single score result of landfilled 4190 ton/year pure cotton textile waste of Eskişehir from the beginning of production to landfilling including recycling"?
2) *Assessing the 50% recycling, whole recycling and reusing effects on the pure cotton household textile waste of Eskişehir:* "What would the global warming potential and single score result changes be, if landfilled 4190 tons/year pure cotton household textile waste in Eskişehir would be sorted and directed to 50 % recycling, whole recycling or reusing"?

In this direction, GWP effects for the current situation, 50% recycling, whole recycling and whole reusing created based on the current situation, scenarios 1,2 and 3 are given the following Figure 4.1. Results can be followed by scenario numbers and color codes as it is explained in Table 4.1.

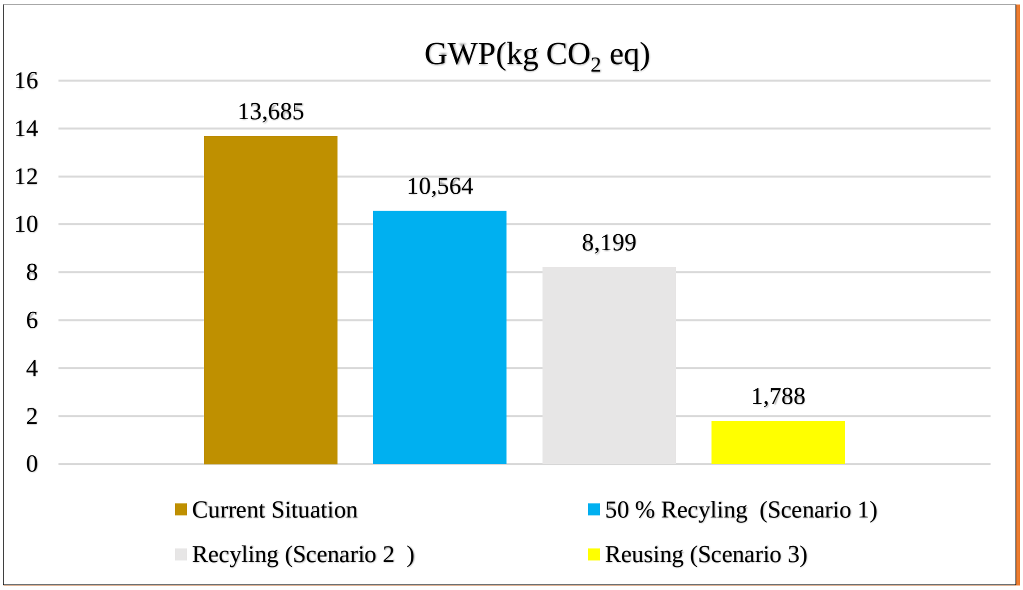

Figure 4.1. GWP effects of current situation, 50% recycling situation, whole recycling situation and whole reusing situation

Single score effects for the current situation, 50% recycling, whole recycling and whole reusing created based on based on the current situation, scenarios 1,2 and 3 are given the following Figure 4.2. Results can be followed by scenario numbers and color codes as it is explained in Table 4.1.

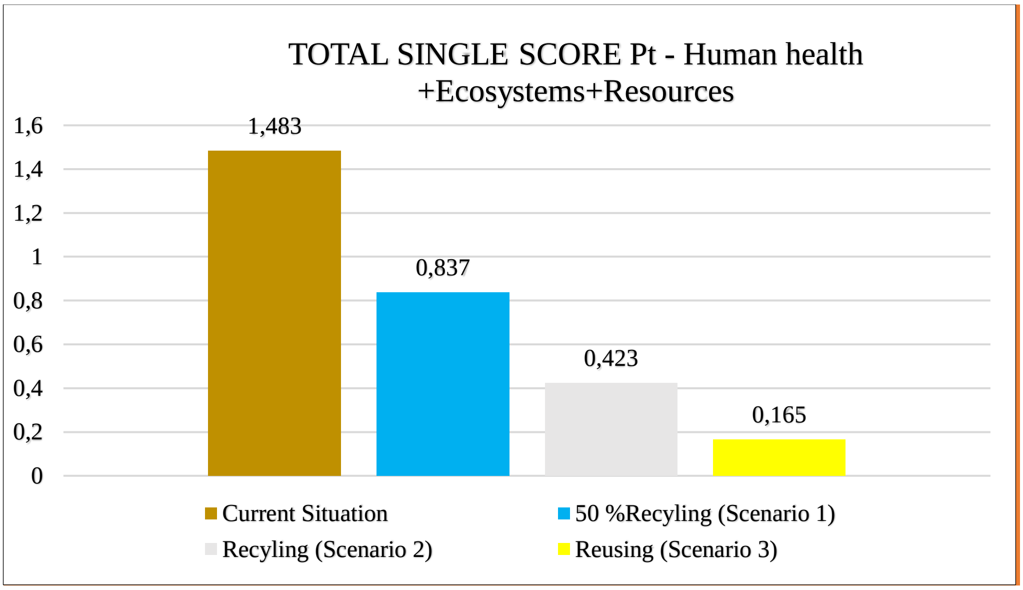

Figure 4.2. Single score effects of current situation, 50% recycling situation, whole recycling situation and whole reusing situation

Interpretation: As it mentioned in the goal and scope definition part, firstly, it was aimed to make the comparison of GWP results for the landfilling of 1 kg pure cotton household textile waste of Eskişehir with the literature. So, according to the results, the GWP of landfilled 1 kg pure cotton textile waste in Eskişehir was calculated to be 13.685 CO_2eq from the beginning of the production to landfilling including 10% recycling rate which can be seen from the Figure 4.1. In this direction GWP of landfilled 1 kg cotton textile waste have been found between 9-15 kg CO_2 in the previous studies conducted with the same scope (Muthu, 2015). Indeed, the obtained results in this study are consistent with the literature. Since the other objectives of this study are specific for Eskişehir, the general results are compared with the literature.

GWP: According to the results given in Figure 4.1, the GWP of current situation for the 1 kg pure cotton household textile waste in Eskişehir was calculated to be 13.7 kg CO_2eq from the beginning of production to landfilling including 10% recycling calculated with the collected data. In case of 50 % recycling of landfilled 4190 tons/year pure cotton household textile waste in Eskişehir, 22.80% CO_2eq emission reduction could be achieved. In case of whole recycling 40.08% CO_2eq emission reduction could be achieved and lastly in case of reusing 86.93% CO_2eq emission reduction could be achieved. The reason to obtain more reduction in reusing is caused as it avoids more textile production stages, as it avoids the transportation impacts caused from the textile supply chain and as it avoids the landfilling process which can be seen in detail given in the inventory of the reusing process in Section 4.2.4. Similar reductions were also obtained in the previous studies (Semba et al., 2020). When the whole recycling and 50% recycling is compared, more environmental benefits were obtained in the whole recycling case which is an expected result (Moazzem et al., 2021b). The reason can be interpreted as follows; When whole recycling is possible; the environmental effects are just arising from the entire life cycle of recycling process by avoiding 1st and 2nd production steps of textile production, by reducing the impact of transportation caused from textile supply chain as recycling transportation has less distance and as it avoids the landfilling (Detailed process inventory given in the Table 4.7). In 50% recycling rate, 50% of environmental effects arise from the entire life cycle of recycling stages and the rest of 50% are caused by landfilling of textile waste from production to landfilling. (Detailed process inventory given in Table 4.6). For this reason, 50% recycling rate has more GWP potential.

Single Score: According to the results given in the Figure 4.2, the single score of landfilled 1 kg pure cotton household textile waste in Eskişehir was calculated to be 1.483 Pt which is: damage to human health + damage to ecocsystem + damage to resources (Lamnatou et al., 2018). In case of 50% recycling of landfilled 4190 tons/year pure cotton household textile waste in Eskişehir, 43.56% Pt reduction could be achieved. In case of whole recycling 71.47% Pt reduction could be achieved and lastly in case of reusing 88.87% Pt reduction could be achieved. The decreases on the single score results are more than the GWP results. The reason to obtain more reductions in the single score results compared to GWP is as the occupation of land, water consumption, chemical consumption, energy consumption, emission to air and water and transportation network belonging to each process are causing not only the GWP but also causing different potential impacts. When different pathways of those impacts have been considered, the environmental benefits obtained by reusing and recycling is increasing which is an expected situation.

4.4 Life Cycle Impact Assessment Results and Interpretations for the 3rd Assessment

In this part of the study the effects of different transportation options of source materials on the current situation, on the 50% recycling situation and on the whole recycling situation are presented and their interpretations are conducted for the third assessment of this study given below.

3) *Assessing the different transportation options effects of source materials on the current situation, on the 50% recycling situation and on the whole recycling situation of the pure cotton household textile waste of Eskişehir:* "What would the global warming potential and single score result changes be on current situation, 50% recycling situation and whole recycling situation if the textile products are supplied from 100% China and 100% from Turkey"?

In this direction, GWP effects of the different textile supply chain options created based on the Scenarios 4, 5, 6 7, 8, and 9 are given the following Figure 4.3. Results can be followed by scenario numbers and color codes as it is explained in Table 4.1.

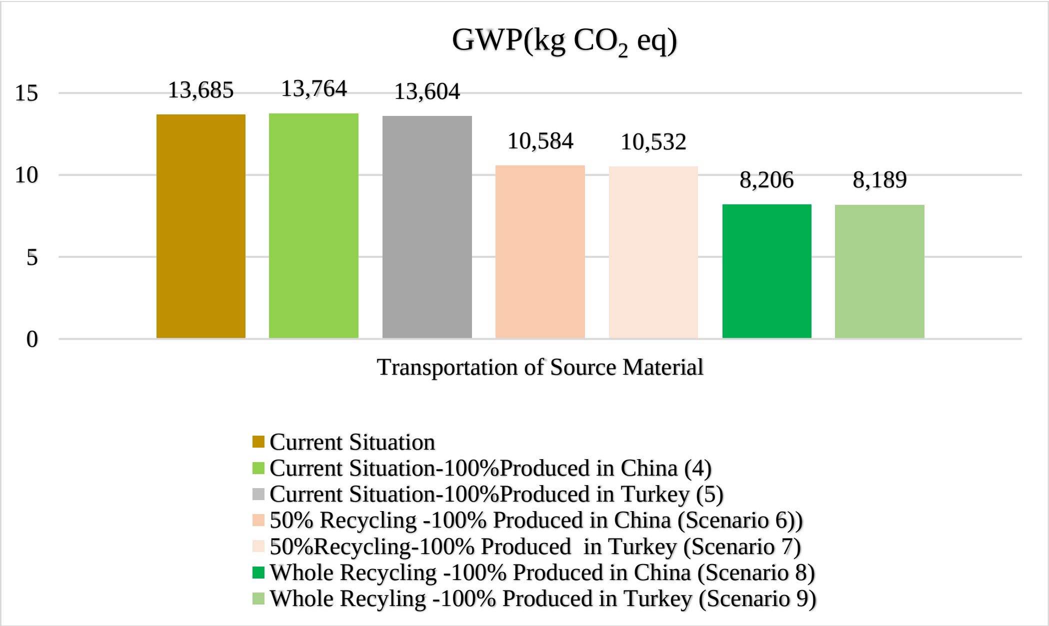

Figure 4.3. GWP effects of different transportation options of the source materials on the current situation, on the 50% recycling situation and on the whole recycling situation

Single Score effects of the different textile supply chain options created based on the Scenarios 4, 5, 6, 7, 8, and 9 are given the following Figure 4.4. Results can be followed by scenario numbers and color codes as it is explained in Table 4.1.

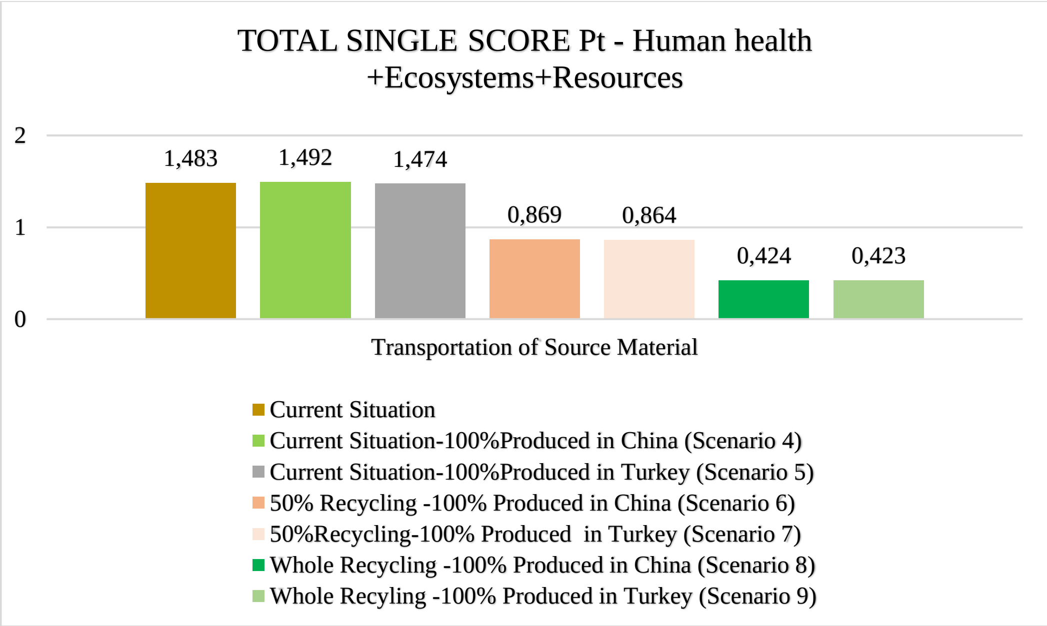

Figure 4.4. Single score effects of different transportation options of source materials on the current situation, on the 50% recycling situation and on the whole recycling situation

Interpretation:

GWP: According to the results given in Figure 4.3, the best supply chain scenario was 100% production in Turkey and the worst scenario was 100% production in China. Their differences were interpreted over the current situation. First comparison is conducted between the Current situation, Scenario 4 and Scenario 5. In this direction, if textile products are supplied 100% from China, there would be 0.57% CO_2eq increase in GWP effect for the current situation. If textile products are supplied 100% from Turkey, there would be 0.57% CO_2eq decrease in the GWP effects for the current situation. The difference between the best and worst supply chain scenarios was 1.15 % CO_2eq GWP effect.

Second comparison is conducted between the Current situation, Scenario 6 and Scenario 7 for the 50% recycling situation. In this direction, if textile products are supplied 100% from China, there would be 22.66% CO_2eq less GWP effects when compared with the current situation. If textile products are supplied 100% from Turkey, there would be 23.04% CO_2eq less GWP effects when compared with the current situation. The difference between the best and worst supply chain scenarios was 0.38 % CO_2eq GWP effect.

Third comparison is conducted between the Current situation, Scenario 8 and Scenario 9 for the whole recycling situation. In this direction, if textile products are supplied 100% from China, there would be 40.34% CO_2eq less GWP effects when compared with the current situation. If textile products are supplied 100% from Turkey, there would be 40.15% CO_2eq less GWP effects when compared with the current situation. The difference between the best and worst supply chain scenarios was 0.11 % CO_2eq GWP effect.

Single Score: According to the results given in Figure 4.4, if textile products are supplied 100% from China, there would be 0.60% Pt increase in environmental effects for the current situation in terms of single score. If textile products are supplied 100% from Turkey, there would be 0.60% Pt decrease in environmental effects for the current situation in terms of single score. The difference between the best and worst supply chain scenarios was 1.2 % Pt in terms of single score. For the 50% recycling situation, if textile products are supplied 100% from China, there would be 41.40% Pt decrease in environmental effects when compared with the current situation. If textile products are supplied 100% from Turkey, there would be 41.73% Pt decrease in environmental effects. The difference between the best and worst supply chain scenarios was 0.33 % Pt in terms of single score. For the whole recycling situation, if textile products are supplied 100% from China, there would be 71.41% Pt decrease in environmental effects when compared with the current situation. If textile products are supplied 100% from Turkey, there would be 71.47% Pt decrease in environmental effects. The difference between the best and worst supply chain scenarios was 0.06 % Pt in terms of single score. The decreases on the single score results are more than the GWP results. However, the differences between the worst and best supply chain scenarios were less on the single score results than GWP results. The reason can be concluded as follows; not only the GWP effects are reduced but also other midpoint effects can be reduced by recycling as all the occupation of land, water consumption, chemical consumption, energy consumption, emission to air and water and transportation network belonging to each process are decreased. However, when looking at the total results in terms of single score, it should be considered that the included parameters more impact on the total results (Moazzem, 2021a; Moazzem, 2021b). Thus, the effects of changes in transportation were reflected more on the effects of GWP than the single score (Dong and Ng, 2014; Huijbregts et al., 2017).

4.5 Life Cycle Impact Assessment Results and Interpretations for the 4.th Assessment

In this part of the study the effects of different transportation options of recycling on the current situation, on the 50% recycling situation and on the whole recycling situation are presented and their interpretations are conducted for the forth assessment of this study given below.

4) *Assessing the different transportation options effects of recycling on the current situation, 50% recycling situation and whole recycling situation of the pure cotton household textile waste of Eskişehir:* "What would the global warming potential and single score result changes be on current situation, 50% recycling situation and whole recycling situation if a new sorting facility is built in Eskişehir and if a new sorting and recycling facility are both built in Eskişehir"?

In this direction, GWP effects of the different transportation options of recycling created based on the Scenarios 10, 11, 12, 13, 14 and 15 are given the following Figure 4.5. Results can be followed by scenario numbers and color codes as it is explained in Table 4.1.

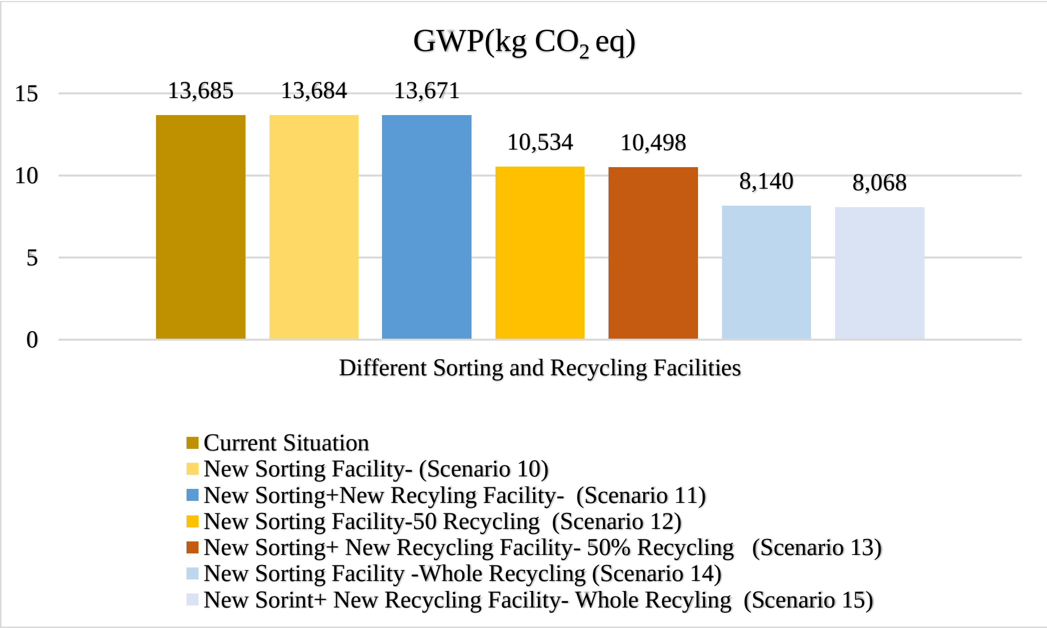

Figure 4.5. GWP effects of different transportation options of recycling on the current situation, on the 50% recycling situation and on the whole recycling situation

Single Score effects of the different textile supply chain options created based on the Scenarios 10, 11, 12, 12, 14, and 15 are given the following Figure 4.6. Results can be followed by scenario numbers and color codes as it is explained in Table 4.1.

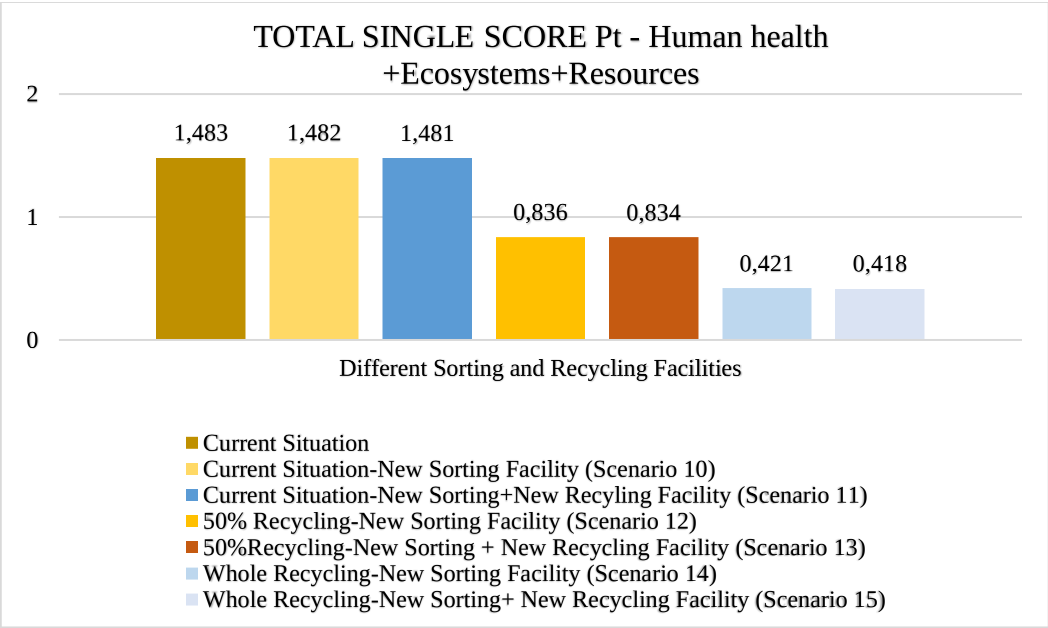

Figure 4.6. Single effects of different transportation options of recycling on the current situation, on the 50% recycling situation and on the whole recycling situation

Interpretation:

GWP: According to the results given in Figure 4.5, first comparison is conducted between the Current situation, Scenario 10 and Scenario 11. As it explained in Section 4.2.6, the transportation distance of new sorting facility case is 970 km by truck and new sorting and recycling facility case is 500 km by truck. This means there is a 470 km truck transportation distance differences between those two cases. In this direction, if a new sorting facility is built in Eskişehir, there would be 0.007% CO_2eq less GWP effect when compared with the current situation. If a new sorting and recycling facility are both built in Eskişehir, there would be 0.102% CO_2eq less GWP effect when compared with the current situation. The difference between these two transportation option is 0.09 % CO_2eq GWP effect.

Second comparison is conducted between the Current situation, Scenario 12 and Scenario 13 for the 50% recycling situation. In this direction, if a new sorting facility is built in Eskişehir, there would be 23.02% CO_2eq less GWP effect when compared with the current situation. If a new sorting and recycling facility are both built in Eskişehir, there would be 23.28% CO_2eq less GWP effect when compared with the current situation. The difference between these two transportation option is 0.26 % CO_2eq GWP effect.

Third comparison is conducted between the Current situation, Scenario 14 and Scenario 15 for the whole recycling situation. In this direction, if a new sorting facility is built in Eskişehir, there would be 40.51% % CO_2eq less GWP effect when compared with the current situation. If a new sorting and recycling facility are both built in Eskişehir, there would be 41.04 % CO_2eq less GWP effect when compared with the current situation. The difference between these two transportation option is 0.52 % CO_2eq GWP effect.

Single Score: According to the results given in Figure 4.6, if a new sorting facility is built in Eskişehir, there would be 0.07% Pt decrease in environmental effects for the current situation in terms of single score. If a new sorting and recycling facility are both built in Eskişehir, there would be 0.13% Pt decrease in environmental effects for the current situation in terms of single score. The difference between these two transportation option is 0.06 % Pt in terms of single score on the current situation. For the 50% recycling situation, if a new sorting facility is built in Eskişehir, there would be 43.62% Pt decrease in environmental effects for the current situation in terms of single score. If a new sorting and recycling facility are both built in Eskişehir, there would be 43.76% Pt decrease in environmental effects for the current situation in terms of single score. The difference between these two transportation option is 0.135 % Pt on the 50% recycling situation. For the whole recycling situation, if a new sorting facility is built in Eskişehir, there would be

71.61% Pt decrease in environmental effects for the current situation in terms of single score. If a new sorting and recycling facility are both built in Eskişehir, there would be 71.81% Pt decrease in environmental effects for the current situation in terms of single score The difference between these two transportation option is 0.203 % Pt on the whole recycling situation. As obtained in the previous assessment, the decreases on the single score results are more than the GWP results. However, the differences between the worst and best supply chain scenarios were less on the single score results than GWP results.

4.6 Sensitivity Analysis Results and Interpretations for the 5.th Assessment

In this part of the study sensitivity of different recycling rates to truck transportation loads belong to recycling and the recycling rates that can provide similar environmental benefits which obtained by reducing truck transportation loads are presented. Besides, their interpretations are conducted for the fifth assessment of this study given below.

5) *Assessing the recycling rates versus reduced truck transportation load effects on the pure cotton household textile waste of Eskişehir:* "What is the sensitivity of different recycling rates to truck transportation load of recycling"? "Is there any recycling rate that provide similar environmental benefits which can be obtained by reducing truck transportation load of recycling"?

For this sensitivity analysis, the transportation distance of the recycling system is reduced via building a new sorting facility. While evaluating this reduced transportation distance option, loads are also included. This means that, truck transportation loads are evaluated. In this direction, numerical results of GWP effects of the 15 different recycling ratios which are applied both on the current situation conditions and on the new sorting facility situation which is replaced with existing sorting facility on the current situation conditions (Scenario 10) are given in Table 4.19 below. Besides, the graph which represents the relation of recycling rates and transportation loads in terms of GWP effects is given in following Figure 4.7.

Table 4.19. Numerical results of GWP effects of 15 different recycling rates with "current situation" and new sorting facility case "scenario 10"for sensitivity analysis

15 Different Recycling Ratios	**GWP Effects (kg CO_2) of 15 different recycling rates with the existing sorting facility case (current situation)**	**GWP Effects (kg CO_2) of 15 different recycling rates with the new sorting facility "scenario 10"**
Current Situation 10% Recycling	13,685	13,684
12% Recycling	13,671	13,664
14% Recycling	13,640	13,631
20% Recycling	12,599	12,587
22% Recycling	12,587	12,574
24% Recycling	12,469	12,453
29% Recycling	12,169	12,152
35% Recycling	11,857	11,836
40% Recycling	11,543	11,519
45% Recycling	10,956	10,929
50% Recycling	10,564	10,534
55% Recycling	10,324	10,292
60% Recycling	10,093	10,058
65% Recycling	9,863	9,825
70% Recycling	9,643	9,602
100% Recycling	8,199	8,140

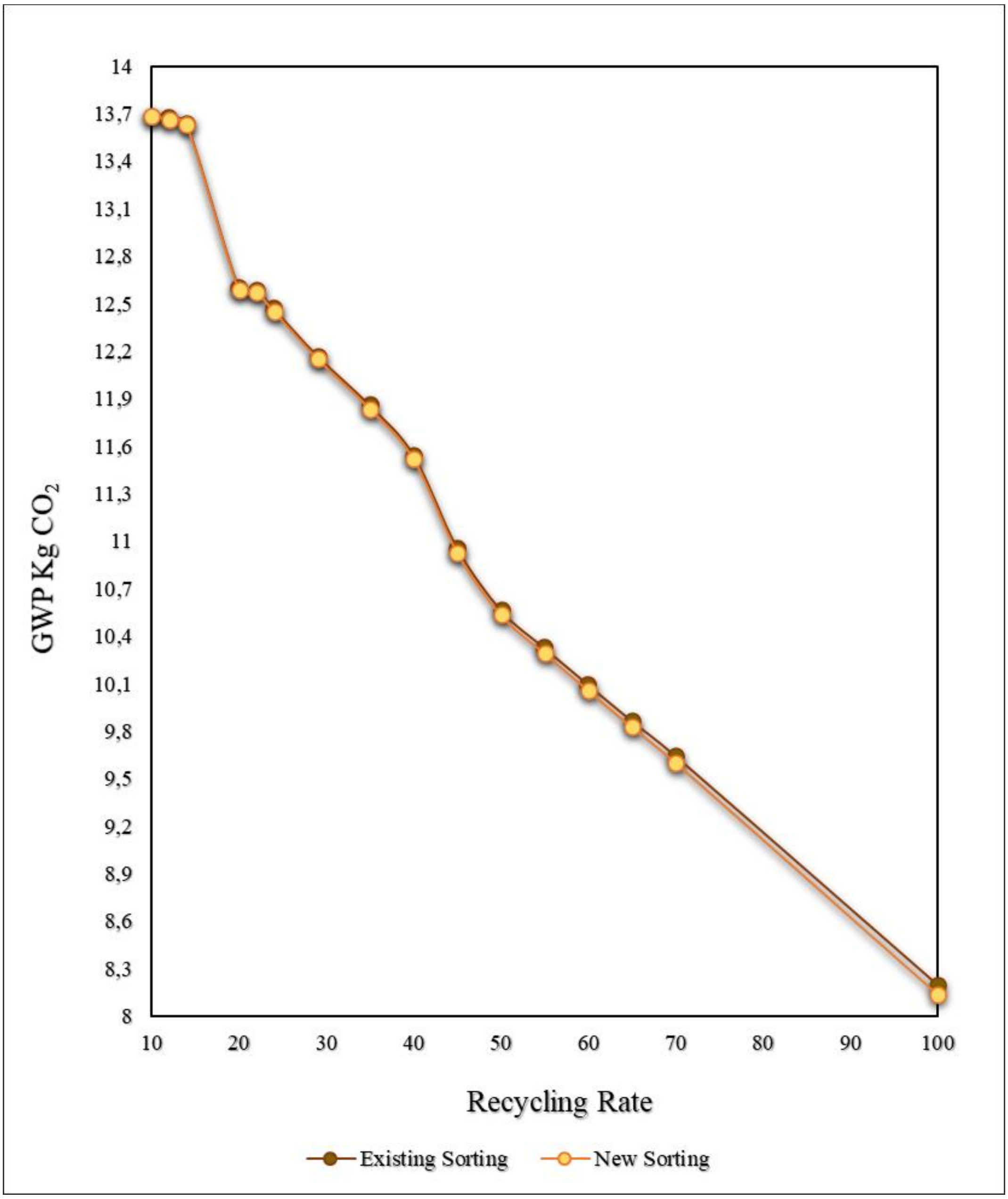

Figure 4.7. GWP Effects of 15 different recycling rates with "current situation" and with new sorting facility case "scenario 10" for sensitivity analysis

Numerical results of single score effects of the 15 different recycling ratios which are applied both on the current situation conditions and on the new sorting facility situation which is replaced with existing sorting facility on the current situation conditions (Scenario 10) are given in Table 4.20. Besides, the graph which represents the relation of recycling rates and transportation loads in terms of single score effects is given in following Figure 4.8.

Table 4.20. Numerical results of single score effects of 15 different recycling rates with "current situation" and new sorting facility case "scenario 10" for sensitivity analysis

15 Different Recycling Ratios	**Single Score Effects (Pt) of 15 different recycling rates with current situation**	**Single Score Effects (Pt) of 15 different recycling rates with new sorting facility case (scenario 10)**
Current Situation 10% Recycling	1,483	1,482
12% Recycling	1,479	1,478
14% Recycling	1,454	1,453
20% Recycling	1,313	1,312
22% Recycling	1,286	1,285
24% Recycling	1,257	1,256
29% Recycling	1,117	1,116
35% Recycling	1,055	1,054
40% Recycling	0,994	0,993
45% Recycling	0,924	0,923
50% Recycling	0,837	0,836
55% Recycling	0,738	0,736
60% Recycling	0,685	0,683
65% Recycling	0,636	0,634
70% Recycling	0,612	0,612
100% Recycling	0,421	0,418

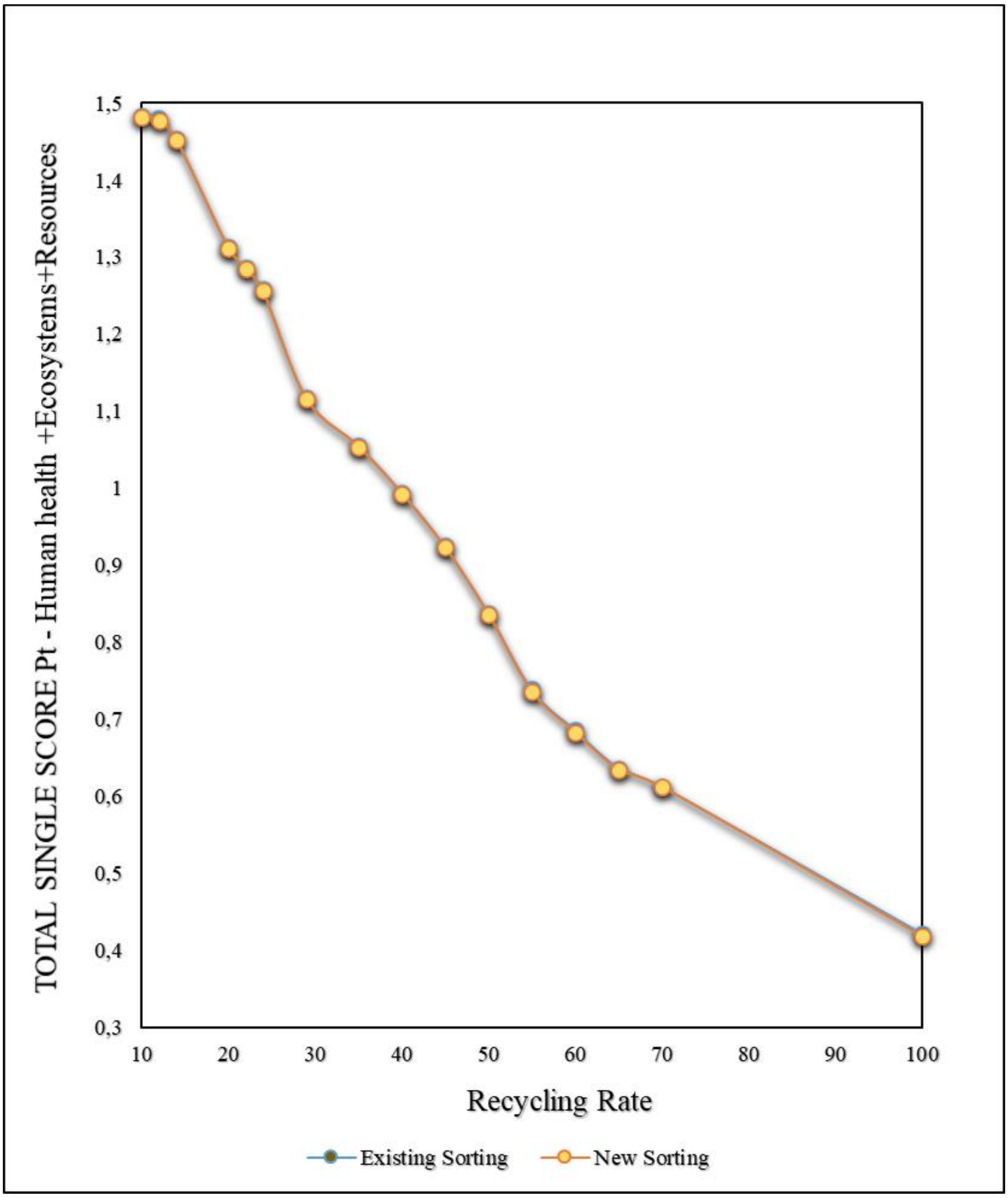

Figure 4.8. Single score effects of 15 different recycling rates of 15 different recycling rates with "current situation" and with new sorting facility case "scenario 10" for sensitivity analysis

Interpreation:

GWP: Conducted sensitivity analysis results for 15 different recycling rates versus two different transportation options belong to recycling are given in Table 4.19 and Figure 4.7. As it explained in Section 4.2.7, the transportation distance of new sorting facility case is 970 km by truck and existing facility case is 1350 km by truck. This means there is a 380 km truck transportation distance differences between those two cases. Besides, the recycling rates given in Table 4.18, are also applied to calculate the load of the waste which are transported for sorting and recycling. According to the results, more decrease in the GWP effects especially after 50% recycling rate can be achieved by building a new sorting facility when compared with the GWP effects of existing sorting facility. This means that, the sensitivity of different recycling rates to truck transportation load of recycling is increasing more after 50% recycling rate in terms of GWP effects. According to numerical results given in Table 4.19, GWP effects of 20% recycling with new sorting facility case is equal to 22% recycling with existing sorting facility case. This means that, 22% recycling rate with existing sorting facility case provide similar environmental benefits with 20% recycling rate with new sorting facility case in terms of GPW effects.

Single Score: Conducted sensitivity analysis for 15 different recycling rates versus two different transportation options belong to recycling are given in Table 4.20 and Figure 4.8. According to the results, the difference between the single score effects of different transport loads up to 50% recycling rate was 0.001 Pt. The difference between 50% -70% recycling rates was 0.002 Pt and it was 0.003 Pt on the whole recycling situation. According to numerical results given in Table 4.20, reduced 380 truck transportation effects were not remarkable in terms of single score.

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CHAPTER 5

CONCLUSION AND DISCUSSION

The main objective of this study was to investigate the transportation and recycling effects on the household textile waste of Eskisehir with LCA methodology. Based on the obtained results, the conclusions are as follows:

- Scaled up GWP effects of landfilled 4,190 tons/year pure cotton household textile waste of Eskişehir was calculated to be 57,340 tonnes/year CO2eq from the beginning of production to landfilling including 10% recycling rate. Single score effects which were sum of the end-point effects calculated by including 17 different midpoint category impacts was found as 6,213.77 Pt. GWP of landfilled cotton textile waste found similar with the previous studies (Muthu, 2015). However, when conducted studies investigating textile waste management with LCA methodology are examined, no single score effect found to make comparison from the following references (Bodin, 2016; Schmidt et al., 2016; Dahlbo et al., 2017; Esteve-Turrillas and de la Guardia, 2017; Koligkioni et al., 2018; Semba et al., 2020; Moazzem et al., 2021a; Moazzem et al., 2021b). For this reason, the results of this study can be used for future studies as it is first sample in terms of single score effects.
- In case of 50 % recycling of landfilled 4,190 tons/year pure cotton household textile waste in Eskişehir, 13,076.99 tonnes/year CO2eq emission reduction could be achieved. In case of whole recycling 22,986.34 tonnes/year CO2eq emission reduction could be achieved and lastly in case of reusing 49,848.43 tonnes/year CO2eq emission reduction could be achieved. When it is focused on single score effects of 50% recycling situation, whole recycling situation

and whole reusing situation, 2,706.74 Pt reduction, 4,441.40 Pt reduction and 5,522.42 Pt reductions could be achieved respectively. In this direction, reduction in GWP effects obtained by reuse corresponds to 86.93% in terms of percentage. This result was consistent with a study conducted in Japan that obtained 70% reduction in GWP effects by overseas reusing (Semba et al., 2020). Reduction in GWP effects obtained by whole recycling corresponds to 40.08% CO2eq in terms of percentage. Another study conducted for a with a similar cotton recycling methodology obtained 54% reduction in GWP effects without landfilling loss (Fidan et al., 2021). As the landfilling loss effects were not considered, the benefits obtained by whole recycling were approximately 10% higher compared to this study.

- According to the transportation of the source material results, the best supply chain scenario was 100% production in Turkey and the worst scenario was 100% production in China. The difference between the best and worst supply chain scenarios were found as 662.02 tonnes/year CO2eq GWP effects on the current situation, 217,88 tonnes/year CO2eq GWP effects on the 50% recycling situation and 62,85 tonnes/year CO2eq GWP effects on the whole recycling situation. In terms of single score effects, the differences between the best and worst supply chain scenarios on the current situation, 50% recycling situation and whole recycling situation were found as 54.47 Pt, 20.95 Pt and 4.17 Pt respectively. The differences of supply chain effects were found more in higher landfilling rates. The reason can be concluded as follows; when the landfilling rate of household textile waste is higher, effects arising from production to landfilling processes are more than the effects arising from recycling processes (Schmidt et al., 2016; Dahlbo et al., 2017). As the production to landfilling processes are avoided or replaced with recycling processes, the effects arising from production to landfilling are decreased and recycling processes and their effects come to fore in case of higher recycling rate (Schmidt et al., 2016; Dahlbo et al., 2017). This means that, supplying the source material is avoided and replaced by recycling transportation. Hence, when recycling rate is higher, environmental effects of transportation of source materials is decreased (Schmidt et al., 2016; Dahlbo et al., 2017; Esteve-Turrillas and de la Guardia, 2017; Koligkioni et al., 2018; Moazzem et al., 2021a; Moazzem et al., 2021b). When landfilling ratios is higher, environmental effects of transportation of source materials is higher. Therefore, the differences between the effects of different supply chains are greater when recycling rates are lower.

- Different transportation options of recycling effects were analyzed on the current situation, 50% recycling situation and whole recycling situation. In this direction, the GWP effects of reduced 470 km truck transportation were found as 54.47 tonnes/year CO2eq on the current situation, 150.84 tonnes/year CO2eq on the 50% recycling situation and 301.68 tonnes/year CO2eq emission on the whole recycling situation. In terms of single score, the effects of reduced 470 kgkm truck transportation on the current situation, 50% recycling situation and whole recycling situation were found as 4.19 Pt, 8.37 Pt and 12.57 Pt respectively. The differences of reduced truck transportation were found to be more in higher recycling rate as the recycling processes and their effects come to fore in case of higher recycling rate (Schmidt et al., 2016; Dahlbo et al., 2017). Thus, when the transportation load of recycling was reduced, more environmental benefits were obtained in higher recycling rates.
- Conducted sensitivity analysis for 15 different recycling rates versus two different transportation options belong to recycling showed that, the sensitivity of different recycling rates to truck transportation load of recycling is increasing more after 50% recycling rate in terms of GWP effects. Besides, GWP effects of 20% recycling with new sorting facility case

was found equal to 22% recycling with existing sorting facility case which was 12.587 CO2eq. This result can be concluded as follows; 22% recycling rate with existing sorting facility case has 267.3 kgkm truck transportation load and 20% recycling rate with new sorting facility case has 174.6 kgkm the truck transportation load. This means that, GWP effects caused from 92.7 kgkm truck transportation load difference can be reduced via increasing the recycling rate nearly by 2%. Also, it was concluded from sensitivity analysis that, even if some of the recycling ratios are increased at the same rates, a constant decrease on the GWP effects could not be observed. Furthermore, while the reductions in GWP were higher up to 40% recycling rate, they started to decrease after 40% recycling. According to single score results, the effects of reduced 380 km reduced truck transportation caused 0.001 Pt decrease up to 50% recycling rate, caused 0.002 Pt decrease between 50%-70% recycling rates and caused 0.003 Pt decrease on the whole recycling situation. This means that truck transportation loads from 34.2 kgkm to 171 kgkm have nearly similar single score effects up to 50% recycling rate. From 171 kgkm to 293.4 kgkm truck transportation loads have nearly similar effects between the 50% to 70% recycling rates. When conducted studies investigating textile waste management with LCA methodology are examined, no sensitivity analysis similar to this study could be found (Bodin, 2016; Schmidt et al., 2016; Dahlbo et al., 2017; Esteve-Turrillas and de la Guardia, 2017; Koligkioni et al., 2018; Semba et al., 2020; Moazzem et al., 2021a; Moazzem et al., 2021b). For this reason, the results of this sensitivity analysis can be used for future studies as it is first sample in terms of comparison of recycling rates versus reduced truck transportation load effects. However, another observation of this sensitivity analysis, which were different GWP effect decreases obtained by a constant recycling rate increasement were different than a conducted study which obtained constantly 5% GWP effect decrease by 1% increase in recycling rate (Sandin and Peters, 2018). The reason can be concluded as follow; 10% landfilling rate of each recycling ratio can create changes in the GWP effects (Sandin and Peters, 2018). This ratio was not considered in the previous study (Fidan et al., 2021). In addition, no transportation loads effects were included in the scope of previous study. However, transportation loads of recycling depend on the recycling rate and the amount of transportation load is different in each recycling rate (Schmidt et al., 2016; Dahlbo et al., 2017). This can also be another reason that prevent a constant decrease in GWP effects.

The overall the results of this study clearly demonstrated that increasing the rate of recycling was much more effective than any other changes on the transportation network for existing pure cotton household textile waste management system in Eskişehir. Considering high public awareness about recycling in Eskişehir, if any improvements in the textile sorting system is made, the recycling rates could also be increased. Hence the results of this study could be implemented in different regions in Turkey on the way of zero waste.

Each LCA model has its own uncertainties and limitations specially for the entire life cycle assessments. While some uncertainties and limitations can be addressed by sensitivity analysis, some uncertainties or limitations cannot be eliminated due to lack of data or due to the process intensity in the full life cycle (Moazzem et al., 2021a). One of the main limitations of this study is to define the functional unit of LCA as 1-kilogram woven household textile waste made from pure cotton instead of defining “a t-shirt”, “a dress”, or “jeans” and so forth. However, during the production of a t-shirt, a dress, jeans etc. the consumption and type of chemicals, energy and water may vary. Since accessing the inventory of the specific dyes and different chemicals for each product is a challenge to obtain the related inventory, the consumptions are considered as 1 kg of fabric production by weaving data as the consumptions of fabric do not differ much. Another limitation is the replacement rate of recycled fibers with the original ones. Although it is stated in the literature and in the conducted interviews that the recycling of textile waste made of pure cotton can almost completely replace with the original fibers, the condition of the waste to be recycled can affect the replacement rates. However, replacement rate of recycling is considered as 90% in this study according to conducted similar studies.

As recommendations for future studies, when the entire life cycle of recycling is also examined, environmental benefits obtained by recycling are caused not only as it prevents the environmental effects occurred from production. In general, these interpretations are conducted from consumer to end of life scope studies. Whereas, as it has been indicated through this study, environmental benefits obtained by recycling is caused not only as it prevents the environmental effects occurred from virgin material production step of textile manufacturing but also as it prevents the effects landfilling or as it can reduce the transportation distance as recycled product supply chain can be replaced with the source material supply chain. For this reason, when the entire life cycle of recycling is examined, the benefits obtained arise from many processes. Thus, for further studies, more textile waste LCA study about recycling is recommended that can evaluate the entire life cycle of textile waste especially in Turkey. Besides, for the studies that aim to evaluate the effects of the transportation network of recycling, it is recommended to consider more than 850 km truck transportation distance which was the maximum changes in this study. Furthermore, many studies only focused on the transportation distances, but transport loads have important effects on the results. For this reason, it is recommended to carry out more studies including transportation loads. Lastly, products made from pure fibers have higher recycling efficiency, but mixed fibers have lower recycling efficiency. For this reason, it is recommended to conduct more studies on the recycling of blended fibers.

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APPENDICES

A. Landfill Site Visit Permissions From Eskişehir Municipality

T.C.
ESKİŞEHİR BÜYÜKŞEHİR BELEDİYE BAŞKANLIĞI
Çevre Koruma ve Kontrol Dairesi Başkanlığı

Sayı : 31824826-155.01.99-642-42822 20.09.2019
Konu : Düzenli Depolama Saha Ziyareti Talebi

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
ÇEVRE MÜHENDİSLİĞİ BÖLÜMÜ
Üniversiteler Mahallesi Dumlupınar Bulvarı No:1
ANKARA

İlgi : 27.08.2019 tarihli dilekçeniz.

Orta Doğu Teknik Üniversitesi Çevre Mühendisliği Bölümü Yüksek Lisans Programı'nda yürütülmekte olan çalışma kapsamında Türkiye'deki düzenli depolama alanlarının sıfır atık analizinin gerçekleştirileceği, öncelikli olarak ülkemizde atıkların düzenli depolama yöntemi ile bertarafını sağlayan tesislerinde incelemelerin yapılmasını, belirlenen sahalarda katı atık envanterinin oluşturulmasını, atık kaynaklarının ve sektörlerinin belirlenmesini, sızıntı suyu, hava kalitesi gibi çevresel çıktıların tespitinin planlandığı ilgi yazınızda belirtilmektedir.

Belediyemiz tarafından evsel katı atıkların bertaraf edildiği 2. Sınıf Düzenli Depolama Tesisine yapacağınız saha ziyaretleriniz sırasında, çalışmalarınıza veri sağlamanız konusunda gerekli destek Daire Başkanlığımız tarafından sağlanacaktır.

Bilgilerinize rica ederim.

Oğuzhan ÖZEN
Belediye Başkanı a.
Genel Sekreter Yardımcısı

İki Eylül Caddesi No:53 26010- ESKİŞEHİR
E-posta: cevre@eskisehir.bel.tr
Bilgi: Atık Yönt. Şb. Müd. Tamer ENTOK
Elektronik Ağ: www.eskisehir.bel.tr
Tel: 0 (222) 211 55 00 / 1284
Fax: 0 (222) 220 35 28

B. Site Visit to Eskişehir 2nd class Sanitary Landfill.

Site Visit Dates;

10.10.2019 Dated Site Visit; Eskişehir 2nd class Sanitary Landfill Facility.

Following questions were asked to authorized personnel during the site visit to get information about landfilling:

Q1: What is the amount of recieved waste in one day to the landfill site?

Authorized Personnel	Averagely 700 tons are received, but 50 % of them are sent to the landfill. The other 50 % is sent to anaerobic treatment. For this reason, 350 tons waste are received to the landfill site in a day.

Q2: What is the maximum distance of your trucks?

Authorized Personnel	50 km

Q3: What is the capacity of your landfill sites?

Authorized Personnel	180.000 m^2 total facility area , 108.000 m^2 landfill area

Q4: What is the avarage land occupation of 1 kg waste?

Authorized Personnel	1-3 m^2

Q5: Do you have a gas collection system for the landfill site?

Authorized Personnel	Yes

Q6: What is the producted energy from the gas collection system of the landfill sites?

Authorized Personnel	Since energy is also produced from anaerobic treatment, no clear information could be obtained about how much is produced from landfill. However, totally 13 MWh (monthly) energy is produced from the facility. It is stated that, approximately 40% of total energy is produced from landfill site. So that monthly production capacity of landfill site is nearly 5,2 MWh.

C. Interview conducted with a production companies with 13.30.01 NACE code.

12.09.2019 Dated Interview; The company interviewed were given a NACE code instead of declaring the company name whose field of business activity is “Textile Finish, Bleaching and Dyeing Services of Fabrics and Textile Products”

Q1: What is your firs process in this faclilty?

"Our first process is woven fabric production from the supplied yarn "

Q2: With which fiber types do you produce?

"Cotton, polyester, linen, hemp, viscose."

Q3: What are your accessible inputs and outputs for 1 kg cotton finished fabric production?

	Cotton
Fabric Production	Avarage Heat; 2-4 MJ Avarage Electricity; 1-2 kwh
Wet Process	Avarage Elctiricity 1-2 kwh Avarage Heat; 32-55 MJ

D. Interview Conducted with the Environmental Management Department of Eskişehir Municipality

Interview Dates;

15.09.2020 Dated Interview; Eskişehir Municipality Environmental Management Department

Following questions were asked to authorized personnel during the interviews to get information about current transportation network of landfilling, reycling and reusing in Eskişehir

Q1: Are there municipal textile waste collection bins in different parts of the city?

Authorized Personnel	Textile waste collection bins belonging to district municipalities are available.

Q2: Up to how many km do you have textile collection bins?

Up to how many km do you have textile collection bins?	Approximately 50 km Including The Eskişehir Villages.

Q3: What do you do with the waste you collect from textile waste bins?

Authorized Personnel	"We have an agreement with a sorting facility in Bursa City. When the bins are full, company comes and collet the accummulated textile waste." Later on it is sent to Uşak for textile recycling

Q4: Are there any action on the reuse option?

Authorized Personnel	"We support reuse with second-hand textiles that citizens bring to social and solidarity organizations belonging to district municipalities. Apart from that, we do not have a study for reuse with textile waste which are collected in textile collection bins because textile waste accumulated in collection bins is quite mixed. So that, separating textile waste within the bins means an extra job and is a very difficult process. For this reason, we made an agreement with the sorting facility in Bursa City. "

E. Interview conducted with a textile sorting company with 38.11.01 NACE code.

16.09.2019 Dated Interview; The company interviewed were given a nace code instead of declaring the company name whose field of business activity is “Collection of non-hazardous wastes (garbage, recyclable materials, textile wastes, etc.) (excluding construction and demolition wastes, debris such as brush, scraps, rubble)”

Q1: How often do you collect the waste from textile collecting bins?

"There is no specific frequency. Whenever the municipalities we have agreements with call us, we start our waste collection journey by drawing the route of the wastes we will collect according to the provinces. "

Q2: What type of textile waste do you encounter the most?

"Garments which are unwearable, old fashioned or quite old. "

Q4: What do you do with this textile waste?

"We first categorize them by color, then try to sort them by type, and finally we sort out the accessories that can be separated and send them to the recycling facilities in Uşak and Düzce provinces. "

Q4: Is this sorting system is done manually or with the machines?

"All processes are conducted manually."

Q5: Do you have any applications for reuse?

"It usually does not happen because there is no reusable items."

F. Interview conducted with recycling companies with 13.10.12 and 13.99.04 NACE codes.

24.12.2019 Dated Interview; The company interviewed were given a NACE code instead of declaring the company name whose field of business activity is “Twisting and spinning cotton fiber” with 13.10.12 NACE code.

25.12.2019 Dated Interview; The companies interviewed were given a nace code instead of declaring the company name whose field of business activity is'' Manufacture of textile scraps (for filling beds, quilts, pillows etc.) ''with 13.99.04 NACE code.

Q1: What do you do with textile waste that you received from sorting plants?

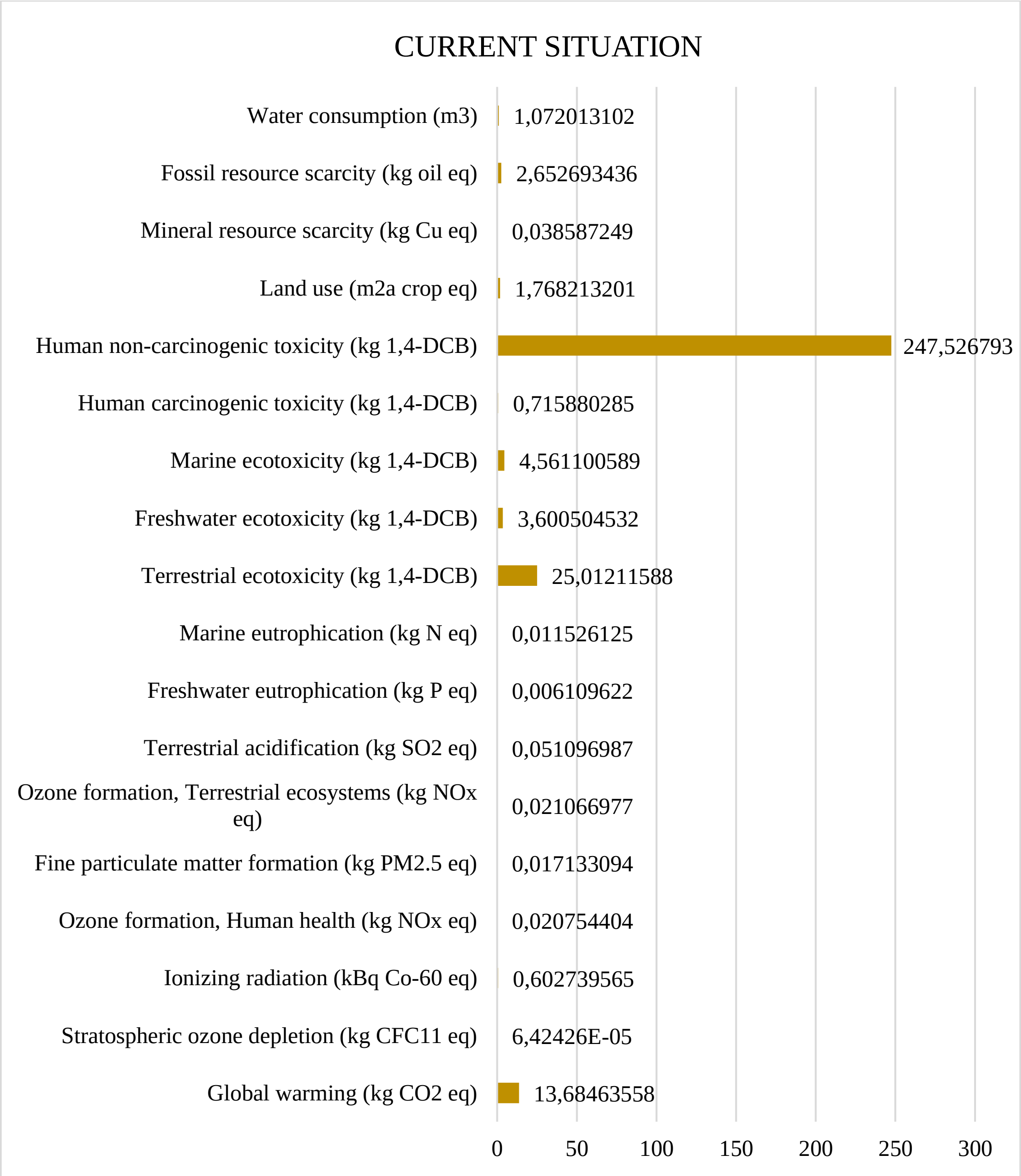
13.10.12 NACE code ''Twisting and spinning cotton fiber''	''We have different processes for textile wastes according to their fiber content such as 100 % cotton, 100 % polyester or for mixed fibers. '' 1-We produce mechanically recycled fibers from 100% cotton textile waste and it can be very close to its original quality. 2-We produce recycled fibers or yarn by melting 100% polyester textile waste and it can still be very close to its original quality. 3- We produce mechanically recycled fiber from mixed fiber textile waste. With our current recycling methods for mixed fiber content, recycled fiber quality can decreases compared to the original fiber.''
13.99.04 NACE Code	''We have different processes for textile wastes according to their fiber content such as 100 % cotton, 100 % polyester or

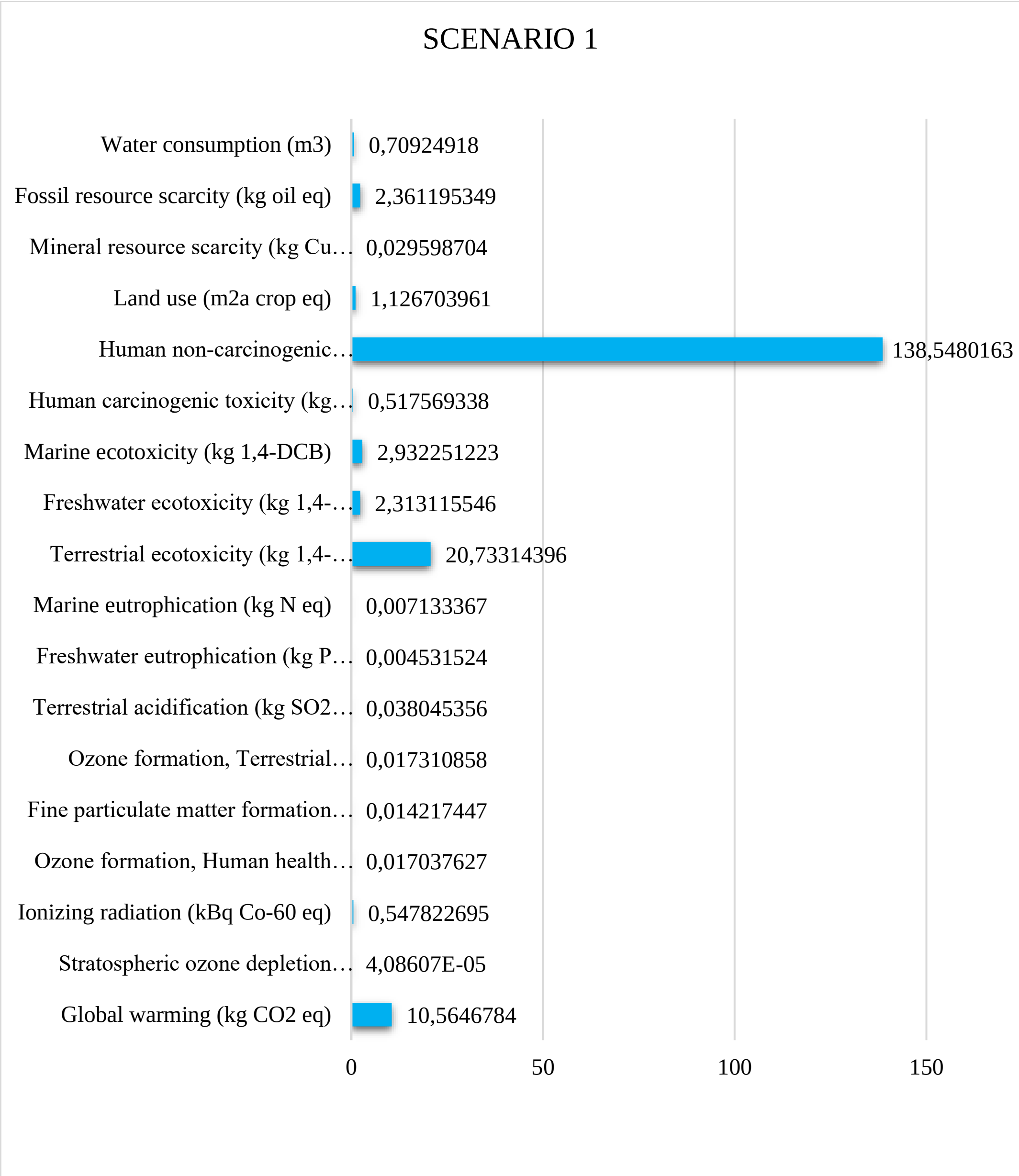
Manufacture of textile scraps (for filling beds, quilts, pillows etc.)	for mixed fibers and according to fabric type such as woven or knitting -We can produce knitted and woven fabrics from knitted textile wastes. -We can produce knitted fabrics from knitted textile wastes. -We can produce recycled yarns from cotton and polyester textile waste.

Q2: What do you do after recycling?

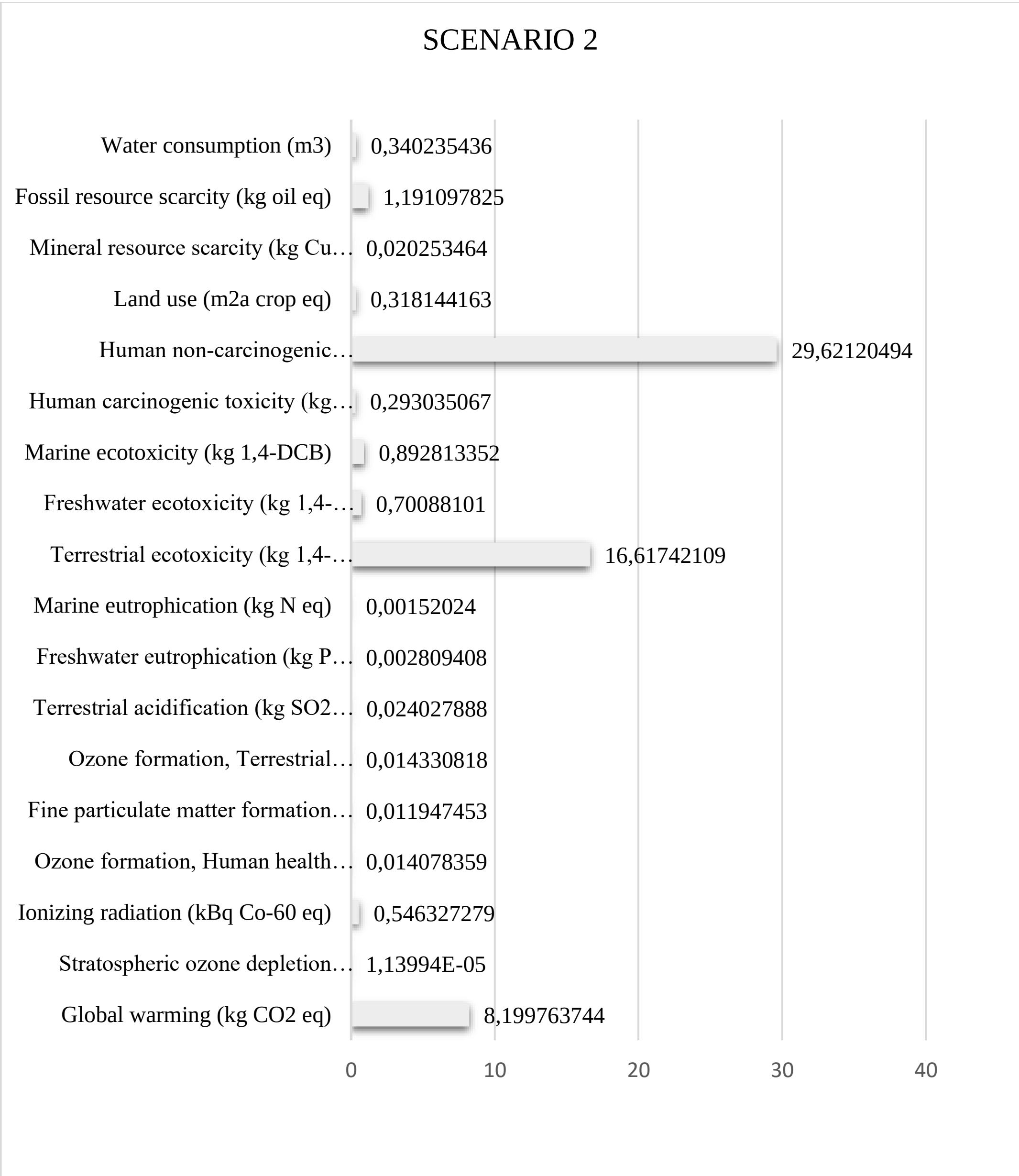
13.10.12 NACE code ''Twisting and spinning cotton fiber''	1-We sell them to textile manufacturing companies located around Turkey and Europe as recycled material importance is increasing due to some textile certificates.
13.99.04 NACE Code Manufacture of textile scraps (for filling beds, quilts, pillows etc.)	1- We sell them to the related manufacturing companies.

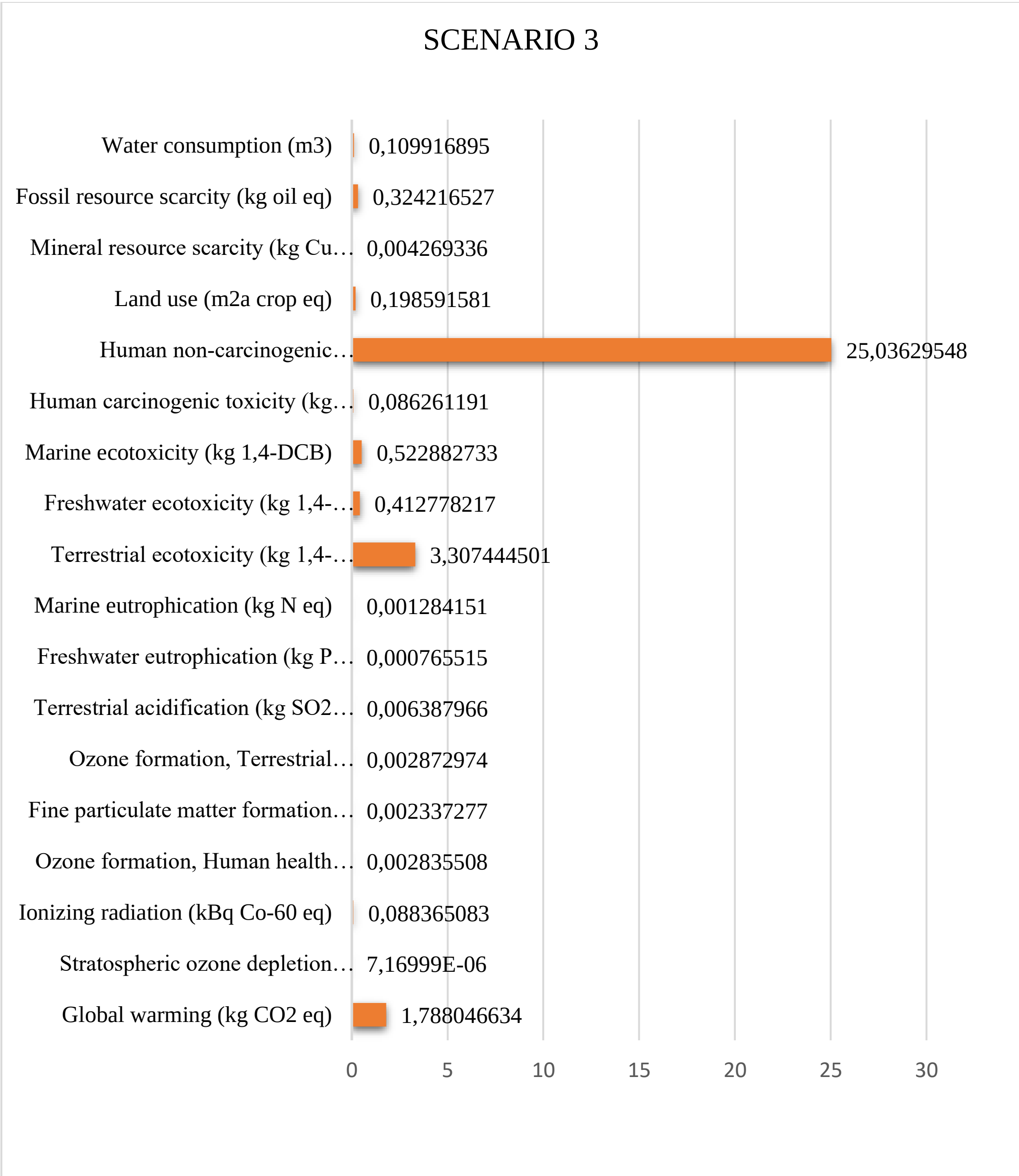
G. All Midpoint Results for the Scenarios and Sensitivity Analysis

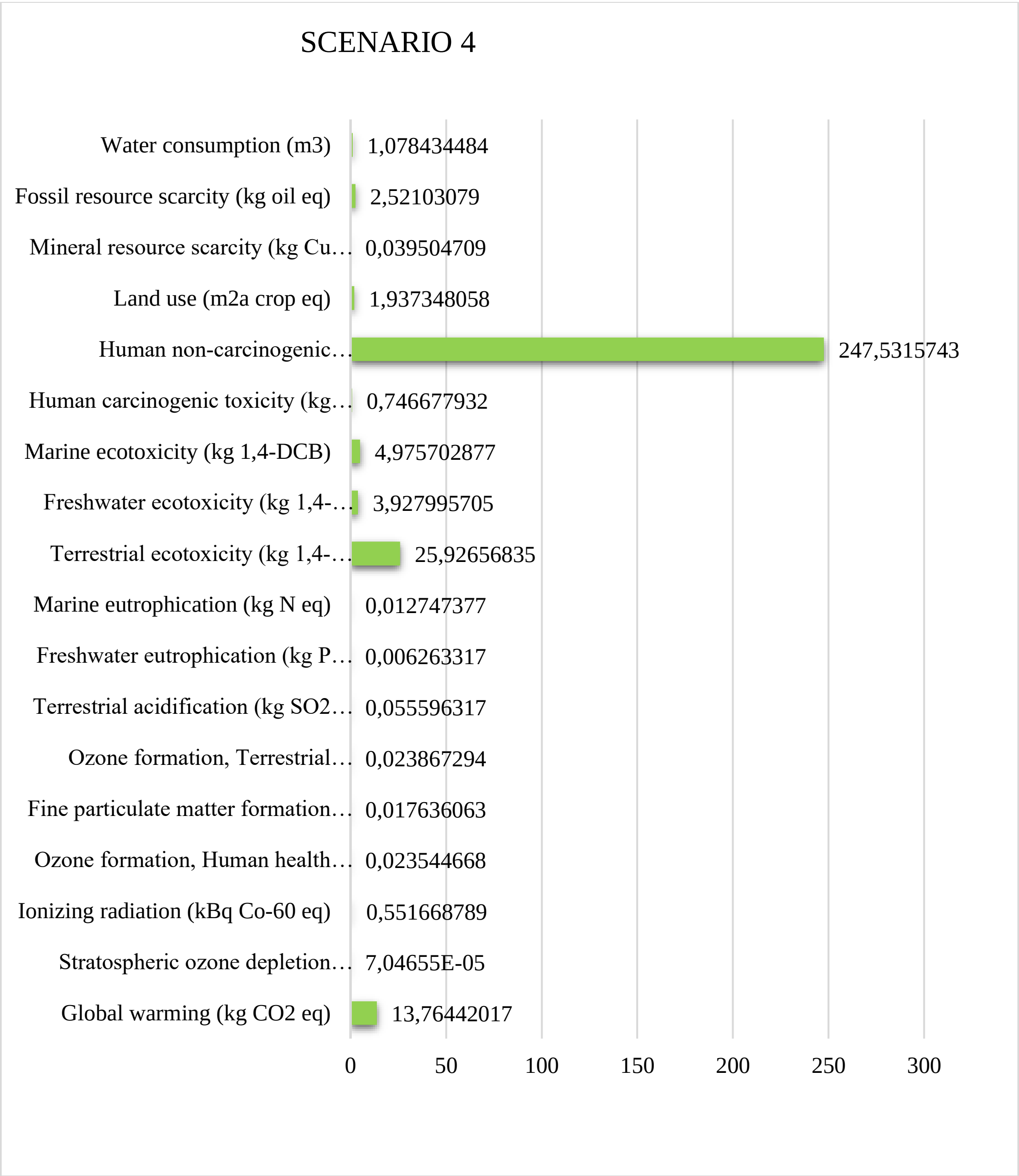


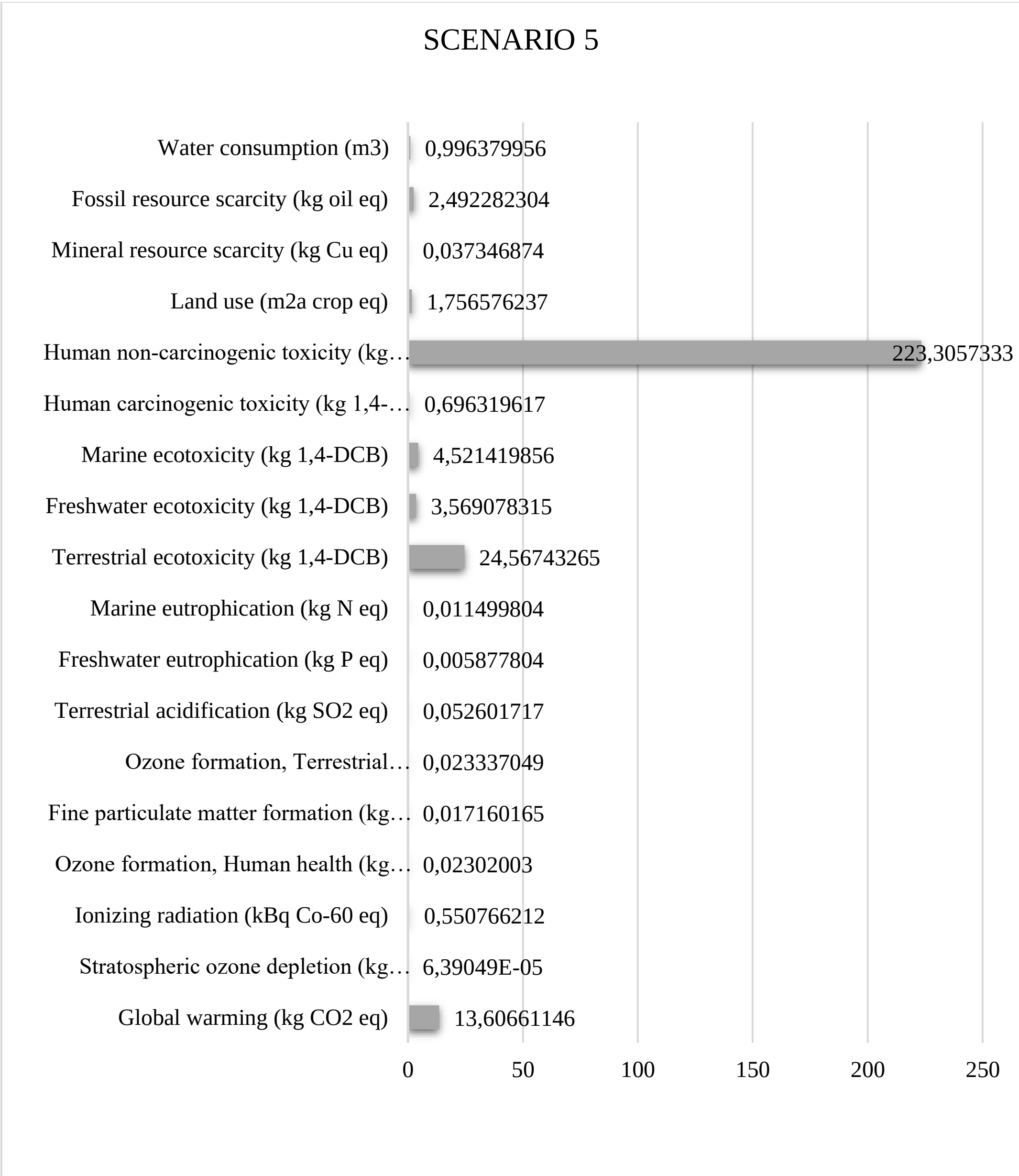


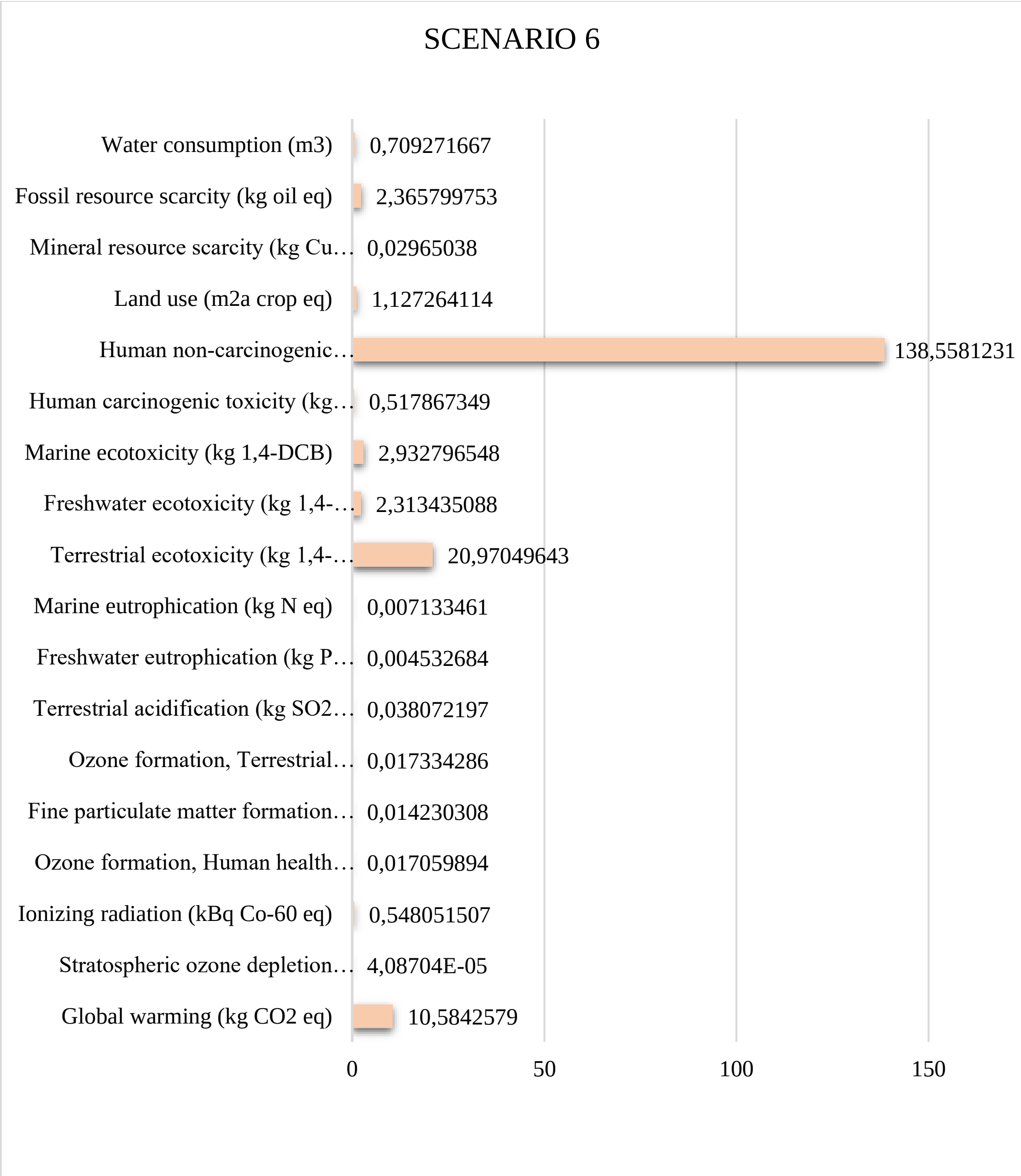
SCENARIO 1
Water consumption (m3)
0,70924918
Fossil resource scarcity (kg oil eq)
2,361195349
Mineral resource scarcity (kg Cu…
0,029598704
Land use (m2a crop eq)
1,126703961
Human non-carcinogenic…
138,5480163
Human carcinogenic toxicity (kg…
0,517569338
Marine ecotoxicity (kg 1,4-DCB)
2,932251223
Freshwater ecotoxicity (kg 1,4-…
2,313115546
Terrestrial ecotoxicity (kg 1,4-…
20,73314396
Marine eutrophication (kg N eq)
0,007133367
Freshwater eutrophication (kg P…
0,004531524
Terrestrial acidification (kg SO2…
0,038045356
Ozone formation, Terrestrial…
0,017310858
Fine particulate matter formation…
0,014217447
Ozone formation, Human health…
0,017037627
Ionizing radiation (kBq Co-60 eq)
0,547822695
Stratospheric ozone depletion…
4,08607E-05
Global warming (kg CO2 eq)
10,5646784
0
50
100
150

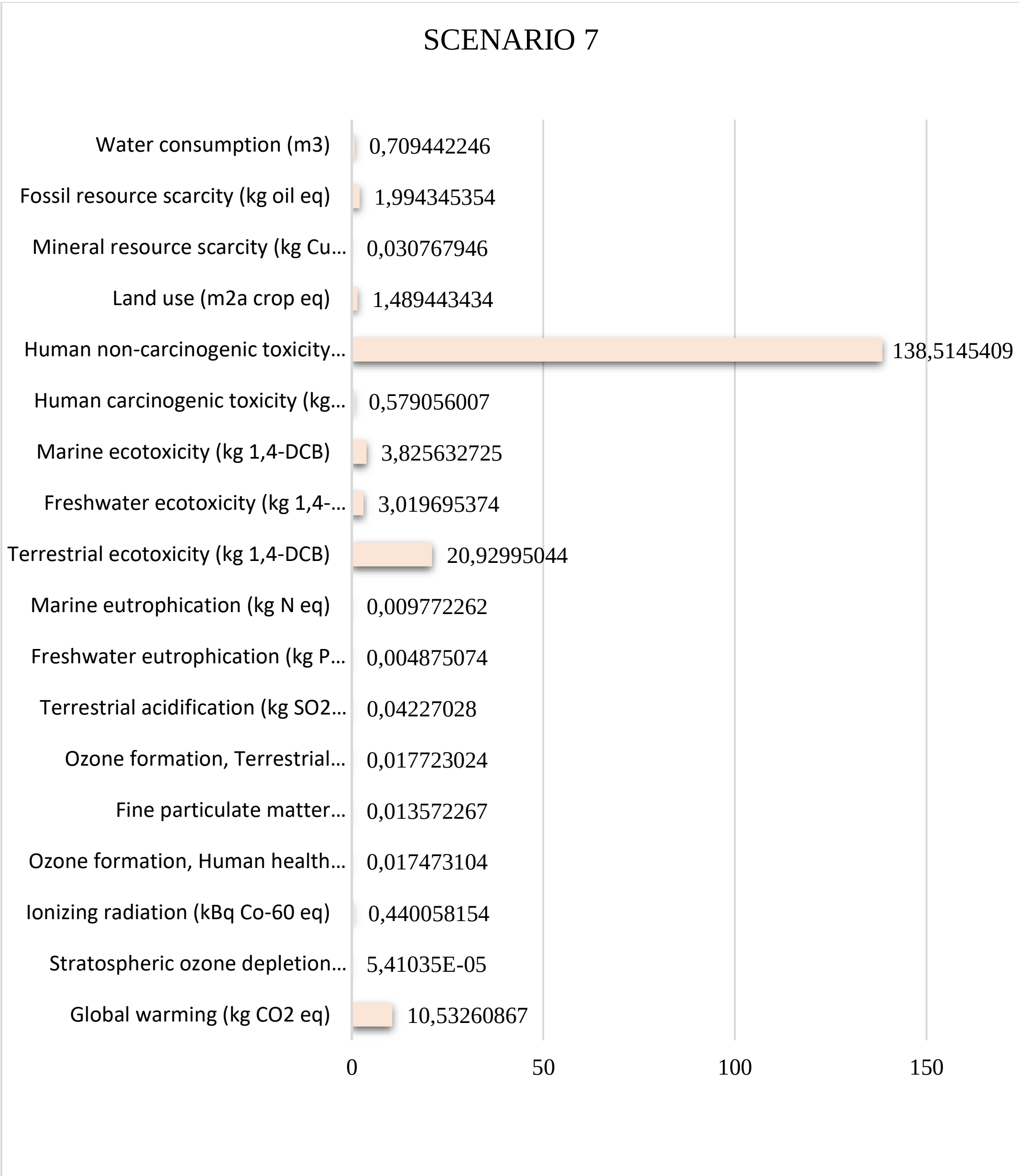

SCENARIO 2
Water consumption (m3)
0,340235436
Fossil resource scarcity (kg oil eq)
1,191097825
Mineral resource scarcity (kg Cu…
0,020253464
Land use (m2a crop eq)
0,318144163
Human non-carcinogenic…
29,62120494
Human carcinogenic toxicity (kg…
0,293035067
Marine ecotoxicity (kg 1,4-DCB)
0,892813352
Freshwater ecotoxicity (kg 1,4-…
0,70088101
Terrestrial ecotoxicity (kg 1,4-…
16,61742109
Marine eutrophication (kg N eq)
0,00152024
Freshwater eutrophication (kg P…
0,002809408
Terrestrial acidification (kg SO2…
0,024027888
Ozone formation, Terrestrial…
0,014330818
Fine particulate matter formation…
0,011947453
Ozone formation, Human health…
0,014078359
Ionizing radiation (kBq Co-60 eq)
0,546327279
Stratospheric ozone depletion…
1,13994E-05
Global warming (kg CO2 eq)
8,199763744
0
10
20
30
40

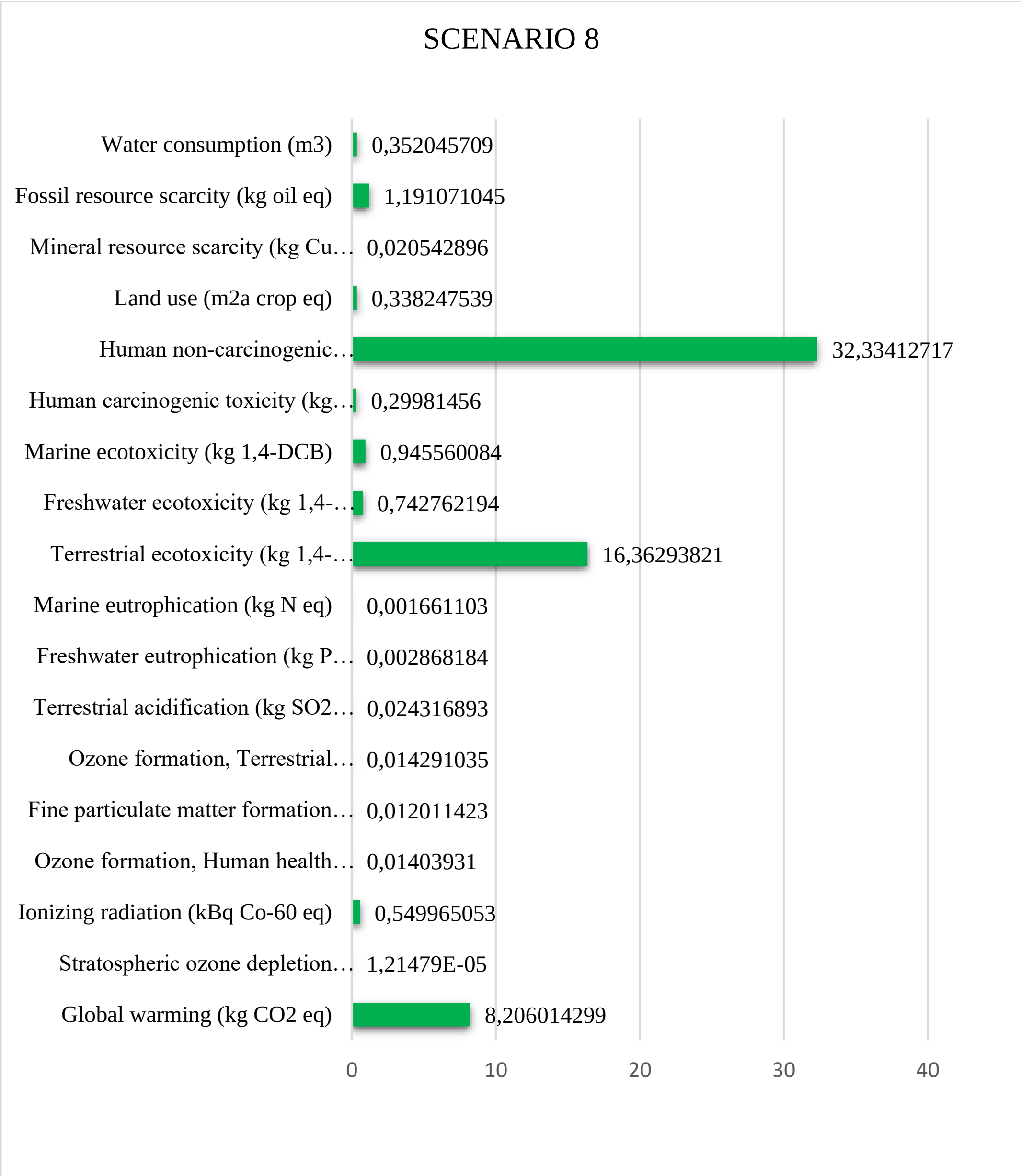

SCENARIO 3
Water consumption (m3)
0,109916895
Fossil resource scarcity (kg oil eq)
0,324216527
Mineral resource scarcity (kg Cu…
0,004269336
Land use (m2a crop eq)
0,198591581
Human non-carcinogenic…
25,03629548
Human carcinogenic toxicity (kg…
0,086261191
Marine ecotoxicity (kg 1,4-DCB)
0,522882733
Freshwater ecotoxicity (kg 1,4-…
0,412778217
Terrestrial ecotoxicity (kg 1,4-…
3,307444501
Marine eutrophication (kg N eq)
0,001284151
Freshwater eutrophication (kg P…
0,000765515
Terrestrial acidification (kg SO2…
0,006387966
Ozone formation, Terrestrial…
0,002872974
Fine particulate matter formation…
0,002337277
Ozone formation, Human health…
0,002835508
Ionizing radiation (kBq Co-60 eq)
0,088365083
Stratospheric ozone depletion…
7,16999E-06
Global warming (kg CO2 eq)
1,788046634
0
5
10
15
20
25
30

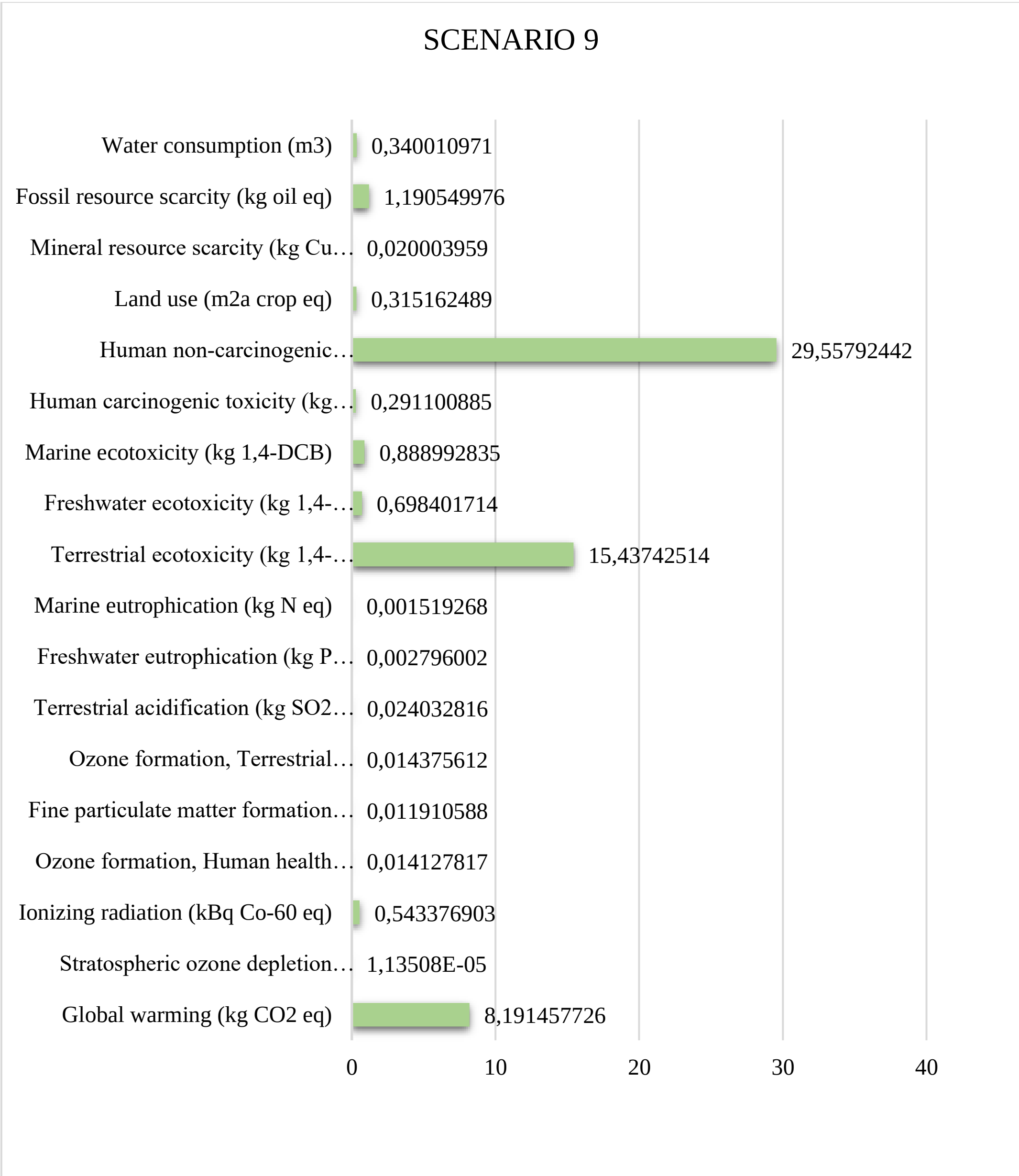

SCENARIO 4
Water consumption (m3)
1,078434484
Fossil resource scarcity (kg oil eq)
2,52103079
Mineral resource scarcity (kg Cu…
0,039504709
Land use (m2a crop eq)
1,937348058
Human non-carcinogenic…
247,5315743
Human carcinogenic toxicity (kg…
0,746677932
Marine ecotoxicity (kg 1,4-DCB)
4,975702877
Freshwater ecotoxicity (kg 1,4-…
3,927995705
Terrestrial ecotoxicity (kg 1,4-…
25,92656835
Marine eutrophication (kg N eq)
0,012747377
Freshwater eutrophication (kg P…
0,006263317
Terrestrial acidification (kg SO2…
0,055596317
Ozone formation, Terrestrial…
0,023867294
Fine particulate matter formation…
0,017636063
Ozone formation, Human health…
0,023544668
Ionizing radiation (kBq Co-60 eq)
0,551668789
Stratospheric ozone depletion…
7,04655E-05
Global warming (kg CO2 eq)
13,76442017
0
50
100
150
200
250
300


SCENARIO 5
Water consumption (m3)
0,996379956
Fossil resource scarcity (kg oil eq)
2,492282304
Mineral resource scarcity (kg Cu eq)
0,037346874
Land use (m2a crop eq)
1,756576237
Human non-carcinogenic toxicity (kg…
223,3057333
Human carcinogenic toxicity (kg 1,4-…
0,696319617
Marine ecotoxicity (kg 1,4-DCB)
4,521419856
Freshwater ecotoxicity (kg 1,4-DCB)
3,569078315
Terrestrial ecotoxicity (kg 1,4-DCB)
24,56743265
Marine eutrophication (kg N eq)
0,011499804
Freshwater eutrophication (kg P eq)
0,005877804
Terrestrial acidification (kg SO2 eq)
0,052601717
Ozone formation, Terrestrial…
0,023337049
Fine particulate matter formation (kg…
0,017160165
Ozone formation, Human health (kg…
0,02302003
Ionizing radiation (kBq Co-60 eq)
0,550766212
Stratospheric ozone depletion (kg…
6,39049E-05
Global warming (kg CO2 eq)
13,60661146
0
50
100
150
200
250

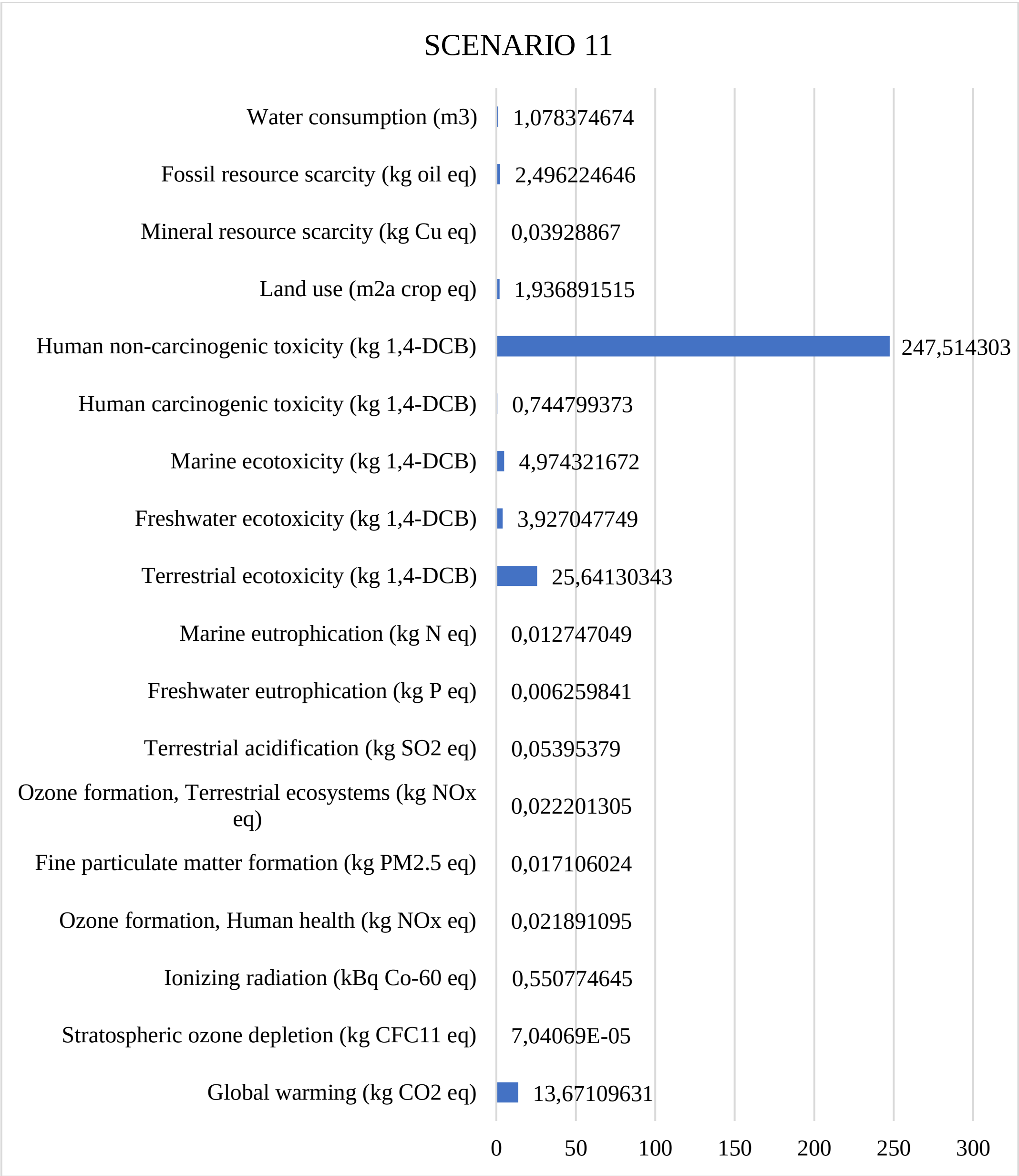

SCENARIO 6
Water consumption (m3)
0,709271667
Fossil resource scarcity (kg oil eq)
2,365799753
Mineral resource scarcity (kg Cu…
0,02965038
Land use (m2a crop eq)
1,127264114
Human non-carcinogenic…
138,5581231
Human carcinogenic toxicity (kg…
0,517867349
Marine ecotoxicity (kg 1,4-DCB)
2,932796548
Freshwater ecotoxicity (kg 1,4-…
2,313435088
Terrestrial ecotoxicity (kg 1,4-…
20,97049643
Marine eutrophication (kg N eq)
0,007133461
Freshwater eutrophication (kg P…
0,004532684
Terrestrial acidification (kg SO2…
0,038072197
Ozone formation, Terrestrial…
0,017334286
Fine particulate matter formation…
0,014230308
Ozone formation, Human health…
0,017059894
Ionizing radiation (kBq Co-60 eq)
0,548051507
Stratospheric ozone depletion…
4,08704E-05
Global warming (kg CO2 eq)
10,5842579
0
50
100
150


SCENARIO 7
Water consumption (m3)
0,709442246
Fossil resource scarcity (kg oil eq)
1,994345354
Mineral resource scarcity (kg Cu…
0,030767946
Land use (m2a crop eq)
1,489443434
Human non-carcinogenic toxicity…
138,5145409
Human carcinogenic toxicity (kg…
0,579056007
Marine ecotoxicity (kg 1,4-DCB)
3,825632725
Freshwater ecotoxicity (kg 1,4-…
3,019695374
Terrestrial ecotoxicity (kg 1,4-DCB)
20,92995044
Marine eutrophication (kg N eq)
0,009772262
Freshwater eutrophication (kg P…
0,004875074
Terrestrial acidification (kg SO2…
0,04227028
Ozone formation, Terrestrial…
0,017723024
Fine particulate matter…
0,013572267
Ozone formation, Human health…
0,017473104
Ionizing radiation (kBq Co-60 eq)
0,440058154
Stratospheric ozone depletion…
5,41035E-05
Global warming (kg CO2 eq)
10,53260867
0
50
100
150

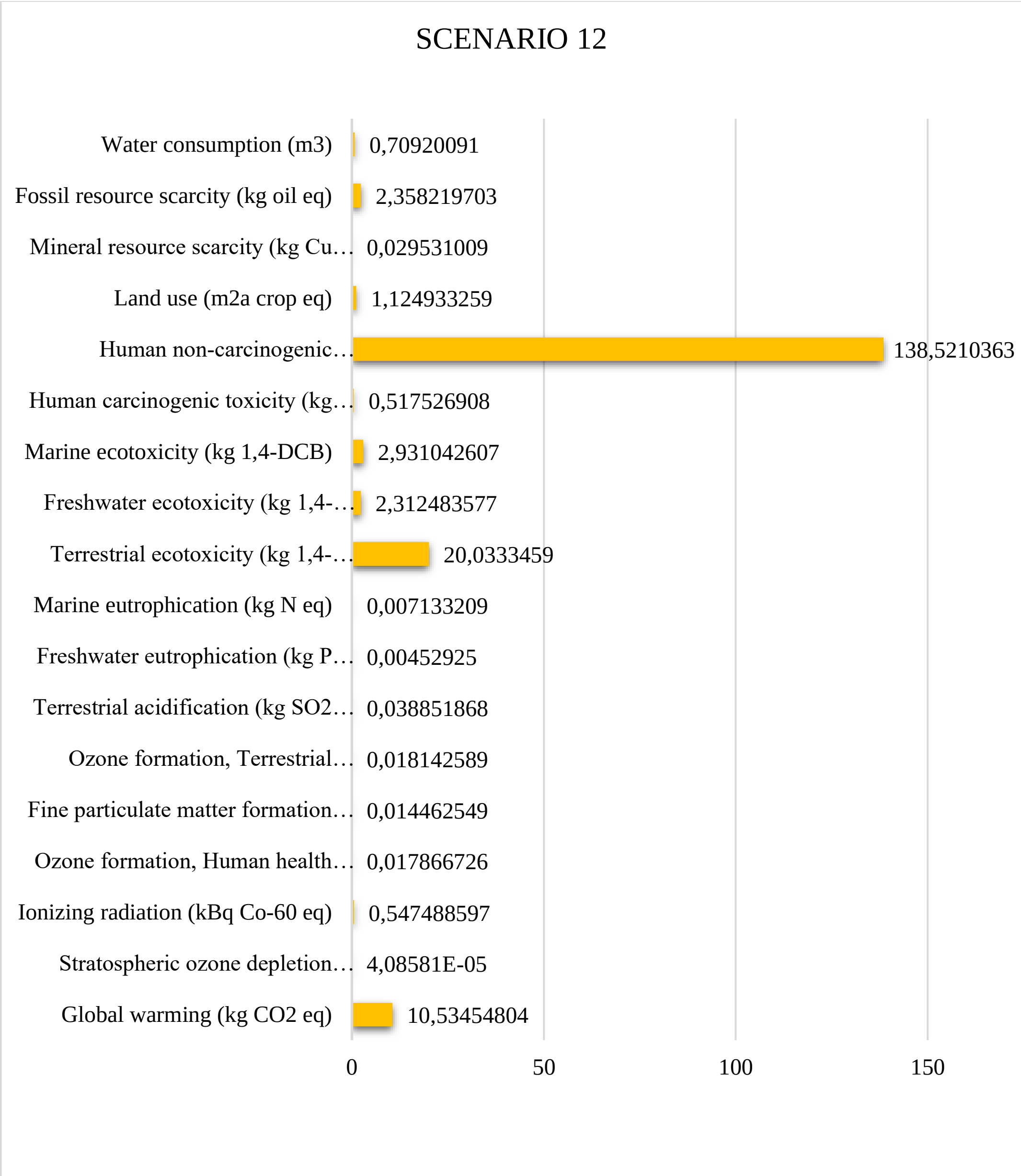

SCENARIO 8
Water consumption (m3)
0,352045709
Fossil resource scarcity (kg oil eq)
1,191071045
Mineral resource scarcity (kg Cu…
0,020542896
Land use (m2a crop eq)
0,338247539
Human non-carcinogenic…
32,33412717
Human carcinogenic toxicity (kg…
0,29981456
Marine ecotoxicity (kg 1,4-DCB)
0,945560084
Freshwater ecotoxicity (kg 1,4-…
0,742762194
Terrestrial ecotoxicity (kg 1,4-…
16,36293821
Marine eutrophication (kg N eq)
0,001661103
Freshwater eutrophication (kg P…
0,002868184
Terrestrial acidification (kg SO2…
0,024316893
Ozone formation, Terrestrial…
0,014291035
Fine particulate matter formation…
0,012011423
Ozone formation, Human health…
0,01403931
Ionizing radiation (kBq Co-60 eq)
0,549965053
Stratospheric ozone depletion…
1,21479E-05
Global warming (kg CO2 eq)
8,206014299
0
10
20
30
40


SCENARIO 9
Water consumption (m3)
0,340010971
Fossil resource scarcity (kg oil eq)
1,190549976
Mineral resource scarcity (kg Cu…
0,020003959
Land use (m2a crop eq)
0,315162489
Human non-carcinogenic…
29,55792442
Human carcinogenic toxicity (kg…
0,291100885
Marine ecotoxicity (kg 1,4-DCB)
0,888992835
Freshwater ecotoxicity (kg 1,4-…
0,698401714
Terrestrial ecotoxicity (kg 1,4-…
15,43742514
Marine eutrophication (kg N eq)
0,001519268
Freshwater eutrophication (kg P…
0,002796002
Terrestrial acidification (kg SO2…
0,024032816
Ozone formation, Terrestrial…
0,014375612
Fine particulate matter formation…
0,011910588
Ozone formation, Human health…
0,014127817
Ionizing radiation (kBq Co-60 eq)
0,543376903
Stratospheric ozone depletion…
1,13508E-05
Global warming (kg CO2 eq)
8,191457726
0
10
20
30
40

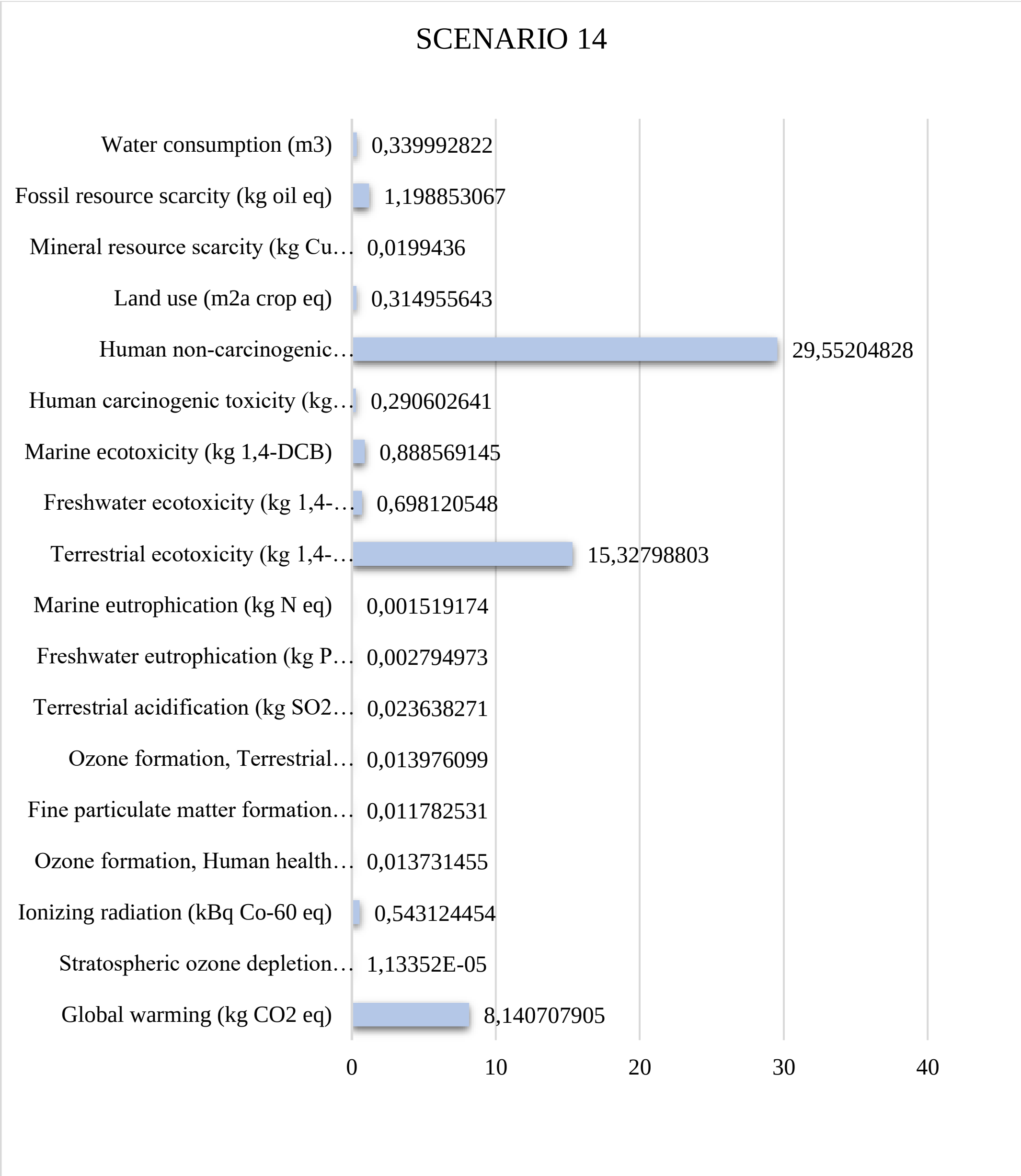

SCENARIO 10
Water consumption (m3)
1,078374674
Fossil resource scarcity (kg oil eq)
2,496224646
Mineral resource scarcity (kg Cu eq)
0,03928867
Land use (m2a crop eq)
1,936891515
Human non-carcinogenic toxicity (kg 1,4-DCB)
247,514303
Human carcinogenic toxicity (kg 1,4-DCB)
0,744799373
Marine ecotoxicity (kg 1,4-DCB)
4,974321672
Freshwater ecotoxicity (kg 1,4-DCB)
3,927047749
Terrestrial ecotoxicity (kg 1,4-DCB)
25,64130343
Marine eutrophication (kg N eq)
0,012747049
Freshwater eutrophication (kg P eq)
0,006259841
Terrestrial acidification (kg SO2 eq)
0,05395379
Ozone formation, Terrestrial ecosystems (kg NOx eq)
0,022201305
Fine particulate matter formation (kg PM2.5 eq)
0,017106024
Ozone formation, Human health (kg NOx eq)
0,021891095
Ionizing radiation (kBq Co-60 eq)
0,550774645
Stratospheric ozone depletion (kg CFC11 eq)
7,04069E-05
Global warming (kg CO2 eq)
13,68499631
0
50
100
150
200
250
300

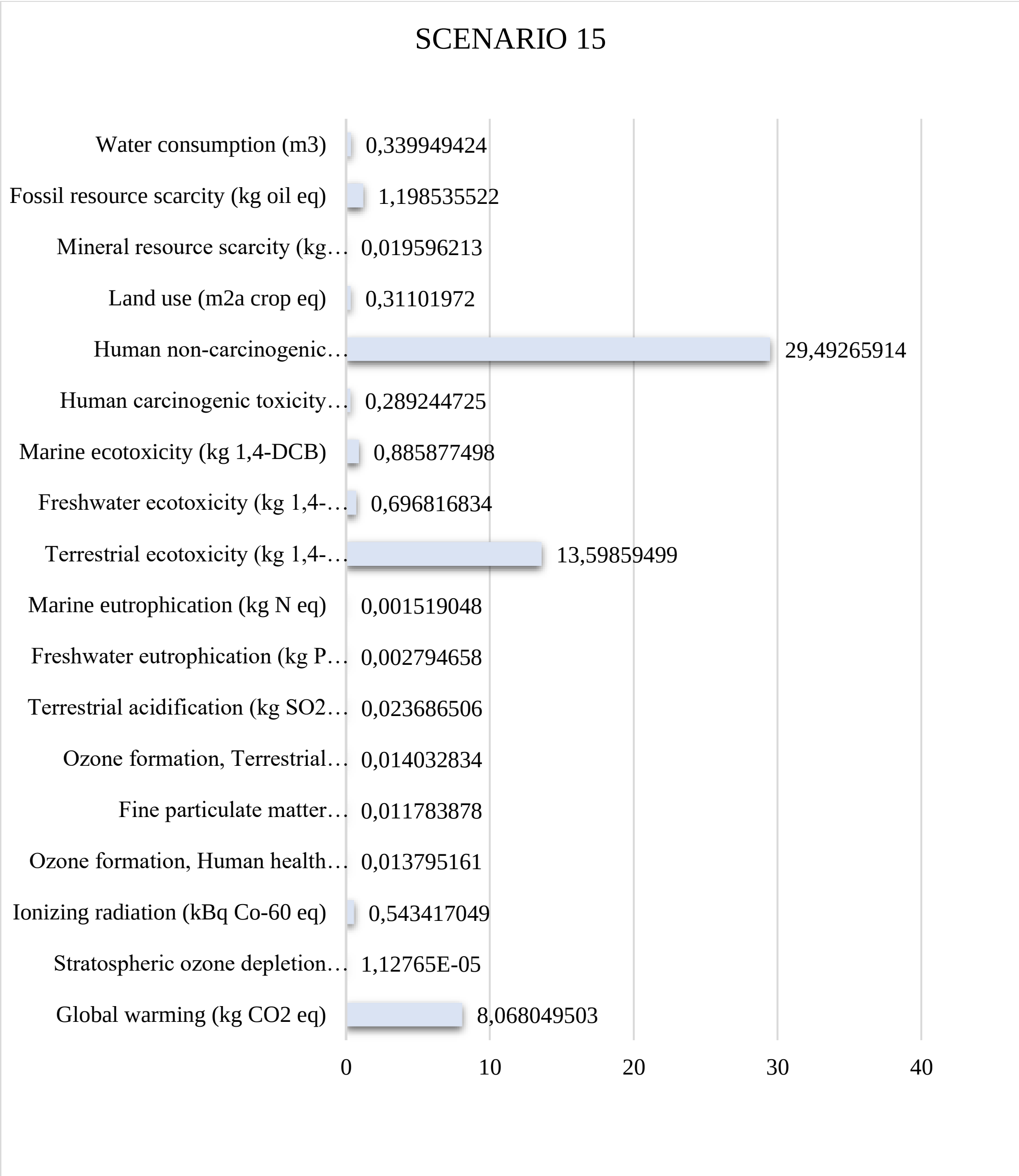


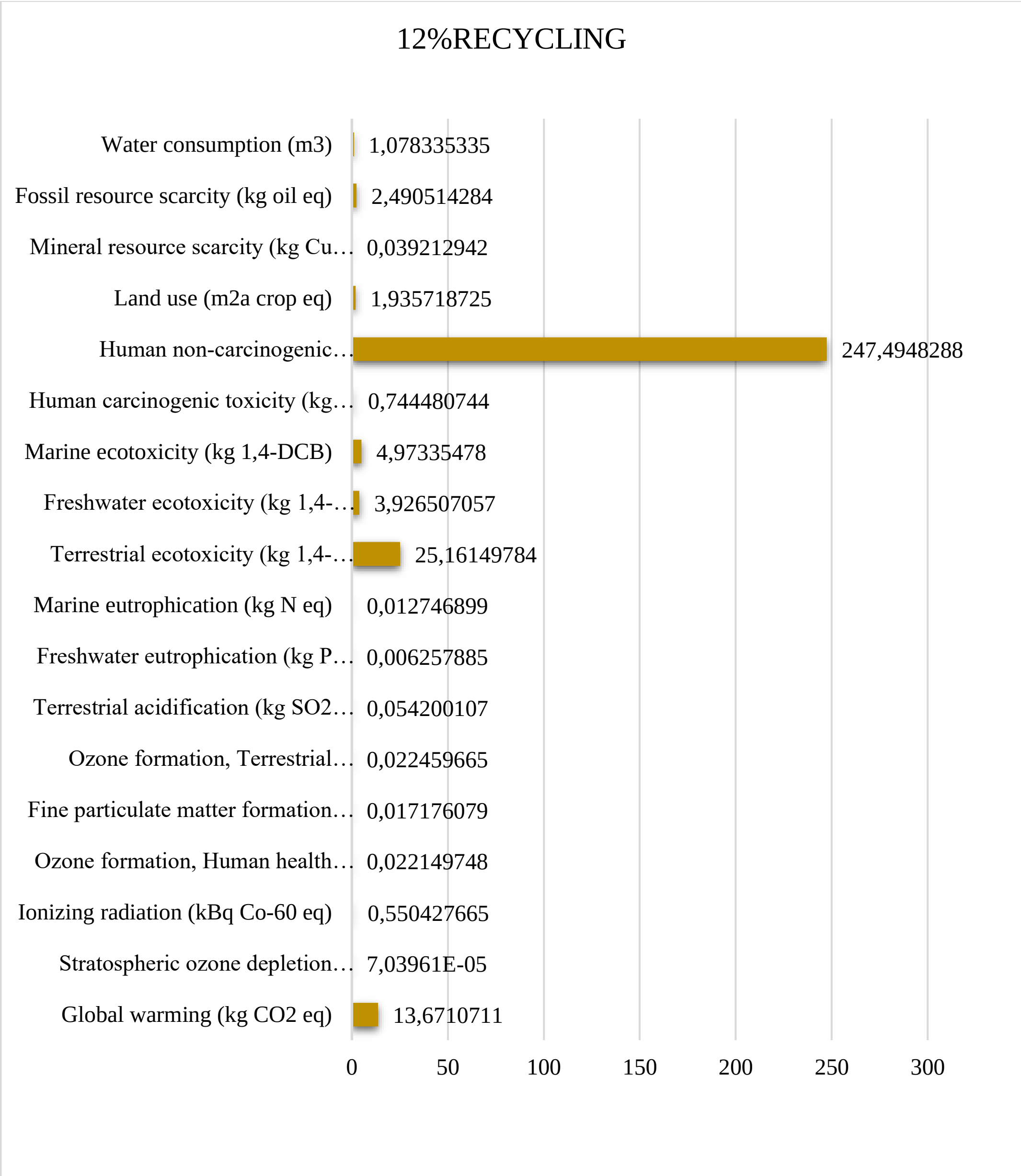
SCENARIO 11
Water consumption (m3)
1,078374674
Fossil resource scarcity (kg oil eq)
2,496224646
Mineral resource scarcity (kg Cu eq)
0,03928867
Land use (m2a crop eq)
1,936891515
Human non-carcinogenic toxicity (kg 1,4-DCB)
247,514303
Human carcinogenic toxicity (kg 1,4-DCB)
0,744799373
Marine ecotoxicity (kg 1,4-DCB)
4,974321672
Freshwater ecotoxicity (kg 1,4-DCB)
3,927047749
Terrestrial ecotoxicity (kg 1,4-DCB)
25,64130343
Marine eutrophication (kg N eq)
0,012747049
Freshwater eutrophication (kg P eq)
0,006259841
Terrestrial acidification (kg SO2 eq)
0,05395379
Ozone formation, Terrestrial ecosystems (kg NOx eq)
0,022201305
Fine particulate matter formation (kg PM2.5 eq)
0,017106024
Ozone formation, Human health (kg NOx eq)
0,021891095
Ionizing radiation (kBq Co-60 eq)
0,550774645
Stratospheric ozone depletion (kg CFC11 eq)
7,04069E-05
Global warming (kg CO2 eq)
13,67109631
0
50
100
150
200
250
300

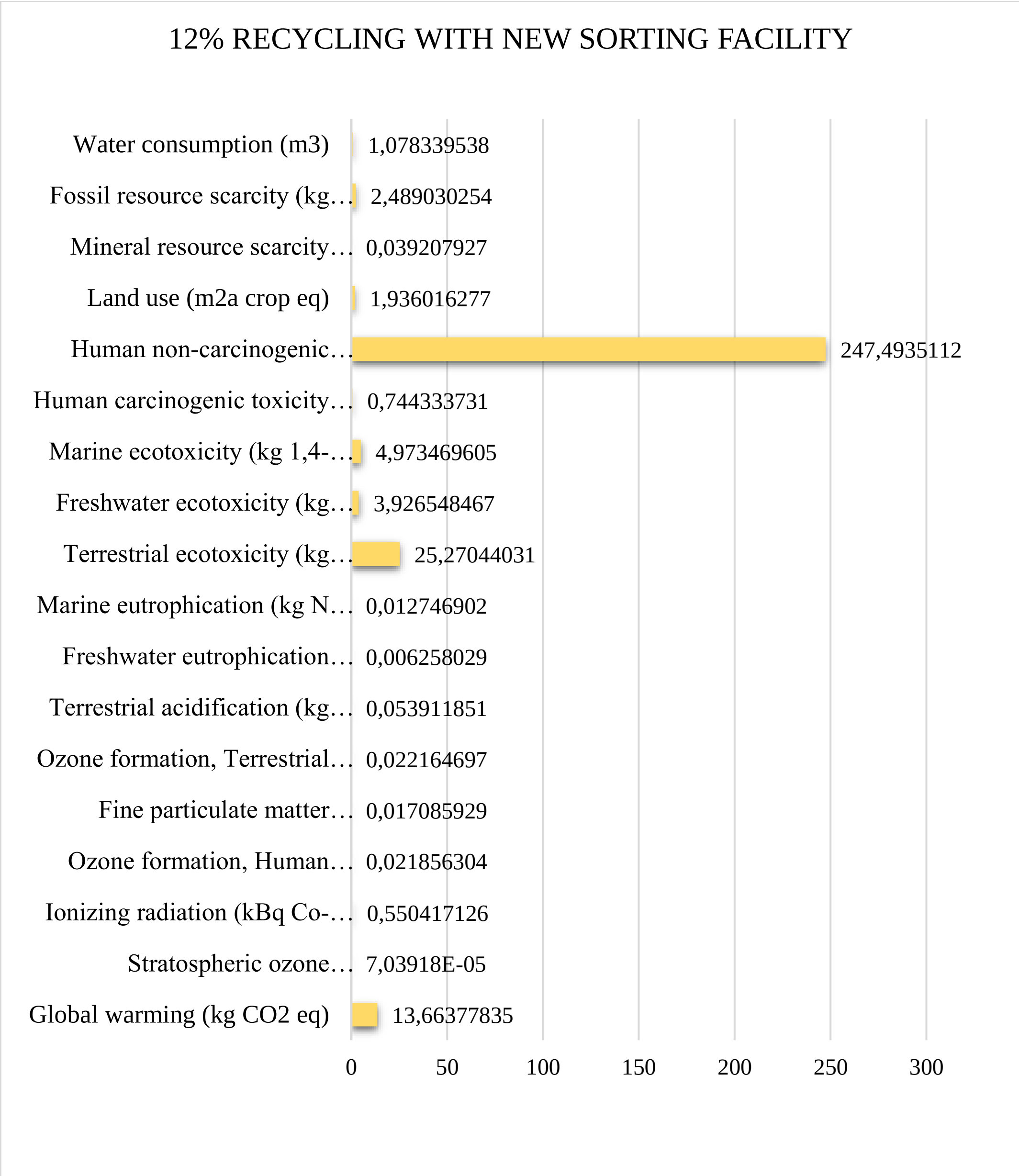

SCENARIO 12
Water consumption (m3)
0,70920091
Fossil resource scarcity (kg oil eq)
2,358219703
Mineral resource scarcity (kg Cu…
0,029531009
Land use (m2a crop eq)
1,124933259
Human non-carcinogenic…
138,5210363
Human carcinogenic toxicity (kg…
0,517526908
Marine ecotoxicity (kg 1,4-DCB)
2,931042607
Freshwater ecotoxicity (kg 1,4-…
2,312483577
Terrestrial ecotoxicity (kg 1,4-…
20,0333459
Marine eutrophication (kg N eq)
0,007133209
Freshwater eutrophication (kg P…
0,00452925
Terrestrial acidification (kg SO2…
0,038851868
Ozone formation, Terrestrial…
0,018142589
Fine particulate matter formation…
0,014462549
Ozone formation, Human health…
0,017866726
Ionizing radiation (kBq Co-60 eq)
0,547488597
Stratospheric ozone depletion…
4,08581E-05
Global warming (kg CO2 eq)
10,53454804
0
50
100
150

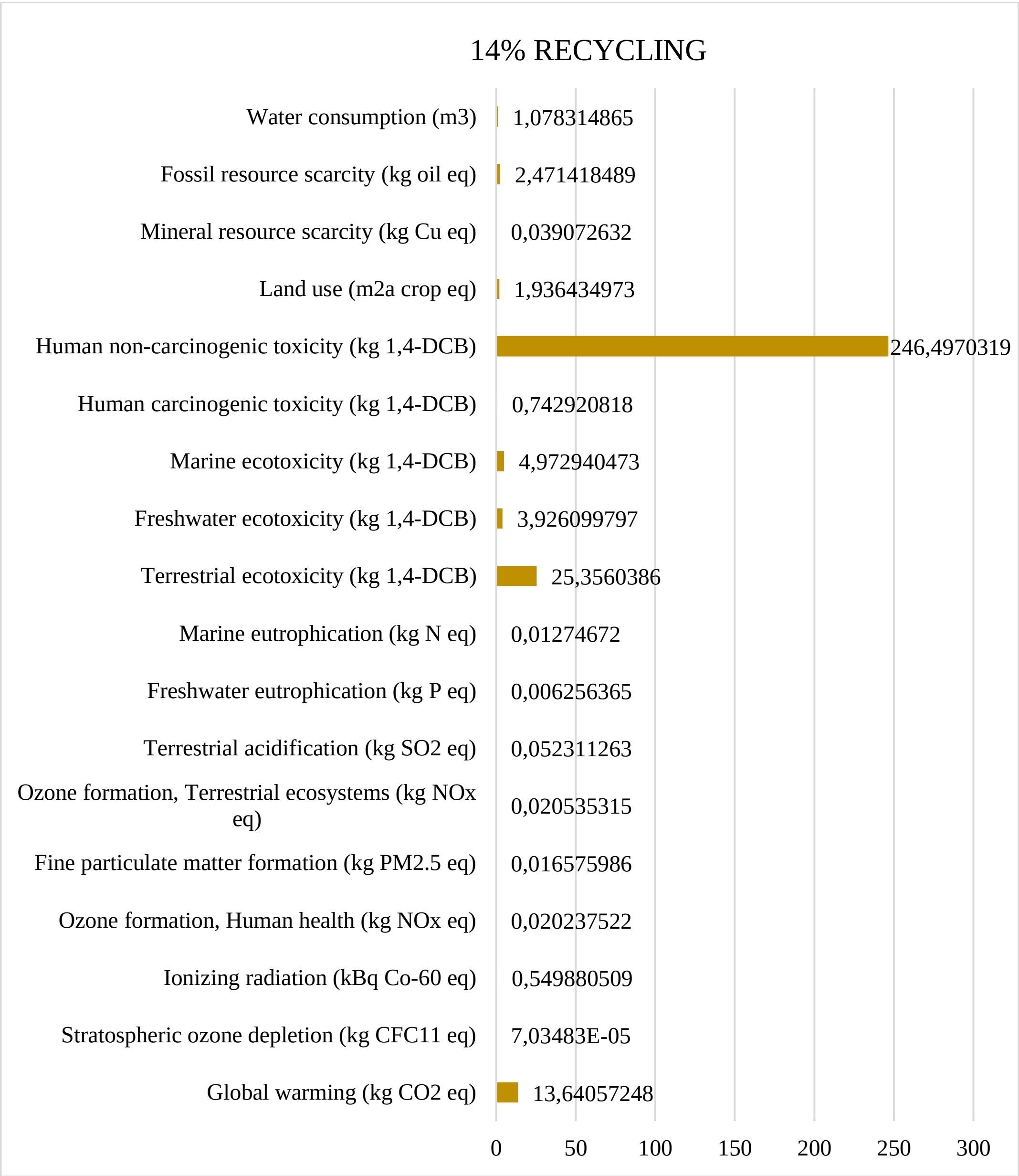

SCENARIO 13
Water consumption (m3)
0,61187323
Fossil resource scarcity (kg oil eq)
1,199595301
Mineral resource scarcity (kg Cu...
0,028049724
Land use (m2a crop eq)
0,868363838
Human non-carcinogenic toxicity...
102,7237931
Human carcinogenic toxicity (kg...
0,465109792
Marine ecotoxicity (kg 1,4-DCB)
2,292952153
Freshwater ecotoxicity (kg 1,4-...
1,807737489
Terrestrial ecotoxicity (kg 1,4-DCB)
19,85304689
Marine eutrophication (kg N eq)
0,005288762
Freshwater eutrophication (kg P...
0,00418864
Terrestrial acidification (kg SO2...
0,035214146
Ozone formation, Terrestrial...
0,017463643
Fine particulate matter...
0,014492392
Ozone formation, Human health...
0,017178579
Ionizing radiation (kBq Co-60 eq)
0,599383448
Stratospheric ozone depletion...
3,14744E-05
Global warming (kg CO2 eq)
10,49859909
0
20
40
60
80
100
120


SCENARIO 14
Water consumption (m3)
0,339992822
Fossil resource scarcity (kg oil eq)
1,198853067
Mineral resource scarcity (kg Cu…
0,0199436
Land use (m2a crop eq)
0,314955643
Human non-carcinogenic…
29,55204828
Human carcinogenic toxicity (kg…
0,290602641
Marine ecotoxicity (kg 1,4-DCB)
0,888569145
Freshwater ecotoxicity (kg 1,4-…
0,698120548
Terrestrial ecotoxicity (kg 1,4-…
15,32798803
Marine eutrophication (kg N eq)
0,001519174
Freshwater eutrophication (kg P…
0,002794973
Terrestrial acidification (kg SO2…
0,023638271
Ozone formation, Terrestrial…
0,013976099
Fine particulate matter formation…
0,011782531
Ozone formation, Human health…
0,013731455
Ionizing radiation (kBq Co-60 eq)
0,543124454
Stratospheric ozone depletion…
1,13352E-05
Global warming (kg CO2 eq)
8,140707905
0
10
20
30
40


SCENARIO 15
Water consumption (m3)
0,339949424
Fossil resource scarcity (kg oil eq)
1,198535522
Mineral resource scarcity (kg…
0,019596213
Land use (m2a crop eq)
0,31101972
Human non-carcinogenic…
29,49265914
Human carcinogenic toxicity…
0,289244725
Marine ecotoxicity (kg 1,4-DCB)
0,885877498
Freshwater ecotoxicity (kg 1,4-…
0,696816834
Terrestrial ecotoxicity (kg 1,4-…
13,59859499
Marine eutrophication (kg N eq)
0,001519048
Freshwater eutrophication (kg P…
0,002794658
Terrestrial acidification (kg SO2…
0,023686506
Ozone formation, Terrestrial…
0,014032834
Fine particulate matter…
0,011783878
Ozone formation, Human health…
0,013795161
Ionizing radiation (kBq Co-60 eq)
0,543417049
Stratospheric ozone depletion…
1,12765E-05
Global warming (kg CO2 eq)
8,068049503
0
10
20
30
40

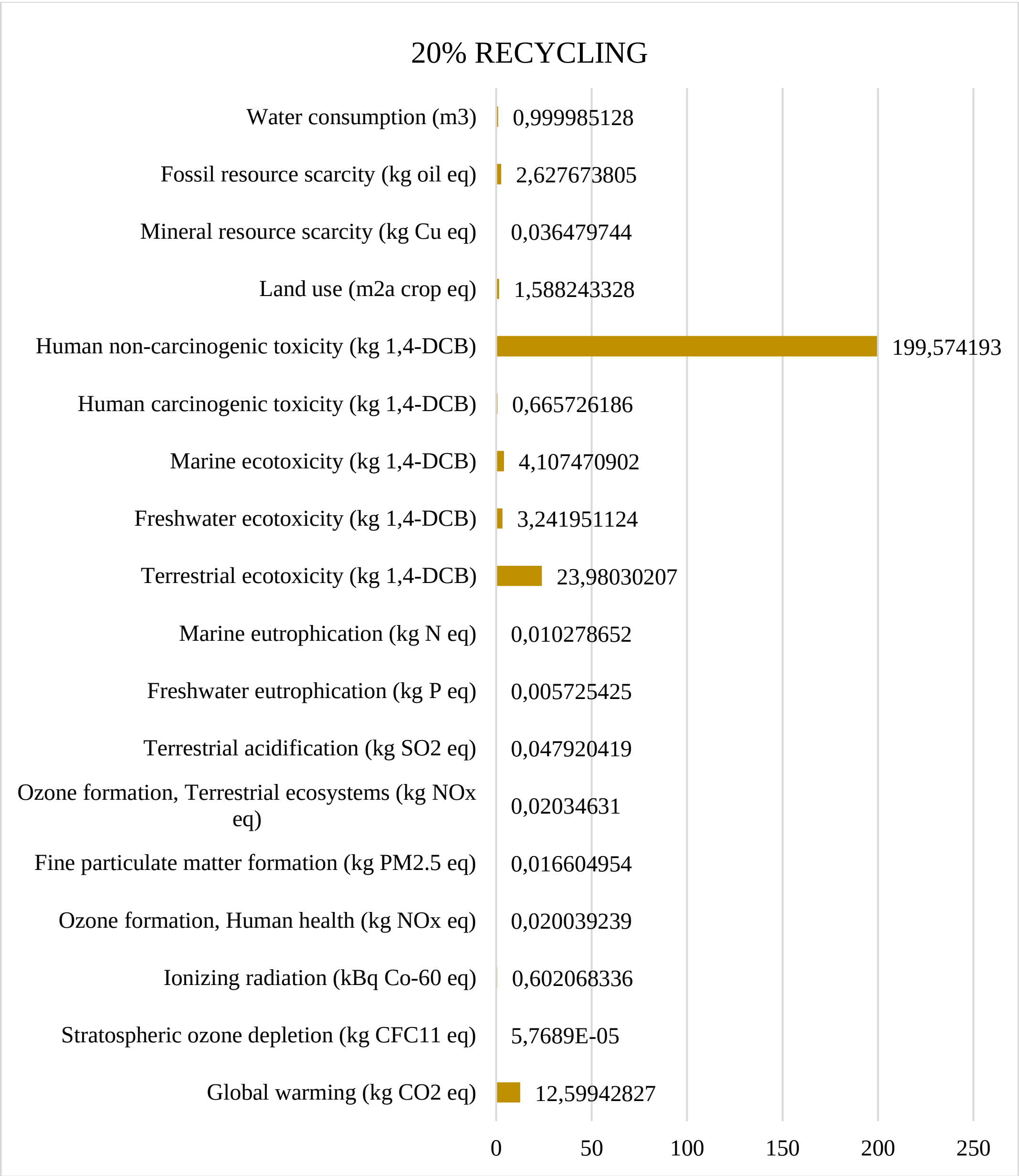

12%RECYCLING
Water consumption (m3)
1,078335335
Fossil resource scarcity (kg oil eq)
2,490514284
Mineral resource scarcity (kg Cu…
0,039212942
Land use (m2a crop eq)
1,935718725
Human non-carcinogenic…
247,4948288
Human carcinogenic toxicity (kg…
0,744480744
Marine ecotoxicity (kg 1,4-DCB)
4,97335478
Freshwater ecotoxicity (kg 1,4-…
3,926507057
Terrestrial ecotoxicity (kg 1,4-…
25,16149784
Marine eutrophication (kg N eq)
0,012746899
Freshwater eutrophication (kg P…
0,006257885
Terrestrial acidification (kg SO2…
0,054200107
Ozone formation, Terrestrial…
0,022459665
Fine particulate matter formation…
0,017176079
Ozone formation, Human health…
0,022149748
Ionizing radiation (kBq Co-60 eq)
0,550427665
Stratospheric ozone depletion…
7,03961E-05
Global warming (kg CO2 eq)
13,6710711
0
50
100
150
200
250
300

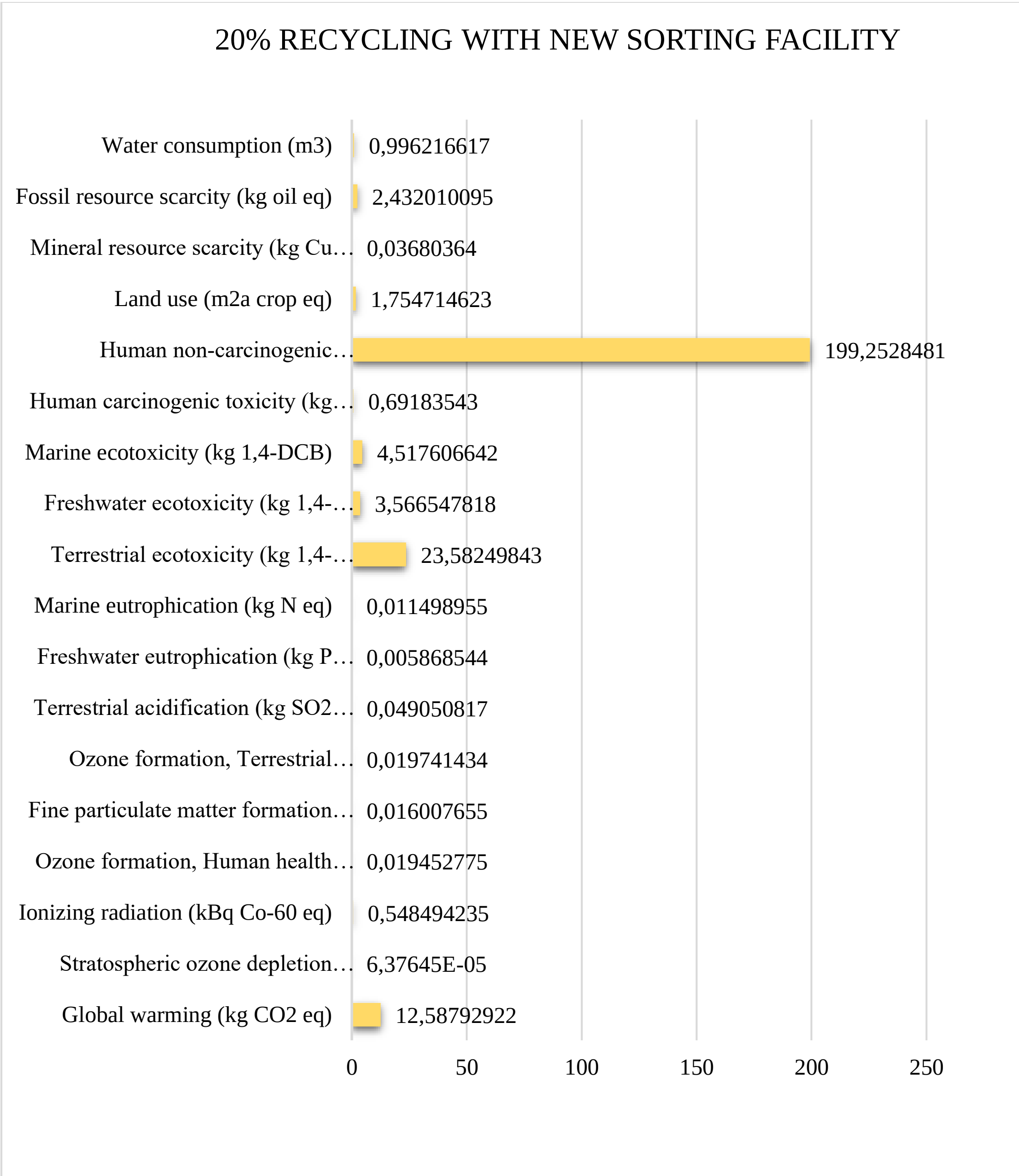

12% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
1,078339538
Fossil resource scarcity (kg…
2,489030254
Mineral resource scarcity…
0,039207927
Land use (m2a crop eq)
1,936016277
Human non-carcinogenic…
247,4935112
Human carcinogenic toxicity…
0,744333731
Marine ecotoxicity (kg 1,4-…
4,973469605
Freshwater ecotoxicity (kg…
3,926548467
Terrestrial ecotoxicity (kg…
25,27044031
Marine eutrophication (kg N…
0,012746902
Freshwater eutrophication…
0,006258029
Terrestrial acidification (kg…
0,053911851
Ozone formation, Terrestrial…
0,022164697
Fine particulate matter…
0,017085929
Ozone formation, Human…
0,021856304
Ionizing radiation (kBq Co-…
0,550417126
Stratospheric ozone…
7,03918E-05
Global warming (kg CO2 eq)
13,66377835
0
50
100
150
200
250
300

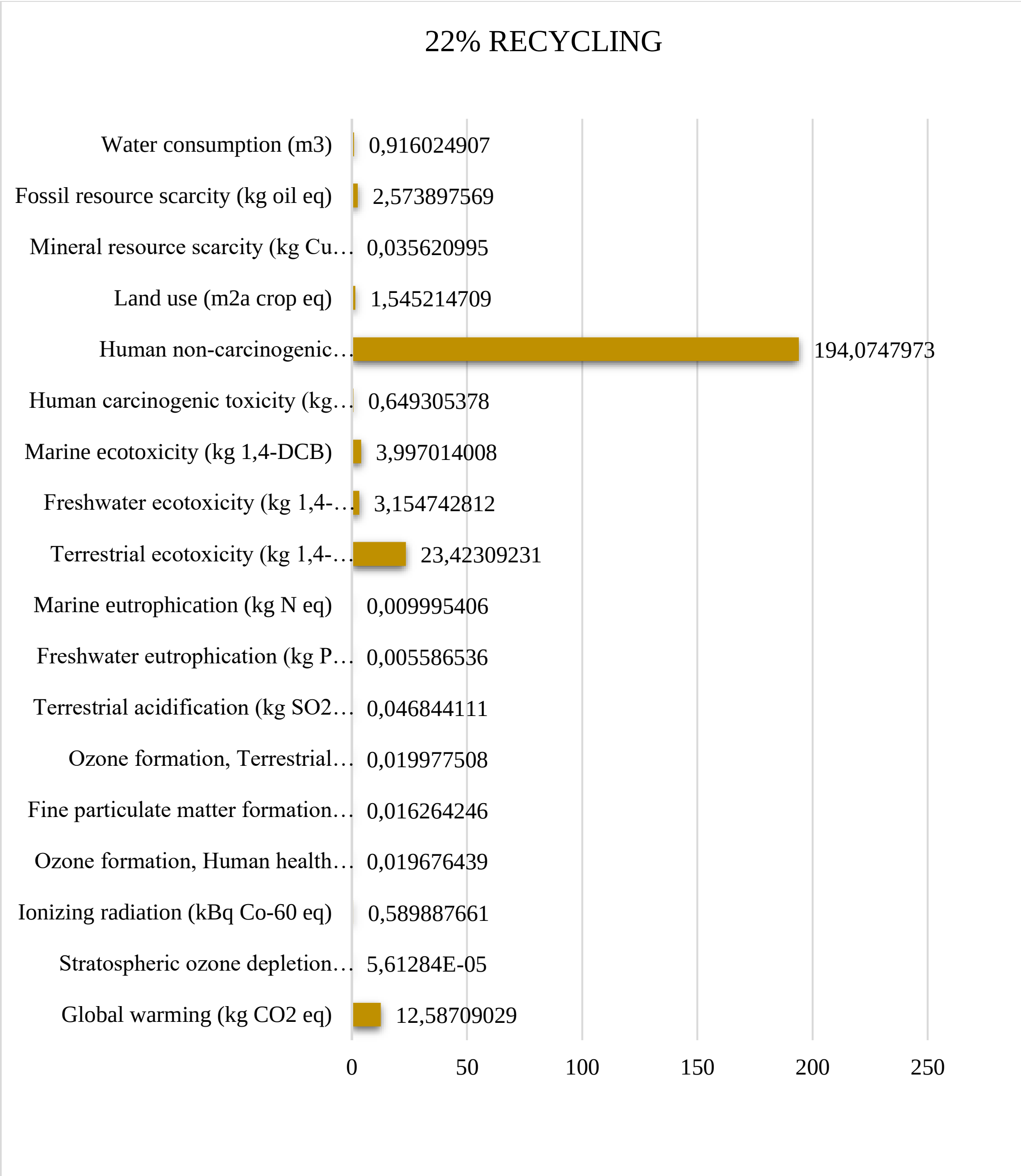


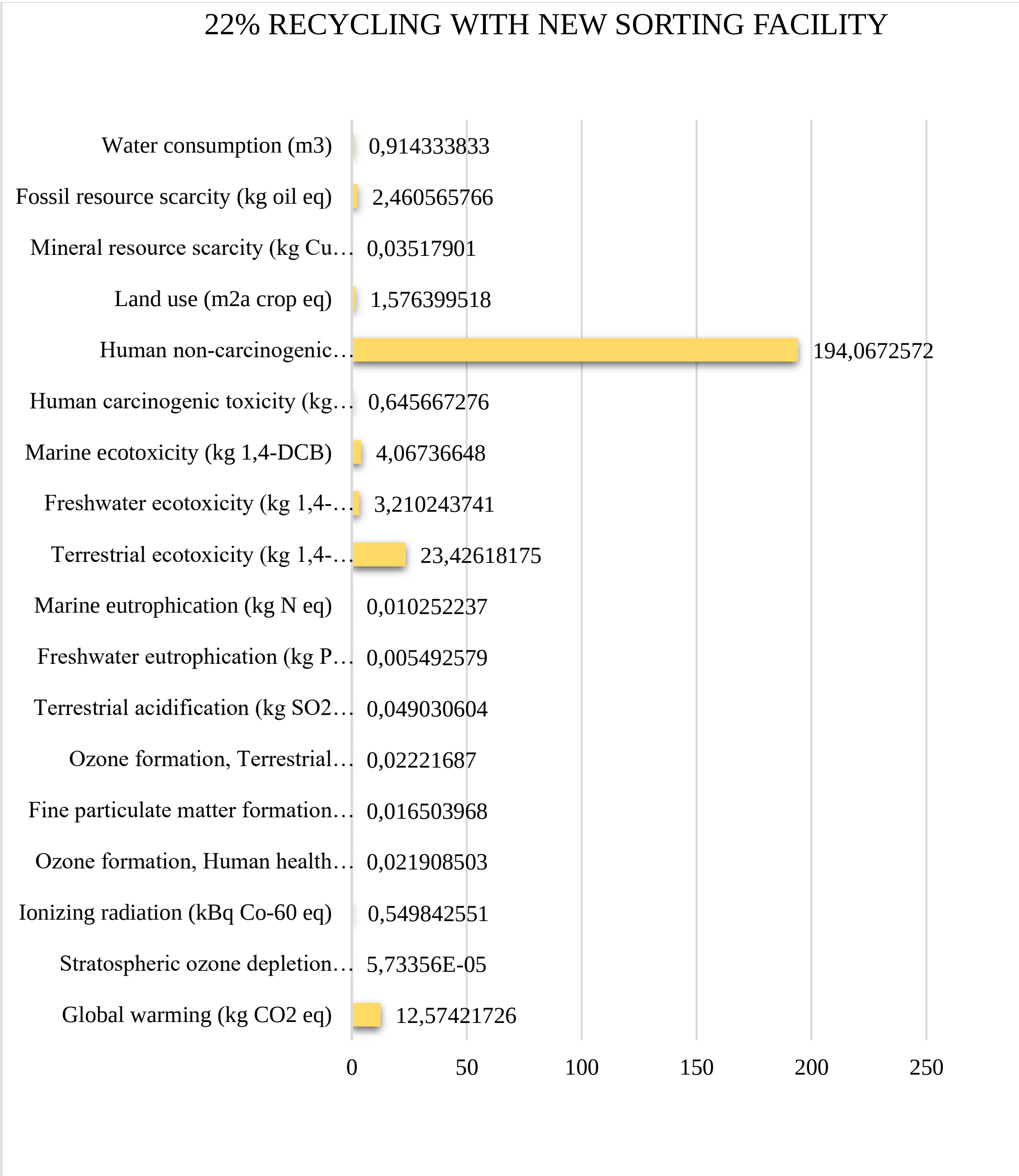
14% RECYCLING
Water consumption (m3)
1,078314865
Fossil resource scarcity (kg oil eq)
2,471418489
Mineral resource scarcity (kg Cu eq)
0,039072632
Land use (m2a crop eq)
1,936434973
Human non-carcinogenic toxicity (kg 1,4-DCB)
246,4970319
Human carcinogenic toxicity (kg 1,4-DCB)
0,742920818
Marine ecotoxicity (kg 1,4-DCB)
4,972940473
Freshwater ecotoxicity (kg 1,4-DCB)
3,926099797
Terrestrial ecotoxicity (kg 1,4-DCB)
25,3560386
Marine eutrophication (kg N eq)
0,01274672
Freshwater eutrophication (kg P eq)
0,006256365
Terrestrial acidification (kg SO2 eq)
0,052311263
Ozone formation, Terrestrial ecosystems (kg NOx eq)
0,020535315
Fine particulate matter formation (kg PM2.5 eq)
0,016575986
Ozone formation, Human health (kg NOx eq)
0,020237522
Ionizing radiation (kBq Co-60 eq)
0,549880509
Stratospheric ozone depletion (kg CFC11 eq)
7,03483E-05
Global warming (kg CO2 eq)
13,64057248
0
50
100
150
200
250
300

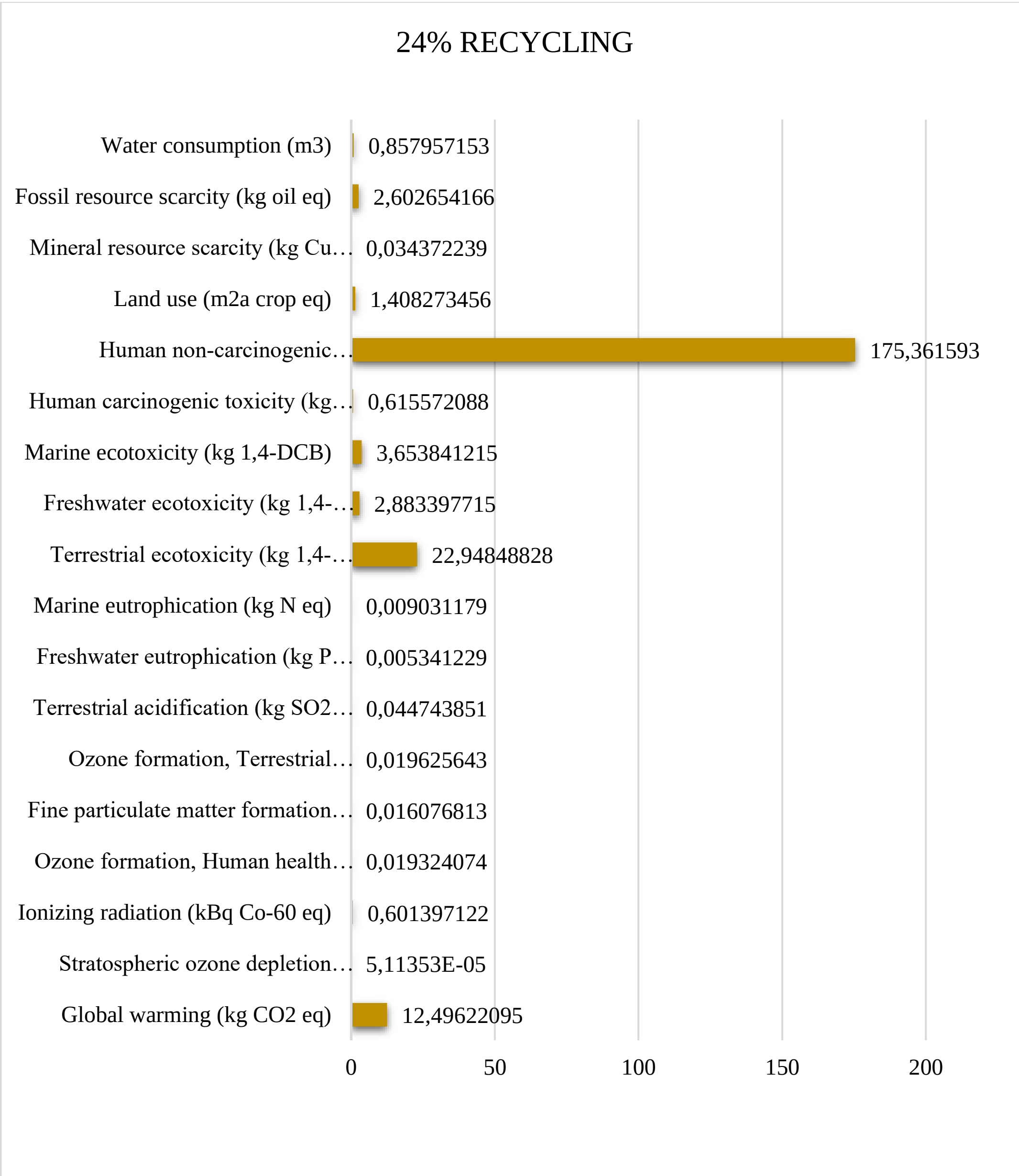

14% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
1,078286755
Fossil resource scarcity (kg oil eq)
2,465662982
Mineral resource scarcity (kg Cu eq)
0,039008037
Land use (m2a crop eq)
1,935734782
Human non-carcinogenic toxicity (kg 1,4-DCB)
246,4843984
Human carcinogenic toxicity (kg 1,4-DCB)
0,742548302
Marine ecotoxicity (kg 1,4-DCB)
4,972258817
Freshwater ecotoxicity (kg 1,4-DCB)
3,92570037
Terrestrial ecotoxicity (kg 1,4-DCB)
25,05934816
Marine eutrophication (kg N eq)
0,012746603
Freshwater eutrophication (kg P eq)
0,006254915
Terrestrial acidification (kg SO2 eq)
0,052277712
Ozone formation, Terrestrial ecosystems (kg NOx eq)
0,020506029
Fine particulate matter formation (kg PM2.5 eq)
0,01655991
Ozone formation, Human health (kg NOx eq)
0,020209689
Ionizing radiation (kBq Co-60 eq)
0,549594489
Stratospheric ozone depletion (kg CFC11 eq)
7,03362E-05
Global warming (kg CO2 eq)
13,6315981
0
50
100
150
200
250
300

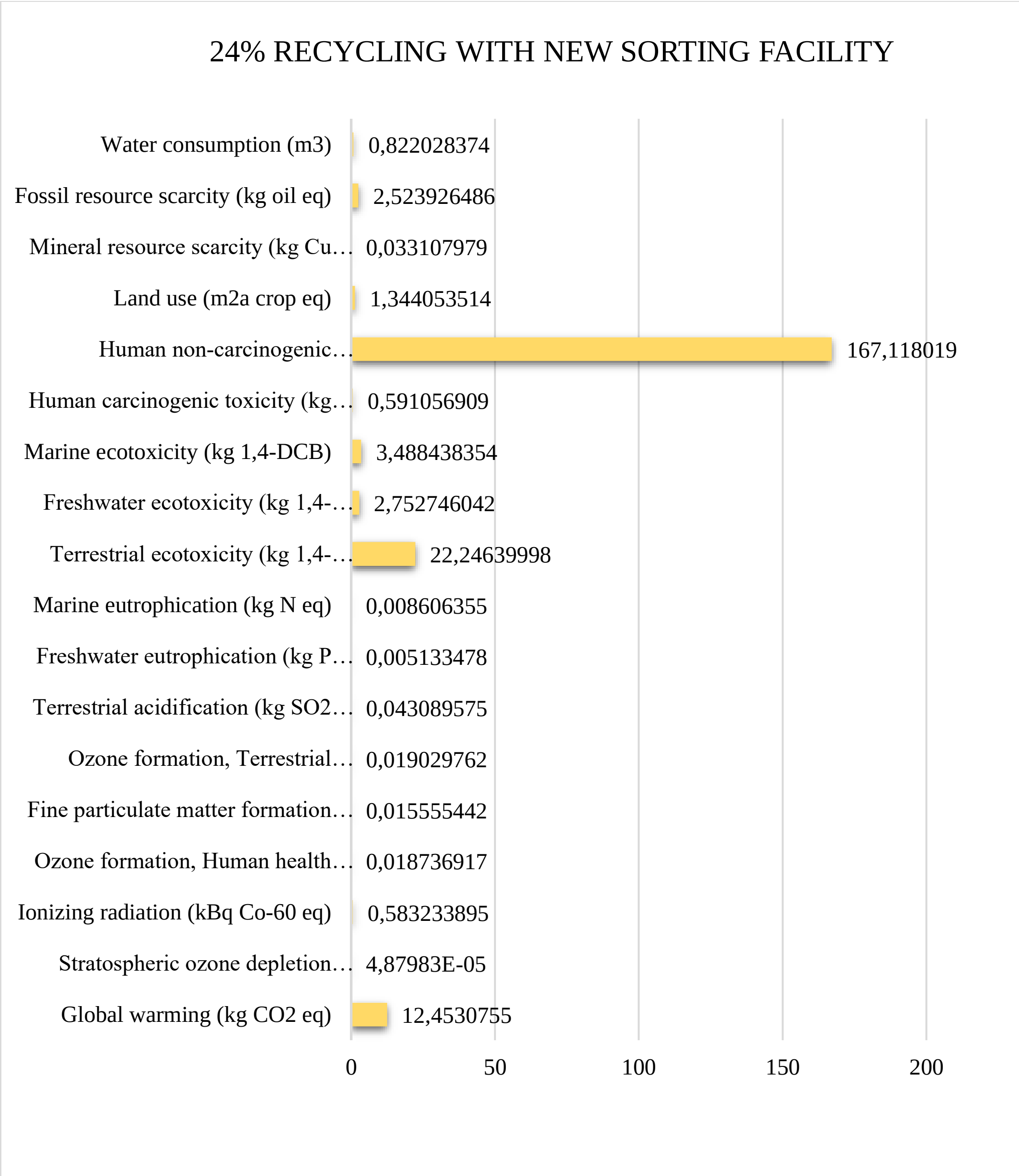

20% RECYCLING
Water consumption (m3)
0,999985128
Fossil resource scarcity (kg oil eq)
2,627673805
Mineral resource scarcity (kg Cu eq)
0,036479744
Land use (m2a crop eq)
1,588243328
Human non-carcinogenic toxicity (kg 1,4-DCB)
199,574193
Human carcinogenic toxicity (kg 1,4-DCB)
0,665726186
Marine ecotoxicity (kg 1,4-DCB)
4,107470902
Freshwater ecotoxicity (kg 1,4-DCB)
3,241951124
Terrestrial ecotoxicity (kg 1,4-DCB)
23,98030207
Marine eutrophication (kg N eq)
0,010278652
Freshwater eutrophication (kg P eq)
0,005725425
Terrestrial acidification (kg SO2 eq)
0,047920419
Ozone formation, Terrestrial ecosystems (kg NOx eq)
0,02034631
Fine particulate matter formation (kg PM2.5 eq)
0,016604954
Ozone formation, Human health (kg NOx eq)
0,020039239
Ionizing radiation (kBq Co-60 eq)
0,602068336
Stratospheric ozone depletion (kg CFC11 eq)
5,7689E-05
Global warming (kg CO2 eq)
12,59942827
0
50
100
150
200
250

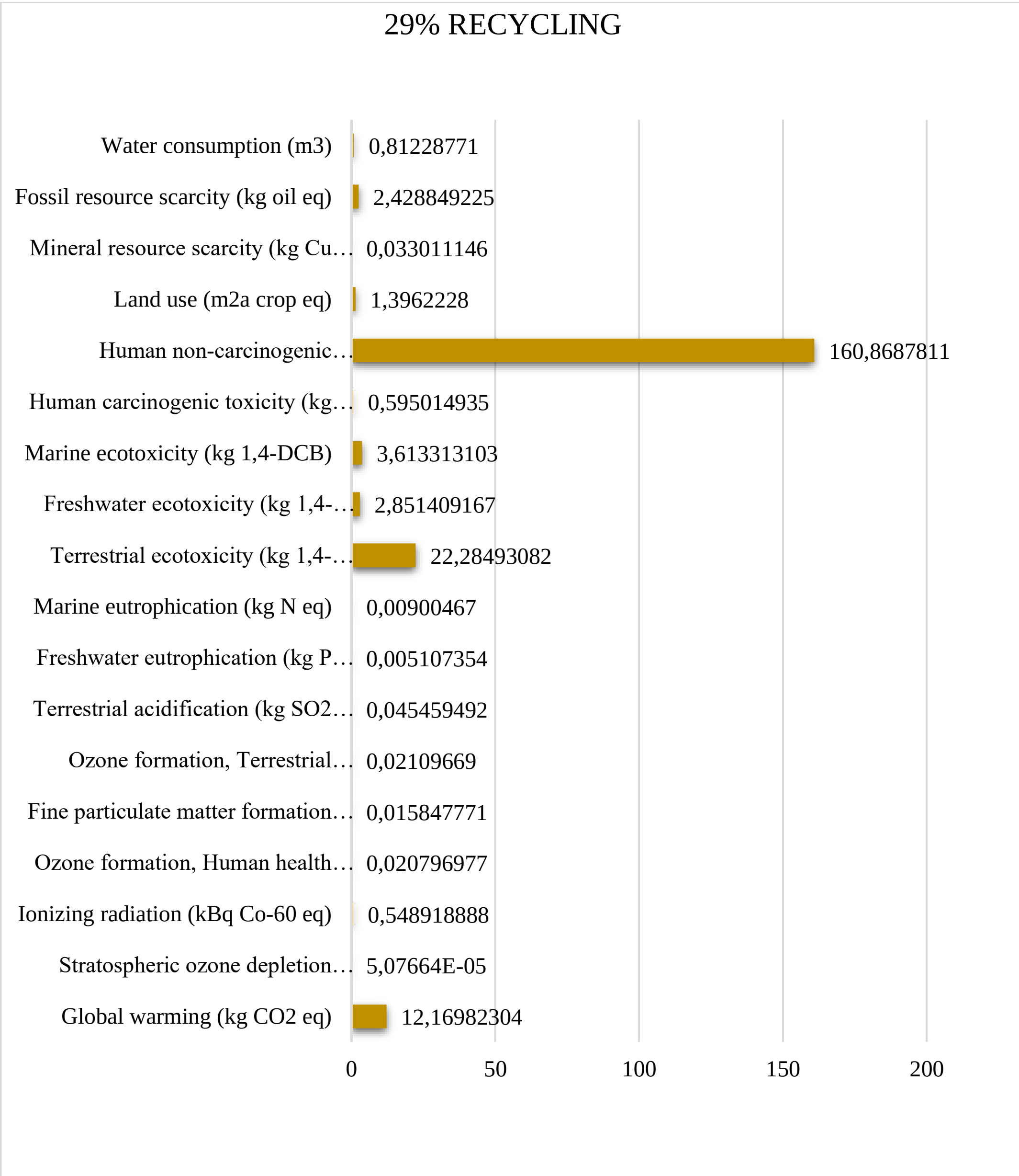

20% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,996216617
Fossil resource scarcity (kg oil eq)
2,432010095
Mineral resource scarcity (kg Cu…
0,03680364
Land use (m2a crop eq)
1,754714623
Human non-carcinogenic…
199,2528481
Human carcinogenic toxicity (kg…
0,69183543
Marine ecotoxicity (kg 1,4-DCB)
4,517606642
Freshwater ecotoxicity (kg 1,4-…
3,566547818
Terrestrial ecotoxicity (kg 1,4-…
23,58249843
Marine eutrophication (kg N eq)
0,011498955
Freshwater eutrophication (kg P…
0,005868544
Terrestrial acidification (kg SO2…
0,049050817
Ozone formation, Terrestrial…
0,019741434
Fine particulate matter formation…
0,016007655
Ozone formation, Human health…
0,019452775
Ionizing radiation (kBq Co-60 eq)
0,548494235
Stratospheric ozone depletion…
6,37645E-05
Global warming (kg CO2 eq)
12,58792922
0
50
100
150
200
250

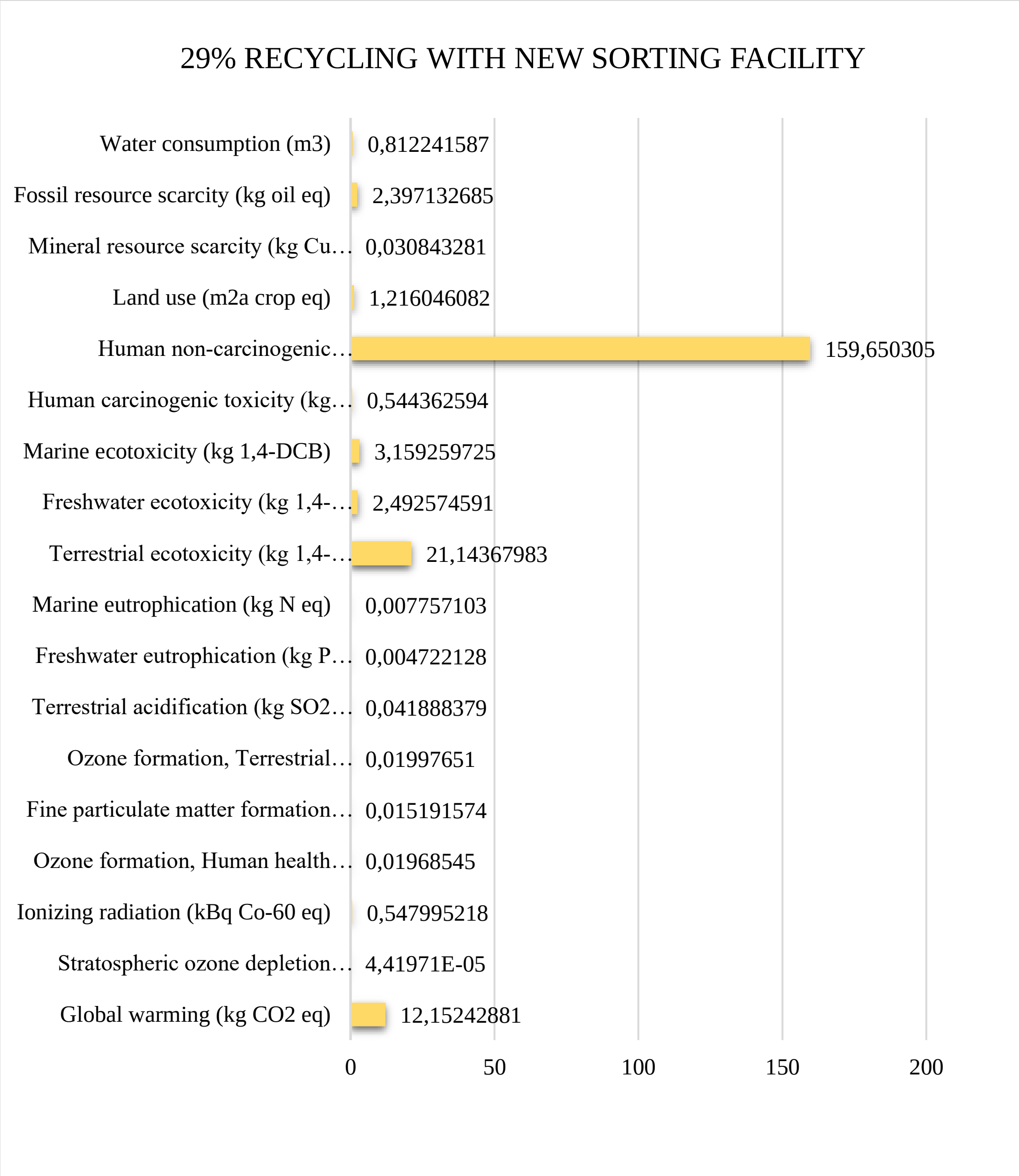

22% RECYCLING
Water consumption (m3)
0,916024907
Fossil resource scarcity (kg oil eq)
2,573897569
Mineral resource scarcity (kg Cu…
0,035620995
Land use (m2a crop eq)
1,545214709
Human non-carcinogenic…
194,0747973
Human carcinogenic toxicity (kg…
0,649305378
Marine ecotoxicity (kg 1,4-DCB)
3,997014008
Freshwater ecotoxicity (kg 1,4-…
3,154742812
Terrestrial ecotoxicity (kg 1,4-…
23,42309231
Marine eutrophication (kg N eq)
0,009995406
Freshwater eutrophication (kg P…
0,005586536
Terrestrial acidification (kg SO2…
0,046844111
Ozone formation, Terrestrial…
0,019977508
Fine particulate matter formation…
0,016264246
Ozone formation, Human health…
0,019676439
Ionizing radiation (kBq Co-60 eq)
0,589887661
Stratospheric ozone depletion…
5,61284E-05
Global warming (kg CO2 eq)
12,58709029
0
50
100
150
200
250

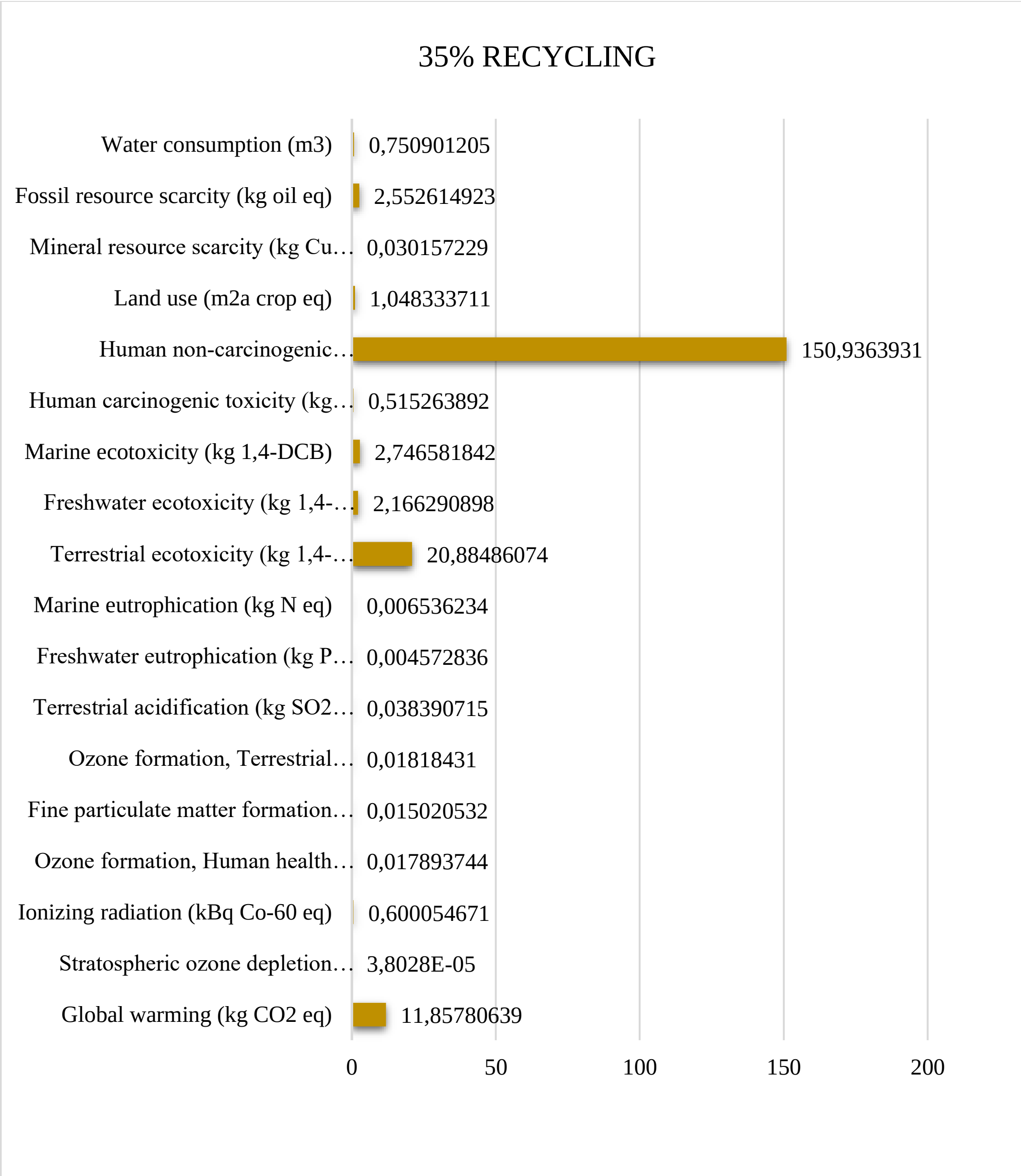

22% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,914333833
Fossil resource scarcity (kg oil eq)
2,460565766
Mineral resource scarcity (kg Cu…
0,03517901
Land use (m2a crop eq)
1,576399518
Human non-carcinogenic…
194,0672572
Human carcinogenic toxicity (kg…
0,645667276
Marine ecotoxicity (kg 1,4-DCB)
4,06736648
Freshwater ecotoxicity (kg 1,4-…
3,210243741
Terrestrial ecotoxicity (kg 1,4-…
23,42618175
Marine eutrophication (kg N eq)
0,010252237
Freshwater eutrophication (kg P…
0,005492579
Terrestrial acidification (kg SO2…
0,049030604
Ozone formation, Terrestrial…
0,02221687
Fine particulate matter formation…
0,016503968
Ozone formation, Human health…
0,021908503
Ionizing radiation (kBq Co-60 eq)
0,549842551
Stratospheric ozone depletion…
5,73356E-05
Global warming (kg CO2 eq)
12,57421726
0
50
100
150
200
250

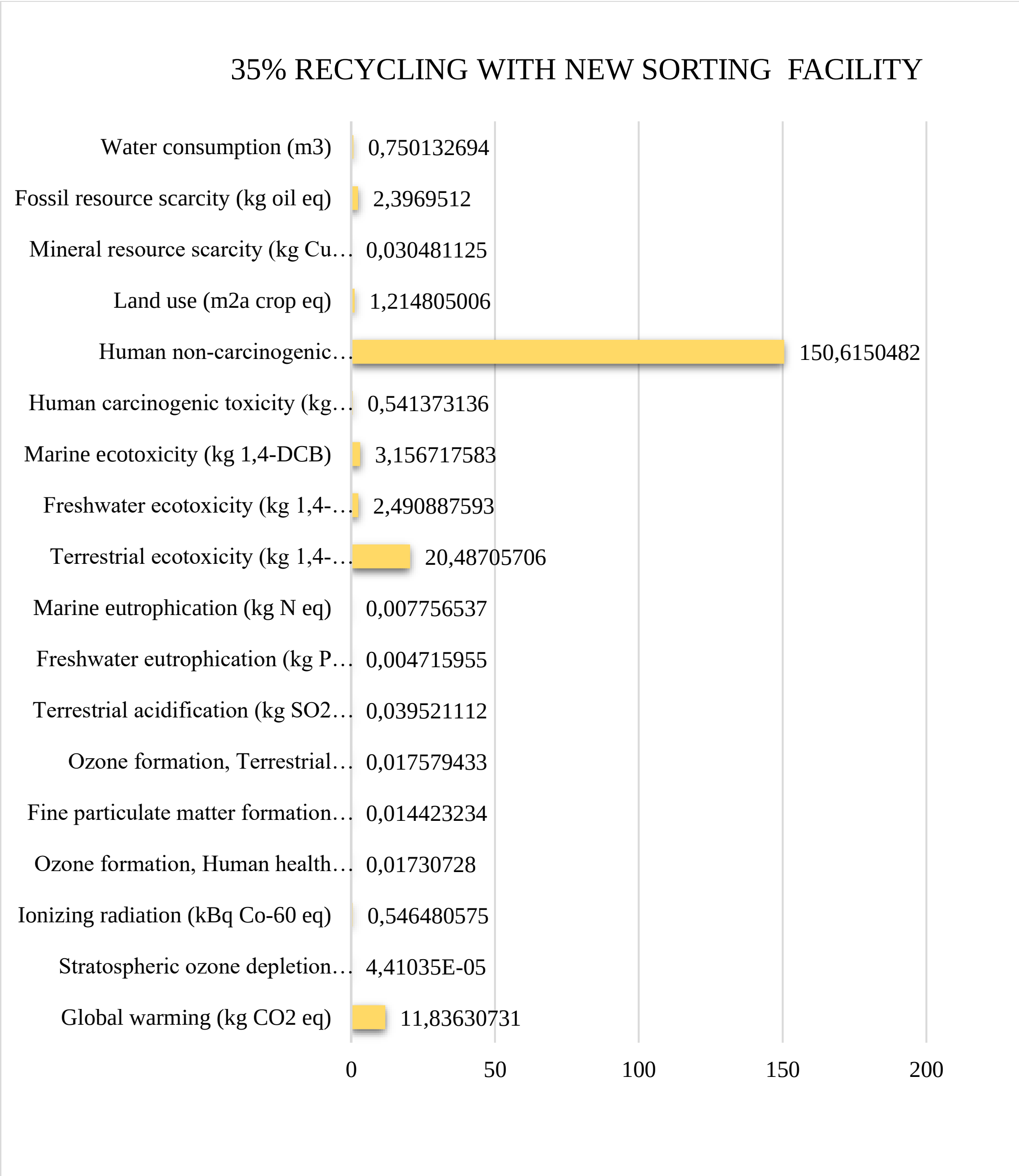

24% RECYCLING
Water consumption (m3)
0,857957153
Fossil resource scarcity (kg oil eq)
2,602654166
Mineral resource scarcity (kg Cu…
0,034372239
Land use (m2a crop eq)
1,408273456
Human non-carcinogenic…
175,361593
Human carcinogenic toxicity (kg…
0,615572088
Marine ecotoxicity (kg 1,4-DCB)
3,653841215
Freshwater ecotoxicity (kg 1,4-…
2,883397715
Terrestrial ecotoxicity (kg 1,4-…
22,94848828
Marine eutrophication (kg N eq)
0,009031179
Freshwater eutrophication (kg P…
0,005341229
Terrestrial acidification (kg SO2…
0,044743851
Ozone formation, Terrestrial…
0,019625643
Fine particulate matter formation…
0,016076813
Ozone formation, Human health…
0,019324074
Ionizing radiation (kBq Co-60 eq)
0,601397122
Stratospheric ozone depletion…
5,11353E-05
Global warming (kg CO2 eq)
12,49622095
0
50
100
150
200

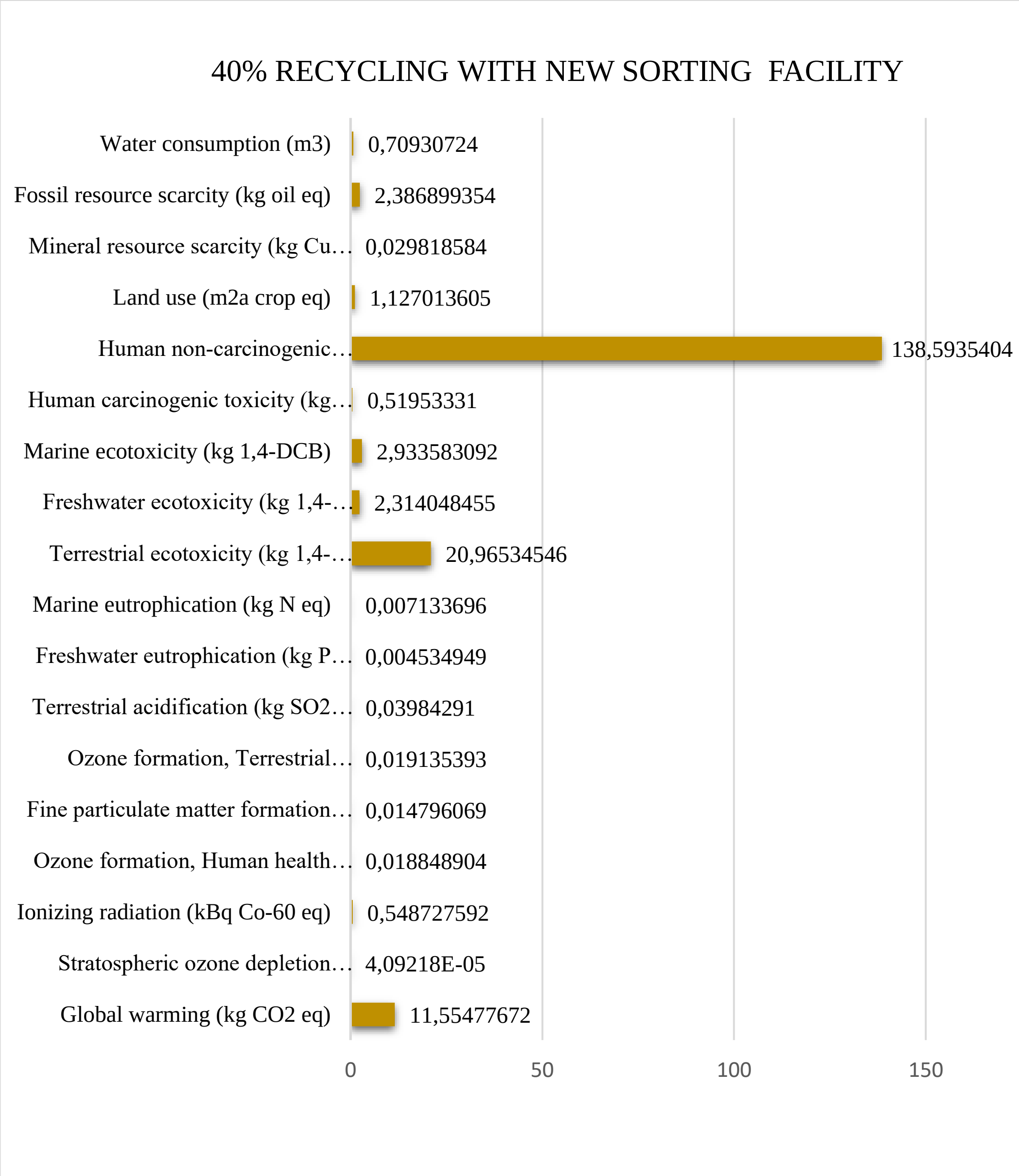

24% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,822028374
Fossil resource scarcity (kg oil eq)
2,523926486
Mineral resource scarcity (kg Cu…
0,033107979
Land use (m2a crop eq)
1,344053514
Human non-carcinogenic…
167,118019
Human carcinogenic toxicity (kg…
0,591056909
Marine ecotoxicity (kg 1,4-DCB)
3,488438354
Freshwater ecotoxicity (kg 1,4-…
2,752746042
Terrestrial ecotoxicity (kg 1,4-…
22,24639998
Marine eutrophication (kg N eq)
0,008606355
Freshwater eutrophication (kg P…
0,005133478
Terrestrial acidification (kg SO2…
0,043089575
Ozone formation, Terrestrial…
0,019029762
Fine particulate matter formation…
0,015555442
Ozone formation, Human health…
0,018736917
Ionizing radiation (kBq Co-60 eq)
0,583233895
Stratospheric ozone depletion…
4,87983E-05
Global warming (kg CO2 eq)
12,4530755
0
50
100
150
200

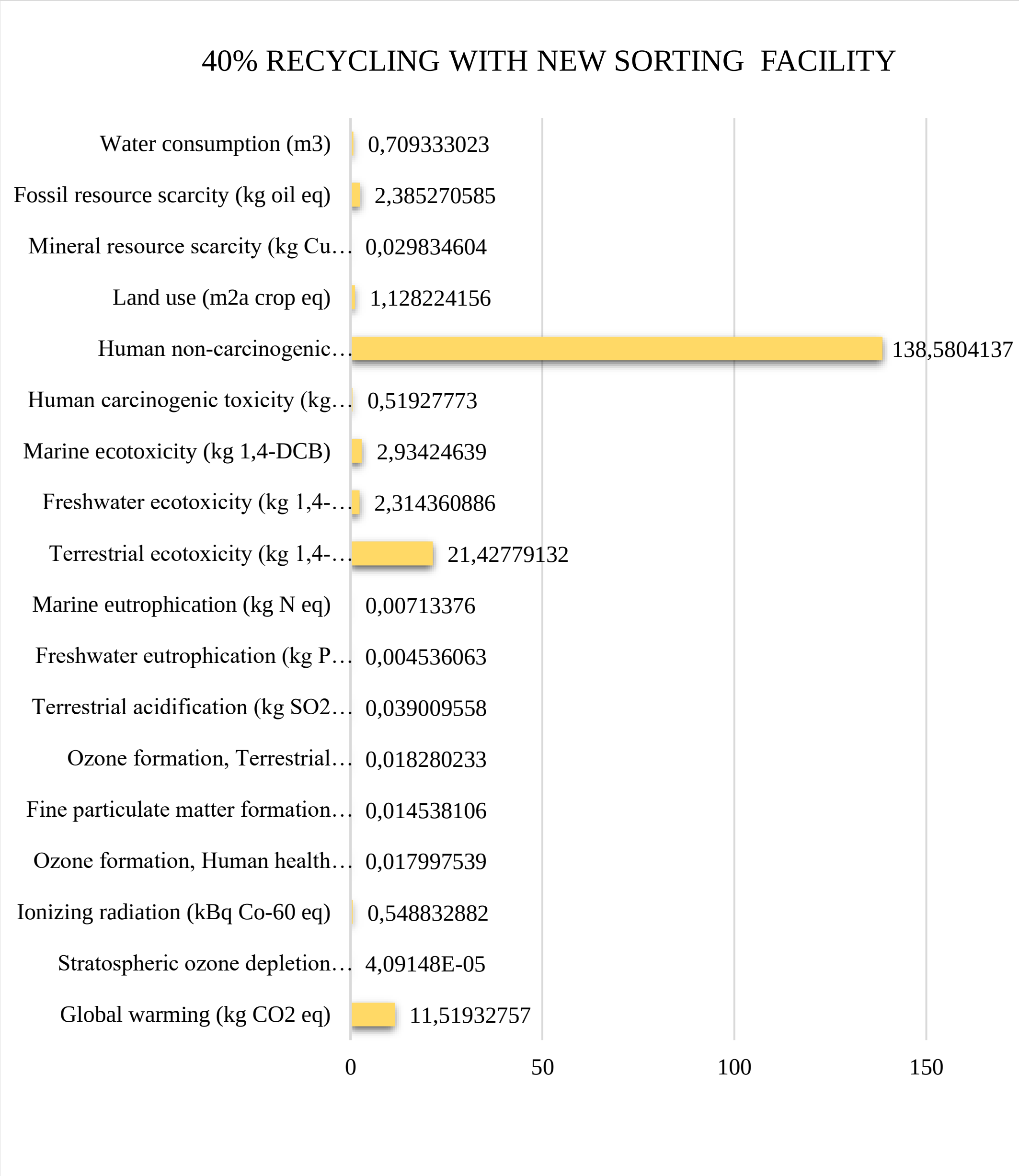

29% RECYCLING
Water consumption (m3)
0,81228771
Fossil resource scarcity (kg oil eq)
2,428849225
Mineral resource scarcity (kg Cu…
0,033011146
Land use (m2a crop eq)
1,3962228
Human non-carcinogenic…
160,8687811
Human carcinogenic toxicity (kg…
0,595014935
Marine ecotoxicity (kg 1,4-DCB)
3,613313103
Freshwater ecotoxicity (kg 1,4-…
2,851409167
Terrestrial ecotoxicity (kg 1,4-…
22,28493082
Marine eutrophication (kg N eq)
0,00900467
Freshwater eutrophication (kg P…
0,005107354
Terrestrial acidification (kg SO2…
0,045459492
Ozone formation, Terrestrial…
0,02109669
Fine particulate matter formation…
0,015847771
Ozone formation, Human health…
0,020796977
Ionizing radiation (kBq Co-60 eq)
0,548918888
Stratospheric ozone depletion…
5,07664E-05
Global warming (kg CO2 eq)
12,16982304
0
50
100
150
200

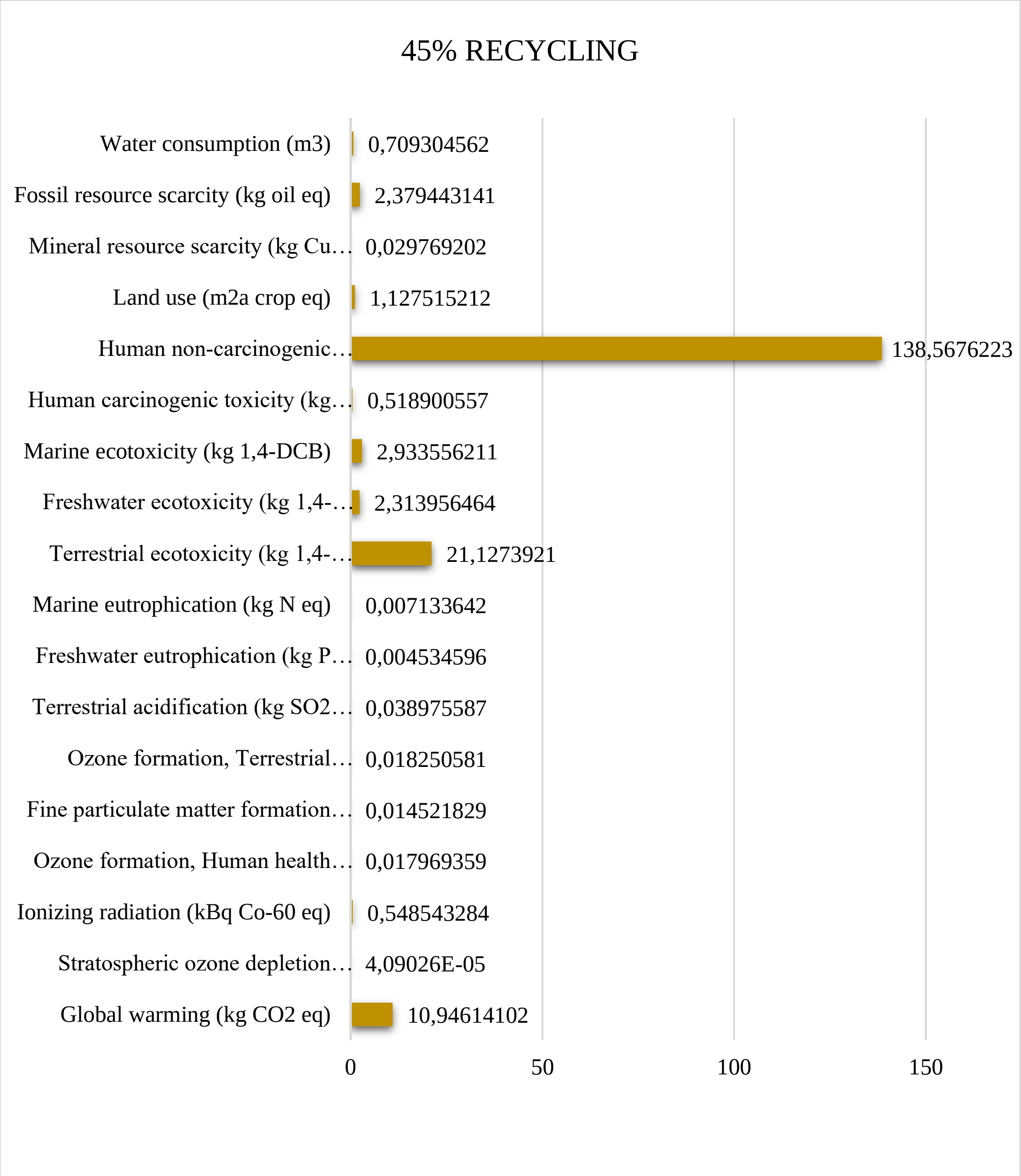

29% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,812241587
Fossil resource scarcity (kg oil eq)
2,397132685
Mineral resource scarcity (kg Cu…
0,030843281
Land use (m2a crop eq)
1,216046082
Human non-carcinogenic…
159,650305
Human carcinogenic toxicity (kg…
0,544362594
Marine ecotoxicity (kg 1,4-DCB)
3,159259725
Freshwater ecotoxicity (kg 1,4-…
2,492574591
Terrestrial ecotoxicity (kg 1,4-…
21,14367983
Marine eutrophication (kg N eq)
0,007757103
Freshwater eutrophication (kg P…
0,004722128
Terrestrial acidification (kg SO2…
0,041888379
Ozone formation, Terrestrial…
0,01997651
Fine particulate matter formation…
0,015191574
Ozone formation, Human health…
0,01968545
Ionizing radiation (kBq Co-60 eq)
0,547995218
Stratospheric ozone depletion…
4,41971E-05
Global warming (kg CO2 eq)
12,15242881
0
50
100
150
200

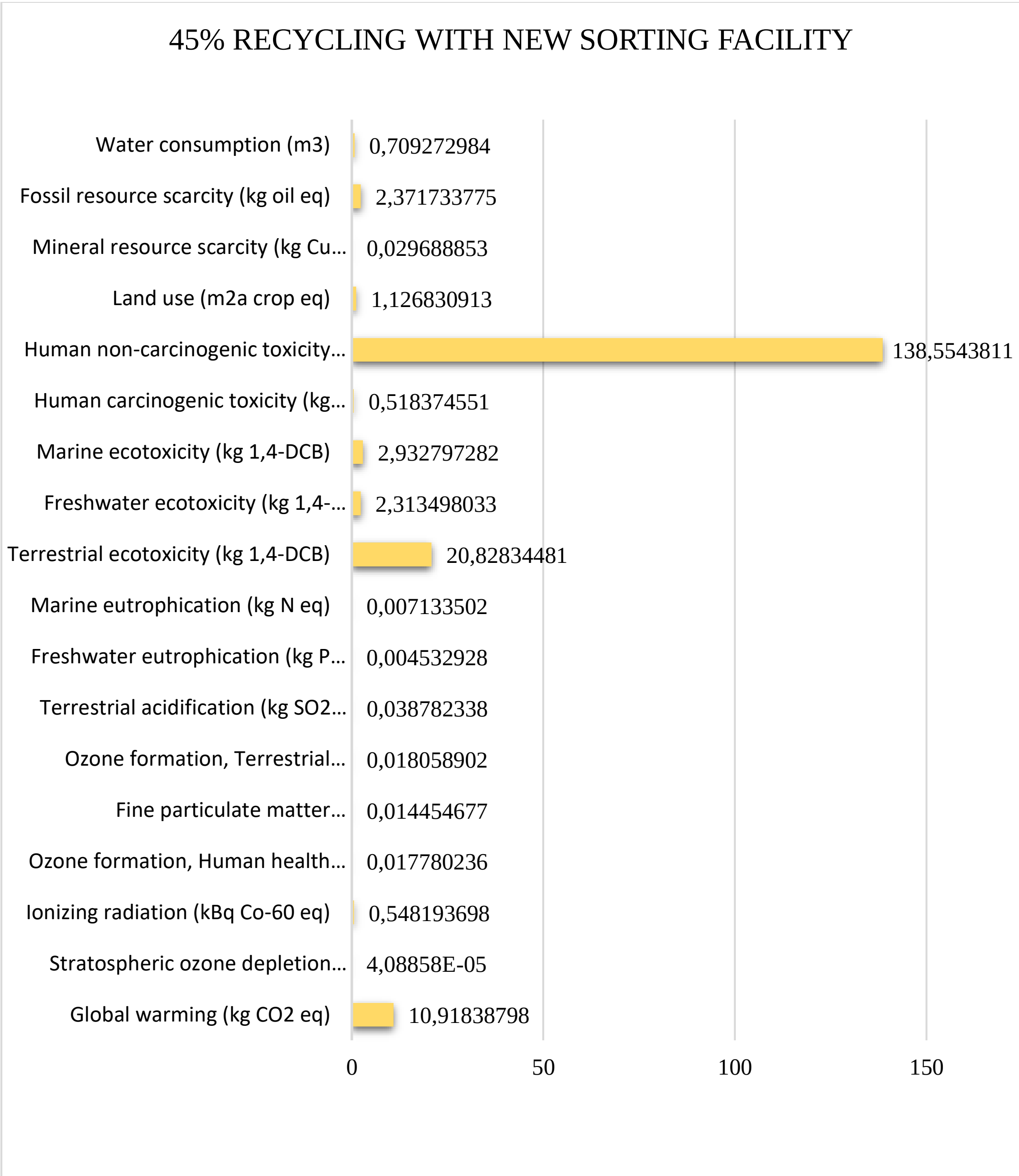

35% RECYCLING
Water consumption (m3)
0,750901205
Fossil resource scarcity (kg oil eq)
2,552614923
Mineral resource scarcity (kg Cu…
0,030157229
Land use (m2a crop eq)
1,048333711
Human non-carcinogenic…
150,9363931
Human carcinogenic toxicity (kg…
0,515263892
Marine ecotoxicity (kg 1,4-DCB)
2,746581842
Freshwater ecotoxicity (kg 1,4-…
2,166290898
Terrestrial ecotoxicity (kg 1,4-…
20,88486074
Marine eutrophication (kg N eq)
0,006536234
Freshwater eutrophication (kg P…
0,004572836
Terrestrial acidification (kg SO2…
0,038390715
Ozone formation, Terrestrial…
0,01818431
Fine particulate matter formation…
0,015020532
Ozone formation, Human health…
0,017893744
Ionizing radiation (kBq Co-60 eq)
0,600054671
Stratospheric ozone depletion…
3,8028E-05
Global warming (kg CO2 eq)
11,85780639
0
50
100
150
200

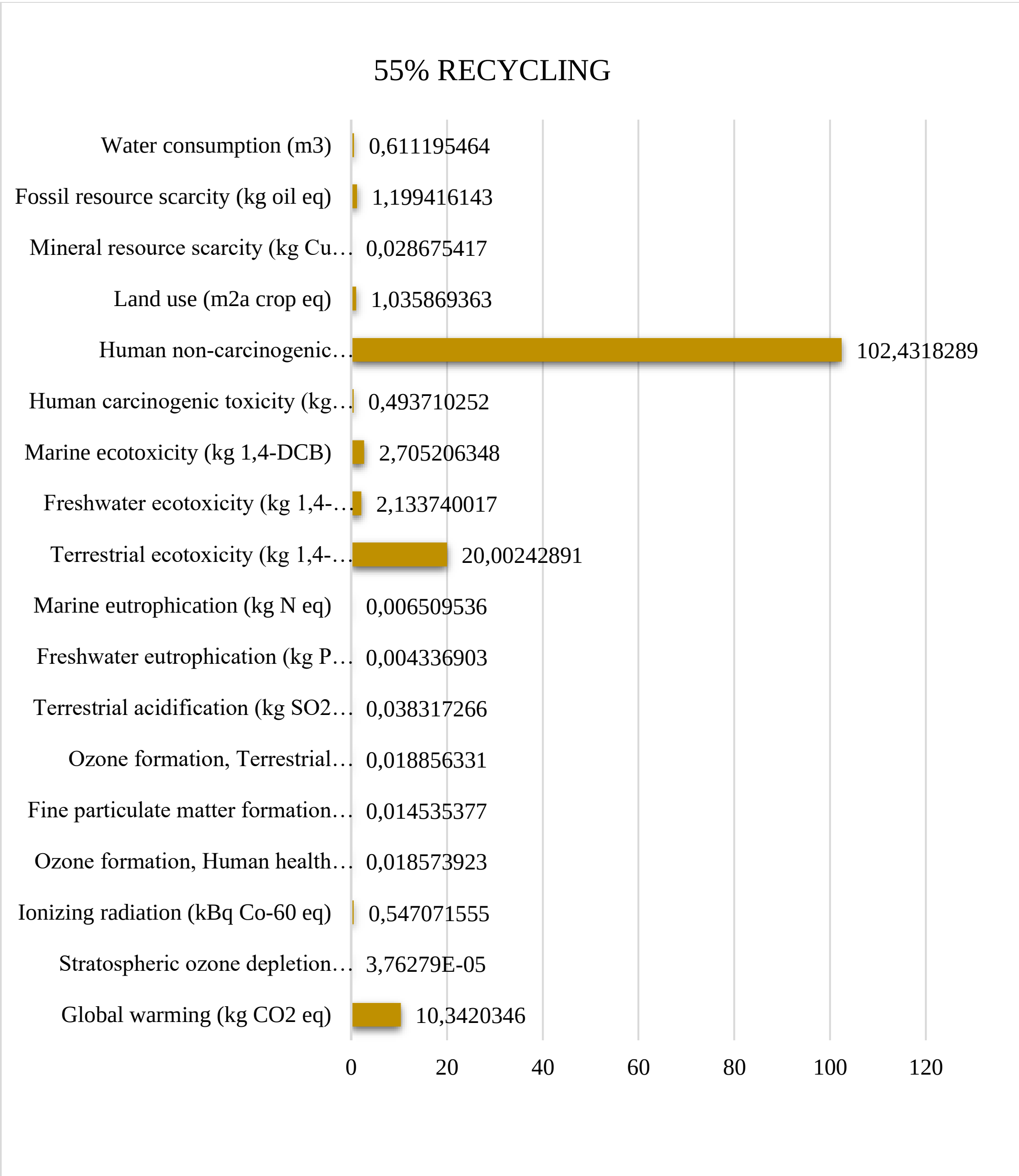

35% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,750132694
Fossil resource scarcity (kg oil eq)
2,3969512
Mineral resource scarcity (kg Cu…
0,030481125
Land use (m2a crop eq)
1,214805006
Human non-carcinogenic…
150,6150482
Human carcinogenic toxicity (kg…
0,541373136
Marine ecotoxicity (kg 1,4-DCB)
3,156717583
Freshwater ecotoxicity (kg 1,4-…
2,490887593
Terrestrial ecotoxicity (kg 1,4-…
20,48705706
Marine eutrophication (kg N eq)
0,007756537
Freshwater eutrophication (kg P…
0,004715955
Terrestrial acidification (kg SO2…
0,039521112
Ozone formation, Terrestrial…
0,017579433
Fine particulate matter formation…
0,014423234
Ozone formation, Human health…
0,01730728
Ionizing radiation (kBq Co-60 eq)
0,546480575
Stratospheric ozone depletion…
4,41035E-05
Global warming (kg CO2 eq)
11,83630731
0
50
100
150
200

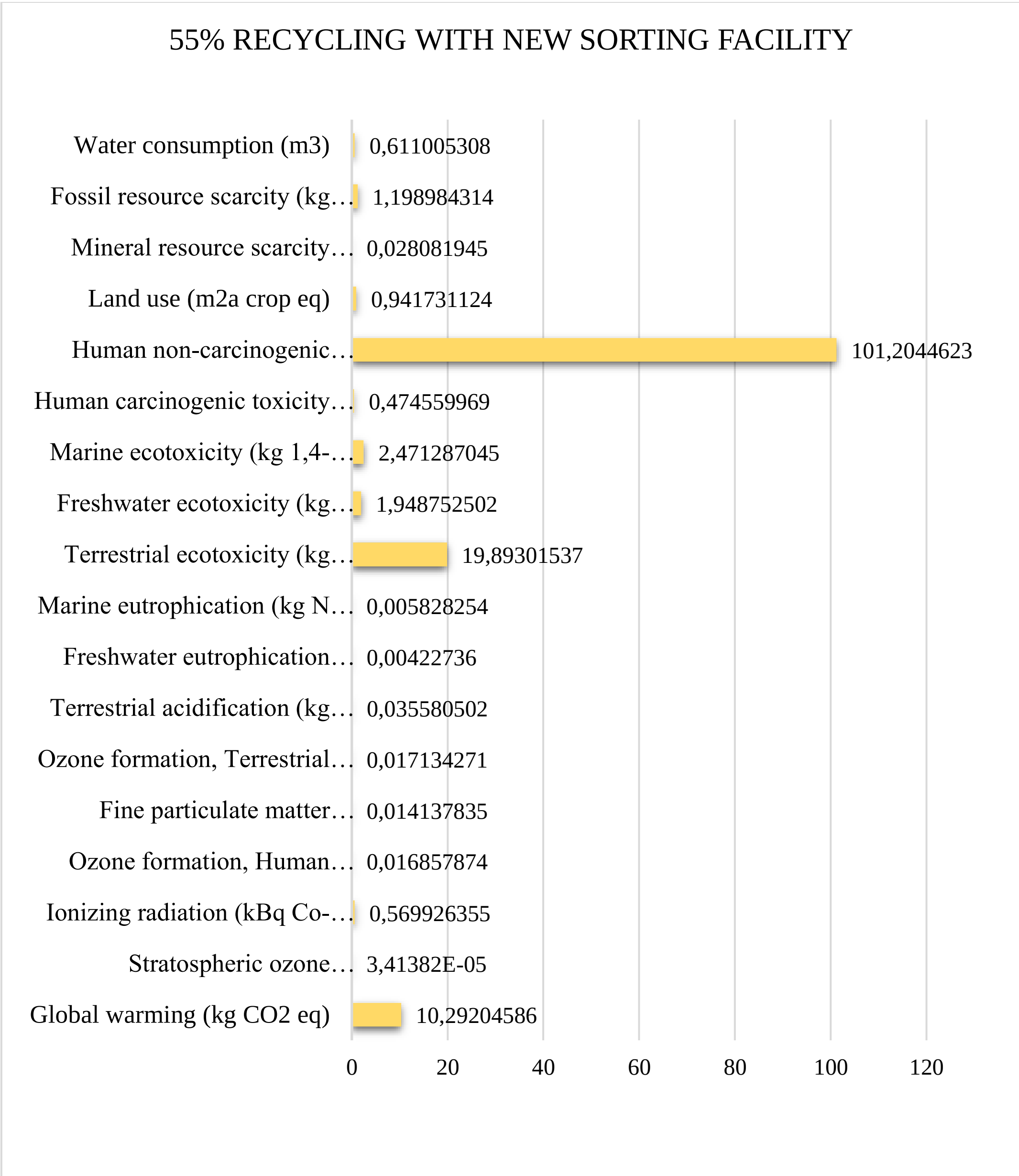

40% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,70930724
Fossil resource scarcity (kg oil eq)
2,386899354
Mineral resource scarcity (kg Cu…
0,029818584
Land use (m2a crop eq)
1,127013605
Human non-carcinogenic…
138,5935404
Human carcinogenic toxicity (kg…
0,51953331
Marine ecotoxicity (kg 1,4-DCB)
2,933583092
Freshwater ecotoxicity (kg 1,4-…
2,314048455
Terrestrial ecotoxicity (kg 1,4-…
20,96534546
Marine eutrophication (kg N eq)
0,007133696
Freshwater eutrophication (kg P…
0,004534949
Terrestrial acidification (kg SO2…
0,03984291
Ozone formation, Terrestrial…
0,019135393
Fine particulate matter formation…
0,014796069
Ozone formation, Human health…
0,018848904
Ionizing radiation (kBq Co-60 eq)
0,548727592
Stratospheric ozone depletion…
4,09218E-05
Global warming (kg CO2 eq)
11,55477672
0
50
100
150

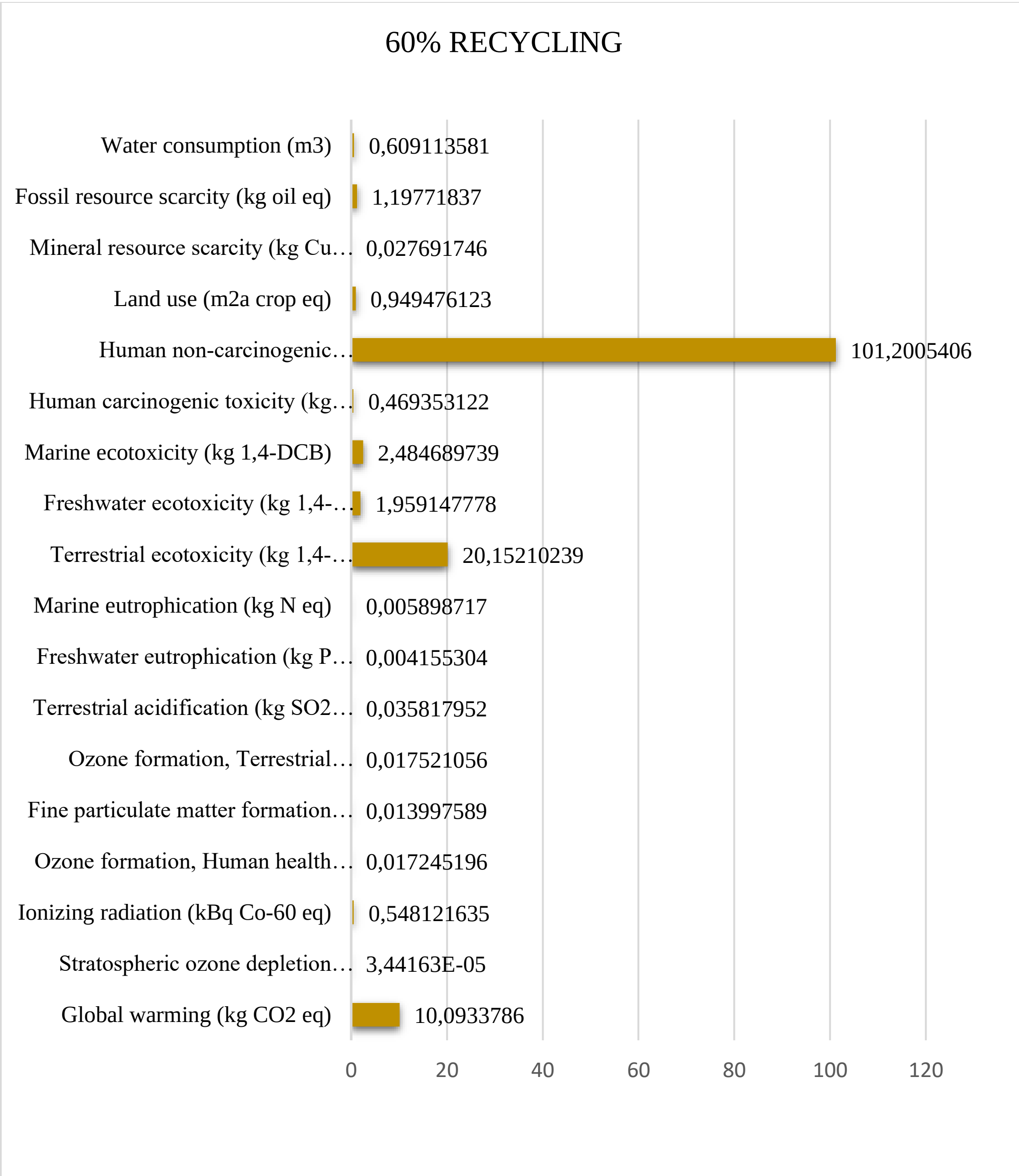

40% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,709333023
Fossil resource scarcity (kg oil eq)
2,385270585
Mineral resource scarcity (kg Cu…
0,029834604
Land use (m2a crop eq)
1,128224156
Human non-carcinogenic…
138,5804137
Human carcinogenic toxicity (kg…
0,51927773
Marine ecotoxicity (kg 1,4-DCB)
2,93424639
Freshwater ecotoxicity (kg 1,4-…
2,314360886
Terrestrial ecotoxicity (kg 1,4-…
21,42779132
Marine eutrophication (kg N eq)
0,00713376
Freshwater eutrophication (kg P…
0,004536063
Terrestrial acidification (kg SO2…
0,039009558
Ozone formation, Terrestrial…
0,018280233
Fine particulate matter formation…
0,014538106
Ozone formation, Human health…
0,017997539
Ionizing radiation (kBq Co-60 eq)
0,548832882
Stratospheric ozone depletion…
4,09148E-05
Global warming (kg CO2 eq)
11,51932757
0
50
100
150

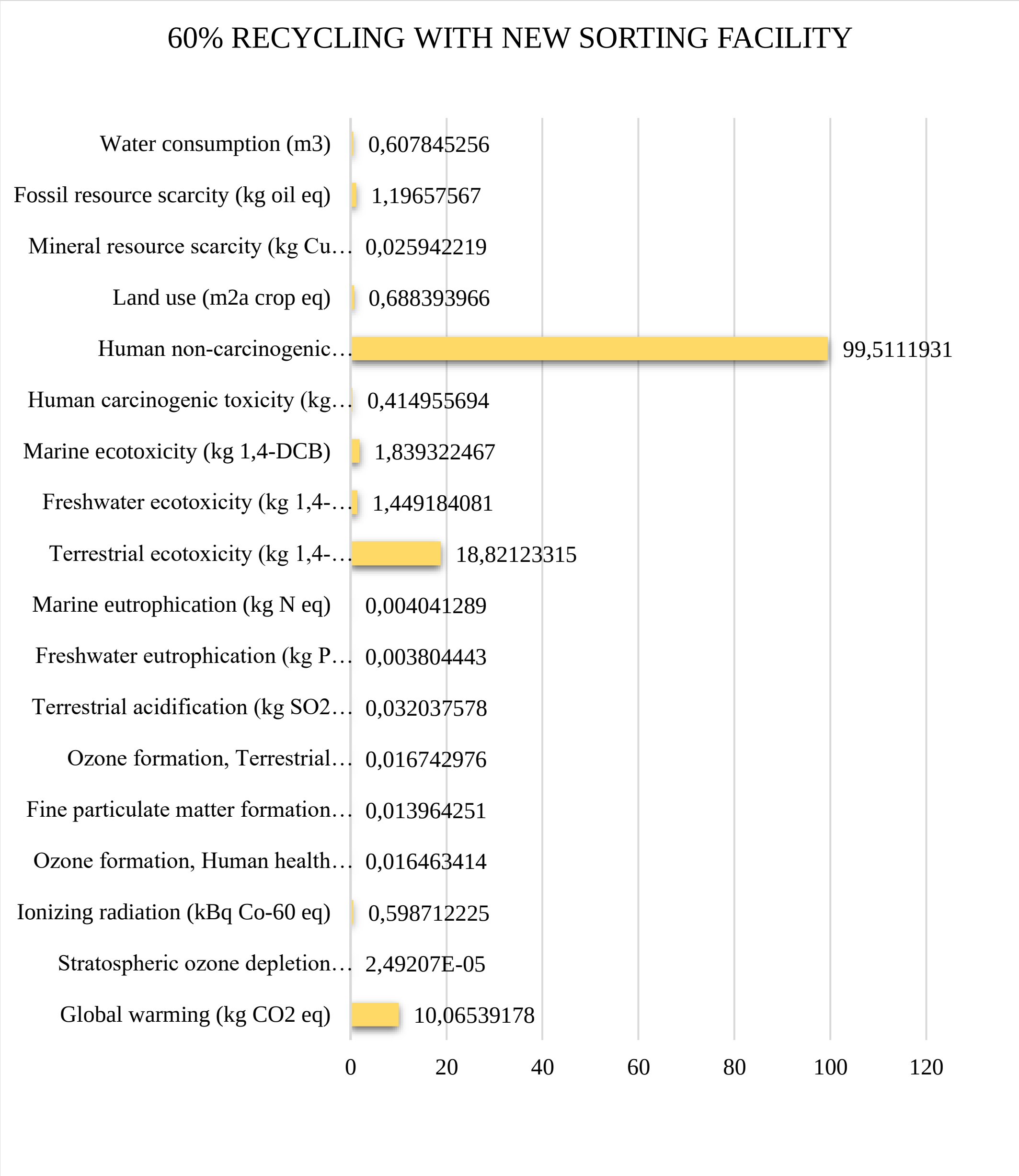

45% RECYCLING
Water consumption (m3)
0,709304562
Fossil resource scarcity (kg oil eq)
2,379443141
Mineral resource scarcity (kg Cu…
0,029769202
Land use (m2a crop eq)
1,127515212
Human non-carcinogenic…
138,5676223
Human carcinogenic toxicity (kg…
0,518900557
Marine ecotoxicity (kg 1,4-DCB)
2,933556211
Freshwater ecotoxicity (kg 1,4-…
2,313956464
Terrestrial ecotoxicity (kg 1,4-…
21,1273921
Marine eutrophication (kg N eq)
0,007133642
Freshwater eutrophication (kg P…
0,004534596
Terrestrial acidification (kg SO2…
0,038975587
Ozone formation, Terrestrial…
0,018250581
Fine particulate matter formation…
0,014521829
Ozone formation, Human health…
0,017969359
Ionizing radiation (kBq Co-60 eq)
0,548543284
Stratospheric ozone depletion…
4,09026E-05
Global warming (kg CO2 eq)
10,94614102
0
50
100
150

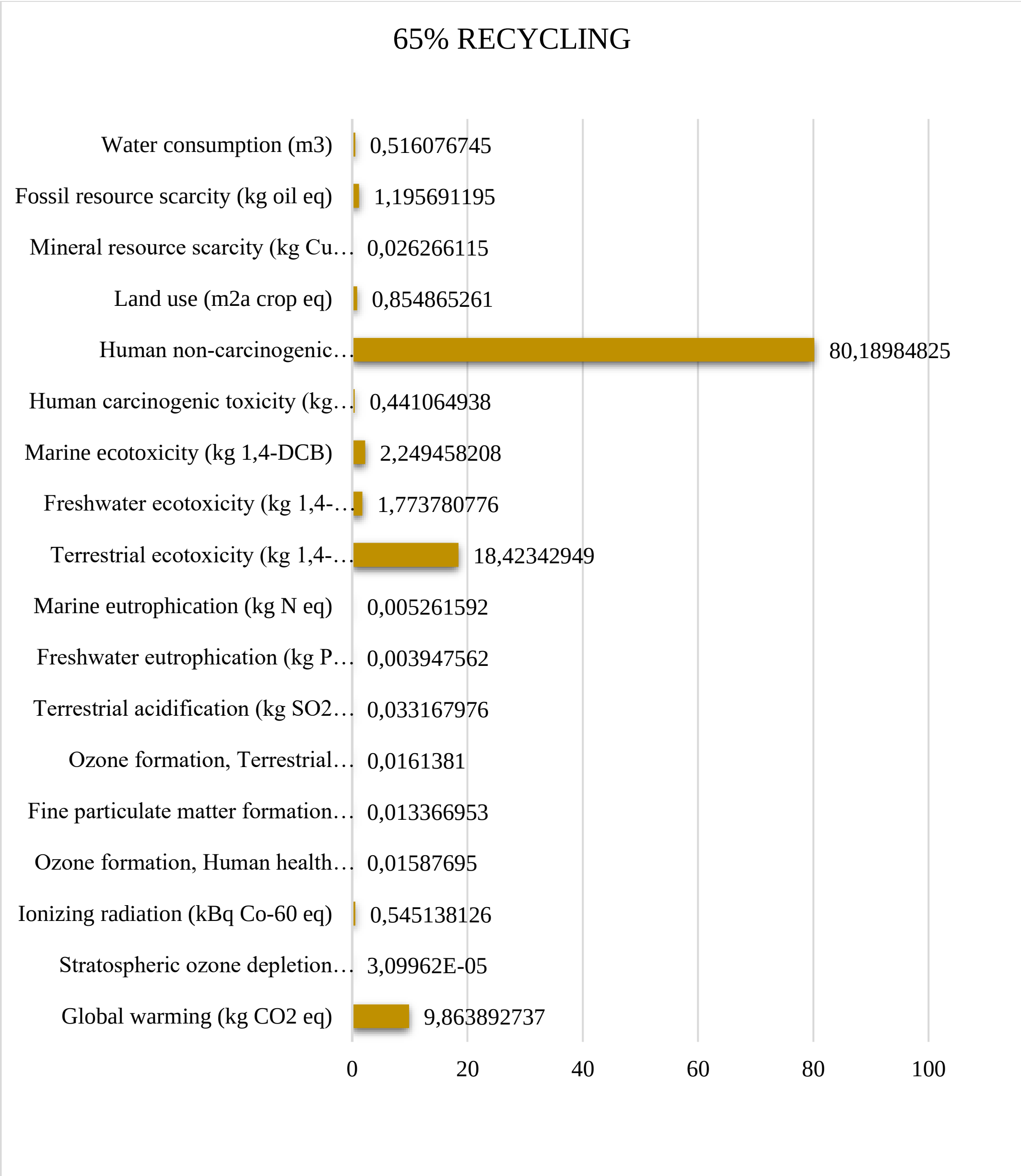

45% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,709272984
Fossil resource scarcity (kg oil eq)
2,371733775
Mineral resource scarcity (kg Cu…
0,029688853
Land use (m2a crop eq)
1,126830913
Human non-carcinogenic toxicity…
138,5543811
Human carcinogenic toxicity (kg…
0,518374551
Marine ecotoxicity (kg 1,4-DCB)
2,932797282
Freshwater ecotoxicity (kg 1,4-…
2,313498033
Terrestrial ecotoxicity (kg 1,4-DCB)
20,82834481
Marine eutrophication (kg N eq)
0,007133502
Freshwater eutrophication (kg P…
0,004532928
Terrestrial acidification (kg SO2…
0,038782338
Ozone formation, Terrestrial…
0,018058902
Fine particulate matter…
0,014454677
Ozone formation, Human health…
0,017780236
Ionizing radiation (kBq Co-60 eq)
0,548193698
Stratospheric ozone depletion…
4,08858E-05
Global warming (kg CO2 eq)
10,91838798
0
50
100
150

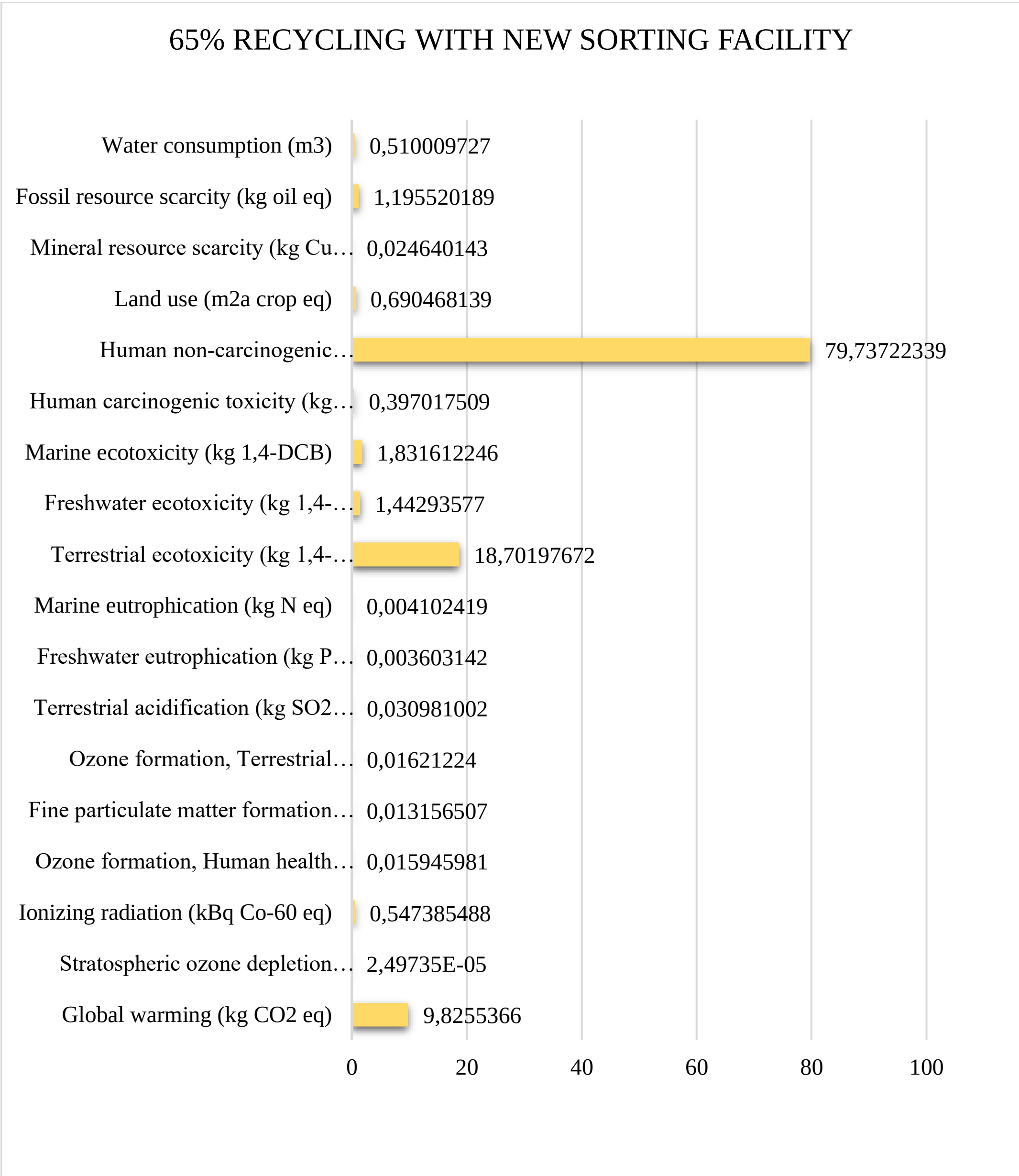

55% RECYCLING
Water consumption (m3)
0,611195464
Fossil resource scarcity (kg oil eq)
1,199416143
Mineral resource scarcity (kg Cu…
0,028675417
Land use (m2a crop eq)
1,035869363
Human non-carcinogenic…
102,4318289
Human carcinogenic toxicity (kg…
0,493710252
Marine ecotoxicity (kg 1,4-DCB)
2,705206348
Freshwater ecotoxicity (kg 1,4-…
2,133740017
Terrestrial ecotoxicity (kg 1,4-…
20,00242891
Marine eutrophication (kg N eq)
0,006509536
Freshwater eutrophication (kg P…
0,004336903
Terrestrial acidification (kg SO2…
0,038317266
Ozone formation, Terrestrial…
0,018856331
Fine particulate matter formation…
0,014535377
Ozone formation, Human health…
0,018573923
Ionizing radiation (kBq Co-60 eq)
0,547071555
Stratospheric ozone depletion…
3,76279E-05
Global warming (kg CO2 eq)
10,3420346
0
20
40
60
80
100
120

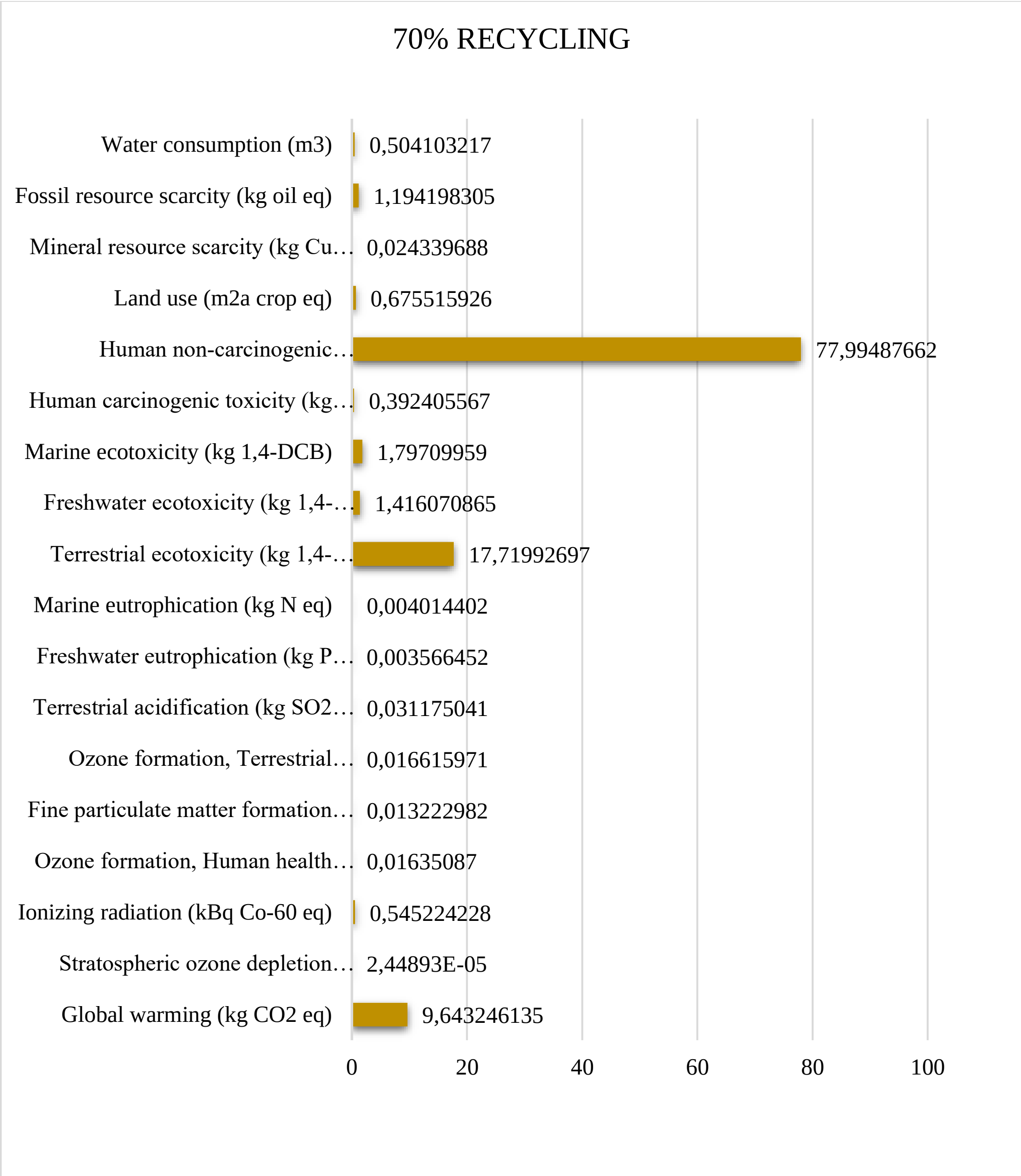

55% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,611005308
Fossil resource scarcity (kg…
1,198984314
Mineral resource scarcity…
0,028081945
Land use (m2a crop eq)
0,941731124
Human non-carcinogenic…
101,2044623
Human carcinogenic toxicity…
0,474559969
Marine ecotoxicity (kg 1,4-…
2,471287045
Freshwater ecotoxicity (kg…
1,948752502
Terrestrial ecotoxicity (kg…
19,89301537
Marine eutrophication (kg N…
0,005828254
Freshwater eutrophication…
0,00422736
Terrestrial acidification (kg…
0,035580502
Ozone formation, Terrestrial…
0,017134271
Fine particulate matter…
0,014137835
Ozone formation, Human…
0,016857874
Ionizing radiation (kBq Co-…
0,569926355
Stratospheric ozone…
3,41382E-05
Global warming (kg CO2 eq)
10,29204586
0
20
40
60
80
100
120

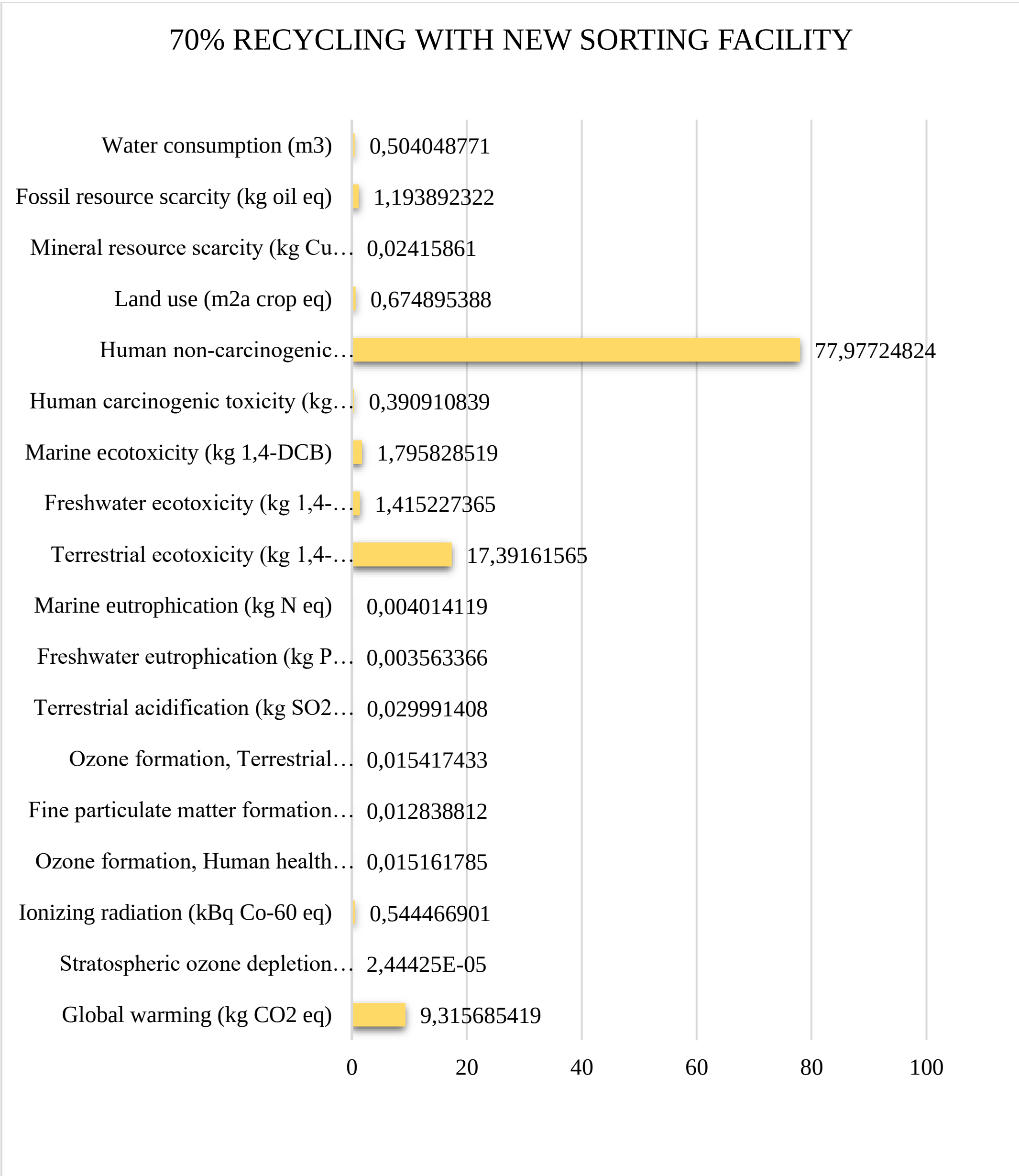

60% RECYCLING
Water consumption (m3)
0,609113581
Fossil resource scarcity (kg oil eq)
1,19771837
Mineral resource scarcity (kg Cu…
0,027691746
Land use (m2a crop eq)
0,949476123
Human non-carcinogenic…
101,2005406
Human carcinogenic toxicity (kg…
0,469353122
Marine ecotoxicity (kg 1,4-DCB)
2,484689739
Freshwater ecotoxicity (kg 1,4-…
1,959147778
Terrestrial ecotoxicity (kg 1,4-…
20,15210239
Marine eutrophication (kg N eq)
0,005898717
Freshwater eutrophication (kg P…
0,004155304
Terrestrial acidification (kg SO2…
0,035817952
Ozone formation, Terrestrial…
0,017521056
Fine particulate matter formation…
0,013997589
Ozone formation, Human health…
0,017245196
Ionizing radiation (kBq Co-60 eq)
0,548121635
Stratospheric ozone depletion…
3,44163E-05
Global warming (kg CO2 eq)
10,0933786
0
20
40
60
80
100
120


60% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,607845256
Fossil resource scarcity (kg oil eq)
1,19657567
Mineral resource scarcity (kg Cu…
0,025942219
Land use (m2a crop eq)
0,688393966
Human non-carcinogenic…
99,5111931
Human carcinogenic toxicity (kg…
0,414955694
Marine ecotoxicity (kg 1,4-DCB)
1,839322467
Freshwater ecotoxicity (kg 1,4-…
1,449184081
Terrestrial ecotoxicity (kg 1,4-…
18,82123315
Marine eutrophication (kg N eq)
0,004041289
Freshwater eutrophication (kg P…
0,003804443
Terrestrial acidification (kg SO2…
0,032037578
Ozone formation, Terrestrial…
0,016742976
Fine particulate matter formation…
0,013964251
Ozone formation, Human health…
0,016463414
Ionizing radiation (kBq Co-60 eq)
0,598712225
Stratospheric ozone depletion…
2,49207E-05
Global warming (kg CO2 eq)
10,06539178
0
20
40
60
80
100
120


65% RECYCLING
Water consumption (m3)
0,516076745
Fossil resource scarcity (kg oil eq)
1,195691195
Mineral resource scarcity (kg Cu…
0,026266115
Land use (m2a crop eq)
0,854865261
Human non-carcinogenic…
80,18984825
Human carcinogenic toxicity (kg…
0,441064938
Marine ecotoxicity (kg 1,4-DCB)
2,249458208
Freshwater ecotoxicity (kg 1,4-…
1,773780776
Terrestrial ecotoxicity (kg 1,4-…
18,42342949
Marine eutrophication (kg N eq)
0,005261592
Freshwater eutrophication (kg P…
0,003947562
Terrestrial acidification (kg SO2…
0,033167976
Ozone formation, Terrestrial…
0,0161381
Fine particulate matter formation…
0,013366953
Ozone formation, Human health…
0,01587695
Ionizing radiation (kBq Co-60 eq)
0,545138126
Stratospheric ozone depletion…
3,09962E-05
Global warming (kg CO2 eq)
9,863892737
0
20
40
60
80
100


65% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,510009727
Fossil resource scarcity (kg oil eq)
1,195520189
Mineral resource scarcity (kg Cu…
0,024640143
Land use (m2a crop eq)
0,690468139
Human non-carcinogenic…
79,73722339
Human carcinogenic toxicity (kg…
0,397017509
Marine ecotoxicity (kg 1,4-DCB)
1,831612246
Freshwater ecotoxicity (kg 1,4-…
1,44293577
Terrestrial ecotoxicity (kg 1,4-…
18,70197672
Marine eutrophication (kg N eq)
0,004102419
Freshwater eutrophication (kg P…
0,003603142
Terrestrial acidification (kg SO2…
0,030981002
Ozone formation, Terrestrial…
0,01621224
Fine particulate matter formation…
0,013156507
Ozone formation, Human health…
0,015945981
Ionizing radiation (kBq Co-60 eq)
0,547385488
Stratospheric ozone depletion…
2,49735E-05
Global warming (kg CO2 eq)
9,8255366
0
20
40
60
80
100


70% RECYCLING
Water consumption (m3)
0,504103217
Fossil resource scarcity (kg oil eq)
1,194198305
Mineral resource scarcity (kg Cu…
0,024339688
Land use (m2a crop eq)
0,675515926
Human non-carcinogenic…
77,99487662
Human carcinogenic toxicity (kg…
0,392405567
Marine ecotoxicity (kg 1,4-DCB)
1,79709959
Freshwater ecotoxicity (kg 1,4-…
1,416070865
Terrestrial ecotoxicity (kg 1,4-…
17,71992697
Marine eutrophication (kg N eq)
0,004014402
Freshwater eutrophication (kg P…
0,003566452
Terrestrial acidification (kg SO2…
0,031175041
Ozone formation, Terrestrial…
0,016615971
Fine particulate matter formation…
0,013222982
Ozone formation, Human health…
0,01635087
Ionizing radiation (kBq Co-60 eq)
0,545224228
Stratospheric ozone depletion…
2,44893E-05
Global warming (kg CO2 eq)
9,643246135
0
20
40
60
80
100


70% RECYCLING WITH NEW SORTING FACILITY
Water consumption (m3)
0,504048771
Fossil resource scarcity (kg oil eq)
1,193892322
Mineral resource scarcity (kg Cu…
0,02415861
Land use (m2a crop eq)
0,674895388
Human non-carcinogenic…
77,97724824
Human carcinogenic toxicity (kg…
0,390910839
Marine ecotoxicity (kg 1,4-DCB)
1,795828519
Freshwater ecotoxicity (kg 1,4-…
1,415227365
Terrestrial ecotoxicity (kg 1,4-…
17,39161565
Marine eutrophication (kg N eq)
0,004014119
Freshwater eutrophication (kg P…
0,003563366
Terrestrial acidification (kg SO2…
0,029991408
Ozone formation, Terrestrial…
0,015417433
Fine particulate matter formation…
0,012838812
Ozone formation, Human health…
0,015161785
Ionizing radiation (kBq Co-60 eq)
0,544466901
Stratospheric ozone depletion…
2,44425E-05
Global warming (kg CO2 eq)
9,315685419
0
20
40
60
80
100