**ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL**

# LIFE CYCLE ASSESSMENT OF WASTE MANAGEMENT AND ENERGY CONSUMPTION FOR A RESTAURANT

**M.Sc. THESIS**

**Meryem BAHADIROĞLU**

**Department of Environmental Engineering**

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**Thesis Advisor: Prof. Dr. Fatma Gülen İSKENDER**

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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ**

# BİR RESTORANIN ATIK YÖNETİMİ VE ENERJİ TÜKETİMİNİN YAŞAM DÖNGÜSÜ ANALİZİ

**YÜKSEK LİSANS TEZİ**

**Meryem BAHADIROĞLU**
**(501181806)**

**Çevre Mühendisliği Anabilim Dalı**

**Çevre Biyoteknolojisi Programı**

**Tez Danışmanı: Prof. Dr. Fatma Gülen İSKENDER**

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Meryem Bahadıroğlu, a M.Sc. student of ITU Graduate School student ID 501181806, successfully defended the thesis/dissertation entitled “Life Cycle Assessment of Waste Management and Energy Consumption for A Restaurant”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

| | | |
|---|---|---|
| **Thesis Advisor :** | **Prof. Dr. Fatma Gülen İSKENDER**<br>İstanbul Technical University | ..... |
| **Jury Members :** | **Prof. Dr. İlda VERGİLİ**<br>Istanbul University | ..... |
| | **Assis. Prof. Dr. Hüseyin GÜVEN**<br>Istanbul Technical University | ..... |

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## FOREWORD

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Meryem Bahadıroğlu

Environmental Engineer

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## ABBREVIATIONS

| | |
|---|---|
| **ND** | **:** No data |
| **Equiv.** | **:** Equivalent |
| **agg** | **:** Aggregated |
| **TUIK** | **:** Turkish Statistical Institute |
| **ROW** | **:** Rest of world |
| **TR** | **:** Turkey |
| **kWh** | **:** Kilowatt-hour |
| **MJ** | : Megajoule |
| **PET** | **:** Polyethylene terephthalate |
| **PS** | **:** Polystyrene |
| **PP** | **:** Polypropylene |
| **LDPE** | **:** Low-density polyethylene |
| **HDPE** | **:** High-density polyethylene |
| **LCA** | **:** Life Cycle Assessment |
| **LCIA** | **:** Life Cycle Impact Assessment |
| **ADP Elements** | **:** Abiotic Element Depletion Potential |
| **ADP Fossil** | **:** Abiotic Fossil Depletion Potential |
| **AP** | **:** Acidification Potential |
| **EP** | **:** Eutrophication Potential |
| **GWP** | **:** Global Warming Potential |
| **POCP** | **:** Photochemical Ozone Creation Potential |
| **ODP** | **:** Ozone Layer Depletion Potential |
| **HTP** | **:** Human Toxicity Potential |
| **FAETP** | **:** Freshwater Aquatic Ecotoxicity Potential |
| **MAETP** | **:** Marine Aquatic Ecotoxicity Potential |
| **TETP** | **:** Terrestric Ecotoxicity Potential |
| **LF** | **:** Landfill |
| **AD** | : Anaerobic digester |
| **COM** | : Composting |
| **AD_LF** | : Anaerobic digester followed by landfill |

**COM_LF** : Composting followed by landfill

**ADcom** : Anaerobic digester followed by composting

**ADgas** : Anaerobic digester followed by gasification

**ADinci** : Anaerobic digester followed by incineration

**Gas** : Gasification

**Inci** **:** Incineration

**NMVOC** **:** Non-methane volatile organic compound

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## LIFE CYCLE ASSESSMENT OF WASTE MANAGEMENT AND ENERGY CONSUMPTION FOR A RESTAURANT

### SUMMARY

The increase of the food sector is observed with the growth of the population of Turkey. Energy, water consumption and waste generation are increasing as a result of this growth. As separation and sending wastes to a waste recovery facility(composting, recycling, incineration, etc) is not commonly preferred, wastes that have a high content of compostable organic and recyclable materials are sent to a sanitary landfill. Alternative waste management options must be chosen rather than sending wastes to landfill facilities. Also water reduction and usage of renewable energy sources should be considered to reduce the environmental impacts caused by them. The goal of this study is to calculate the environmental impact potentials of waste management and energy consumption for a restaurant with a life cycle assessment approach and interpret the results.

In this study, the studied restaurant is located in Florya-Istanbul. Inventory data belong to 2019 were gathered in order to calculate environmental impacts. Electricity, water and natural gas consumptions, waste generation of the restaurant and waste management according to waste characterization were considered in the life cycle assessment system boundary. System boundary also covers transportation of inputs to the studied restaurant and transportation of wastes to the waste management facility. Inventory data that were gathered from the investigated restaurant were applied to the software and results were gathered. Different energy scenarios, water reduction scenario and according to the waste characterization of the investigated restaurant, different waste management scenarios were developed, calculations were completed on Gabi 7.3 Software. Differences in environmental impact potentials with the changes in energy sources and waste management methods were interpreted.

In this study, the functional unit was selected as 1000 services. All inputs and outputs were represented for 1000 services and all environmental impact potentials were calculated for 1000 services. Gabi 7.3 Software was used to evaluate the Life Cycle Assessment study. Ecoinvent 3.1 Database was used and CML 2001 Impact Assessment Method was selected to calculate environmental impact potentials. Results were gathered for Acidification Potential(AP), Eutrophication Potential(EP), Global Warming Potential(GWP), Human Toxicity Potential(HTP), Ozone Layer Depletion Potential(ODP), Photochemical Ozone Creation Potential(POCP), Abiotic Element Depletion Potential for Elements(ADP Elements), Abiotic Fossil Depletion Potential(ADP Fossil), Freshwater Aquatic Ecotoxicity Potential(FAETP), Marine

Aquatic Ecotoxicity Potential(MAETP), Terrestric Ecotoxicity Potential(TETP) and results were interpreted.

Results of this study were compared with the literature. Results show that energy consumption of the restaurant is the most critical point in the study. It is seen that electricity-related environmental impacts mainly come from “electricity production, lignite” and “electricity production, hard coal” processes. This is caused by the high amounts of lignite and hard coal percentages in the electricity mix of Turkey-2019. These processes cause negative impacts on the environment.

In ADP Elements, FAETP and TETP, also “transmission network” process has negative impacts on the environment as a result of consumption of non-renewable elements such as copper and lead, emissions to freshwater such as copper and emissions to industrial soil such as chromium, respectively. Natural gas shows higher impact than electricity in ODP as a result of high amount of refrigerant usage in natural gas pipelines.

Results indicate that switching electricity mix with wind power and solar power can reduce the environmental impact potentials. The only increase is seen in ADP Element and ODP when electricity mix is replaced with solar power. High amount of non-renewable elements such as copper, gold and silver are used in solar power production. This situation increases the ADP Elements. Also certain materials usage, such as teflon, in producing solar cells increase the ODP.

The amount of waste that is sent to landfill is another important point in this study. Results show that this factor mainly contributes to EP and FAETP. Landfill effect on these environmental impact categories is mainly caused by emissions to freshwater from “treatment of municipal solid waste” process in the sanitary landfill model. Reducing the amount of waste to be sent to landfill is another important point in this study.

In this study, transportation takes place at close distances. According to the results, the transportation factor does not show a considerable impact on the environment in this study. Only for ADP Elements and ODP, transportation-related impact contributes higher than 10%. ADP Element result is caused by non-renewable element consumption such as cadmium, copper, gold and lead in transportation. ODP result is caused by halogenated organic emissions to air in the transportation process.

Overall results show that water reduction does not have an important changing on the results as water contributions to impact categories are very low.

Paper recycling, anaerobic digestion of organic waste and composting of organic waste processes were applied in this study in different scenarios. In the case of recycling, only paper recycling was considered as other recyclable waste amounts were considerably lower than paper waste.

Results show that adding paper recycling process to the scenario mainly lowers ADP Element, ADP Fossil, AP, POCP and TETP. Adding anaerobic digestion or composting to the scenario lowers the EP, FAETP, GWP, HTP, MAETP as a result of

reducing the amount of waste that is sent to landfill. Adding anaerobic digester or composting to the scenario does not considerably contribute to the overall results as their percentages are very low in overall scenarios. This can be caused by sending a relatively low amount of waste to anaerobic digester and composting. If individual results of anaerobic digester and composting are compared, it is seen that composting gave higher results than anaerobic digester in all environmental impact potentials except ADP Fossil and ODP. In this case, ADP Elements result is caused by crude oil consumption of heat requirements of anaerobic digester. ODP result is caused by halogenated organic emissions to air caused by heat requirements and machine operation of anaerobic digester.

Adding anaerobic digester or composting to scenarios do not make a considerable increasing but those processes mostly tend to increase AP and GWP as a result of inorganic emissions to air from treatment of biowaste processes in anaerobic digestion and composting.

# BİR RESTORANIN ATIK YÖNETİMİ VE ENERJİ TÜKETİMİNİN YAŞAM DÖNGÜSÜ ANALİZİ

## ÖZET

Sürekli olarak artmakta olan nüfüs ile beraber Türkiye'deki yiyecek sektörüne bağlı işyeri sayısı da artış göstermektedir. Enerji ve su kullanımları, aynı zamanda atık miktarları da bu yükselişe bağlı olarak artmaktadır. Atıkların ayrıştırılması ve geri kazanılmasının yeterince sağlanamaması nedeniyle yüksek oranda organik madde ve geri dönüştürülebilir ambalaj atığı içeriğine sahip bu atıklar düzenli depolamaya gönderilmektedir. Düzenli depolamaya gönderilen atık miktarı azaltılarak, alternatif atık bertaraf yöntemlerine yönelinmesi gerekmektedir. Bu çalışmanın amacı, bir restoranın atık yönetimi ve enerji tüketiminin çevresel etkilerinin yaşam döngüsü analizi ile değerlendirilmesidir.

Bu çalışmada Yaşam Döngüsü Analizi yapılan restoran Florya-İstanbul'da bulunmaktadır. Restoran gözlemlenmiş ve 2019 yılına ait girdi ve çıktı verileri toplanmıştır. Katı atık yönetimi ve atıksu yönetimi ile ilgil ilave bilgiler ilgili Belediye ve Büyükşehir Belediyesi ile görüşülerek elde edilmiştir. Restoranın harcadığı elektrik, su ve doğalgaz, restoranın oluşturduğu atık miktarı, atık karakterizasyonu ve atık bertaraf yöntemleri yaşam döngüsü analizi kapsamında kabul edilmiştir. Girdilerin restorana ulaştırılması ve aynı zamanda restoranda oluşan atıkların atık bertaraf tesislerine gönderilmesi sırasında taşımacılığın oluşdurduğu çevresel etkiler sistem sınırları içerisinde kabul edilmiştir. Restorandan toplanan envanter verileri kullanılarak hesaplamalar yapılmıştır. İncelenen restoranın atık karakterizasyonuna göre farklı atık beraberaf yöntemi senaryoları belirlenip, hesaplamalar Gabi 7.3 yazılımı üzerinden yapılmış ve elde edilen sonuçlar yorumlanmıştır. Farklı enerji senaryoları belirlenmiş ve enerji kaynağının değişimi ile beraber çevresel etki değerleri üzerinde oluşan değişimler yorumlanmıştır.

Bu çalışmada fonksiyonel birim 1000 servis olarak belirlenmiştir. Tüm girdi ve çıktılar 1000 servis için belirtilmiş, tüm hesaplamalar 1000 servis başına yapılmış ve sunulmuştur. Çevresel etki potansiyellerinin elde edilmesi için Gabi 7.3 yazılımı kullanılmıştır. Kullanılan veritabanı Ecoinvent 3.1'dir ve çevresel etki değerlendirme metodu olarak CML 2001 seçilmiştir. Asidifikasyon Potansiyeli(AP), Ötröfikasyon Potansiyeli(ÖP), Küresel Isınma Potansiyeli(KIP), Ozon Tabakası Delinmesi Potansiyeli(OTDP), İnsan Toksisitesi Potansiyeli(İTP), Fotokimyasal Ozon Oluşumu Potansiyesi(FOOP), Abiyotik Tüketim Potansiyeli(ATP-Element), Abiyotik Tüketim Potansiyeli(ATP-Fosil), Tatlı Su Ekotoksisitesi Potansiyeli(TSETP), Deniz

Ekotoksisitesi Potansiyeli(DETP), Karasal Ekotoksisite Potansiyeli(KETP) çevresel etki kategorileri için Gabi 7.3 yazılımı ile sonuçlar alınmış ve yorumlanmıştır.

Sonuçlar literatür ile karşılaştırılmıştır. Sonuçlar göz önünde bulundurulduğunda, bu çalışmada en önemli noktaların restoran tarafından kullanılan elektrik ve doğalgaz oldukları ve en çok çevresel etkilerin bu faktörlerden geldiği belirlenmiştir.

Restoran tarafından kullanılan elektrikten kaynaklanan çevresel etkinin, büyük çoğunlukla "linyitten elektrik üretimi" ve "kömürden elektrik üretimi" proseslerinden geldiği görülmektedir. Bunun nedeni, "linyitten elektrik üretimi" ve "kömürden elektrik üretimi" yüzdelerinin Türkiye'nin 2019 yılına ait elektrik üretimi içerisindeki payların yüksek oluşudur. Bu prosesler çevreye olumsuz etkide bulunmaktadır. Ayrıca "aktarım şebekesi" ATP Element, TSETP ve KETP kategorilerinin artmasına katkı sağlayan bir faktördür. Bu faktörün ATP Element üzerindeki etkisi, bakır ve kurtşun gibi yenilenemeyen element kullanımım yüksek oluşudur. TSETP ve KETP üzerindeki etkileri, bakır ve krom gibi emisyonların tatlı su kaynaklarına salınımının yüksek oluşudur.

Şebeke elektriği kullanımının, rüzgar enerjisi ile değiştirilmesi durumunda tüm çevresel etki kategorilerinde azalım gözlenmiştir. Şebeke elektriği kullanımının güneş enerjisi ile değiştirilmesi durumunda ise, ATP Element ve OTDP için artış gözlemlenirken, diğer tüm etki kategorilerinde azalım gözlemlenmiştir. ATP Element için bu artışın nedeni, güneş paneli üretiminde yüksek miktarda gümüş, altın ve bakır gibi yenilenemeyen elementlerin kullanımıdır. OTDP için bu artışın nedeni ise, güneş paneli hücrelerinin üretiminde teflon gibi birtakım materyallerin kullanımıdır. Aynı zamanda güneş enerjisi doğalgaza göre %40 oranında daha yüksek OTDP'ye neden olmaktadır. 2019 Türkiye elektrik üretim verilerine göre Türkiye elektriği içerisindeki doğalgaz yüzdesinin yüksek olması, güneş enerjisine geçildiğinde OTDP'nin artmasını açıklamaktadır.

Bu çalışmada bir diğer önemli faktör, düzenli depolamaya gönderilen atık miktarıdır. Sonuçlar yorumlandığında, düzenli depolamaya gönderilen atık miktarlarındaki değişimin en fazla TSETP ve ÖP kategorilerinde etki gösterdiği görülmektedir. Bu etki kategorilerindeki düzenli depolama etkisi çoğunlukla düzenli depolama tesisi modelindeki "kentsel katı atıkların arıtılması" prosesinden kaynaklanan, tatlısuya yapılan salınımlardır. Düzenli depolamaya yollanan katı atıkların azaltılması, çevresel etkileri azaltmada önemli bir rol oynamaktadır.

Bu çalışmada nakliye yakın mesafeler arasında gerçekleşmektedir. Bu nedenle çevresel etkilerde nakliye aşamasından kaynaklanan kaydadeğer bir artış gözlemlenmemiştir. Yalnızca ATP Element ve OTDP etki kategorilerinde, tüm faktörler arasında nakliye 10%'dan yüksek bir paya sahiptir. ATP Element için bunun nedeni, nakliye için kadminyum, bakır, kurşun gibi yenilenemeyen elemenlerin kullanımının yüksek oluşu; OTDP için ise nakliye sırasında halojenize organiklerin havaya emisyonlarıdır.

Sonuçlara bakıldığında, su tüketimi faktörünün çevresel etki kategorileri üzerindeki etkisinin çok düşük olduğu gözlemlenmiştir. Bu nedenle, su tüketiminin azaltılması, bu faktörün çevresel etkilerini 36% oranında azaltmasına rağmen, tüm çalışma içerisindeki sonuçlara gözle gözülebilir bir etki sağlamamıştır.

Bu çalışmada kağıt geri dönüşümü, organik atıkların anaerobik çürütücüye gönderilmesi ve organik atıkların kompost tesisine gönderilmesi senaryoları incelenmiştir.

Geri dönüştürülebilir atıklar arasından yalnızca kağıt geri dönüşümünün göz önünde bulundurulmasına karar verilmiştir. Bunun nedeni geri dönüştürülebilir atıklar arasından kağıdın yüksek orana sahip olmasıdır.

Kağıt geri dönüşümünün tüm etki kategorileri için eksi değerli sonuçlar getirdiği gözlemlenmiştir. Bu sonuç, kağıt geri dönüşümünün tüm etki kategorilerinde çevreye olumlu etki sağladığını göstermektedir. Kağıt geri dönüşümünün genel olarak ATP Fosil, AP, FOOP ve KETP üzerinde azaltıcı etkiye neden olduğu söylenebilir.

Çalışmaya anaerobik çürücü veya kompost ünitesi eklenmesi durumunda ÖP, TSETP, KIP, İTP ve DETP etki kategorilerinde azalma gözlemlenmiştir. Bunun nedeni 100 km uzaklıktaki düzenli depolamaya gönderilen atık miktarının azaltılmış olması ve organik atığın 39 km uzaklıktaki anaerobik çürütücü veya kompost tesisine gönderilmesidir. Anaerobik çürücü ve kompost ünitelerinin genel etki üzerindeki etki payı oldukça düşüktür. Bunun nedeni enerji kullanımının payının çok yüksek olması ve nispeten düşük miktarda organik atığın bu tesislere gönderilmiş olmasıdır. Bu iki ünite için ayrı ayrı alınan sonuçlar karşılaştırıldığında kompost ünitesinin ATP Fosil ve OTDP haricindeki tüm etki kategorilerinde anaerobik çürütücüden daha yüksek sonuç verdiği gözlemlenmiştir. Bu sonuçları elde etmede ATP Fosil kategorisi için en önemli faktör petrol kullanımıdır. Kompost ünitesi için petrol kullanımının getirdiği etkinin hemen hemen tamamı nakliyeden gelmektedir. Nakliyeden gelen etki kompost ve anaerobik çürütücü için aynıdır. Bunun nedeni anaerobik çürütücü ve kompost tesislerinin restorana uzaklıklarının ve taşınan atık miktarının aynı olmasıdır. Anerobik çürütücüde ısı gereksinimleri için petrol tüketiminin olması, ATP Fosil için kompostlamadan yüksek sonuç vermesine neden olmuştur. OTDP için önemli faktör halojenize organiklerin havaya olan emisyonlarıdır. Kompost ünitesi için bu emisyonların getirdiği etkinin hemen hemen tamamı nakliyeden kaynaklanmaktadır. Anaerobik çürütücüde ısı sağlanması ve makine operasyonları sırasında oluşan emisyonlar, OTDP için kompostlamadan yüksek sonuç vermesine neden olmuştur. AP ve KIP etki kategorilerini yükseltici etkiye neden olmalarına rağmen, senaryoya anaerobik çürütücü veya kompost ünitesi eklemek, toplam çevresel etki üzerinde önemli bir değişime neden olmamıştır.

# 1. INTRODUCTION

## 1.1. Importance of The Study

Turkey is a country which has a growing population and the population is currently 83 million. As a result of the growing population and technology, pollution ( water, air, soil, etc.) also increases. Restaurants and retail stores have high energy usages. Also transportation distances of store supplies and customer orders, transportation frequency and fuel sources affect the emissions to the atmosphere(Skunca et al., 2018). Replacement of fossil fuels with an environmentally friendly fuel sources, quality and transportation frequency arrangements, environmentally friendly waste management options may decrease the negative impacts on the environment.

Life Cycle Assessment (LCA) gives an opportunity to have computer software-based calculated results that can be used to detect what needs to be changed in the process to achieve environmental benefits and sustainability by defining different scenarios.

This study has been done to contribute to determine the negative environmental impacts of waste management and energy consumption for a restaurant.

## 1.2. Aim and Scope of The Study

The objective of this study is to evaluate the environmental impacts of waste management and energy consumption for a restaurant located in Istanbul by Life Cycle Assessment. This study can be used as a guideline for restaurant owners and managers to get development ideas that help to select more environmentally friendly systems.

In this study, a life cycle inventory that includes inputs and outputs of the system in the frame of system boundary was collected according to ISO 14040:2006 and 14044:2006. This study covers the activities that take place inside the restaurant(storage, food preparation, cooking and baking, food service) and transportation stages. All inputs, outputs, and environmental impact potentials are

represented per 1000 services (Baldwin et al., 2010). In the study, impact categories were calculated with CML 2001 – Jan 2016 Impact Assessment Method.

In this study, calculated environmental impact potentials were Abiotic Depletion Potential, Acidification Potential, Eutrophication Potential, Freshwater Aquatic Ecotoxicity Potential, Global Warming Potential, Human Toxicity Potential, Marine Aquatic Ecotoxicity Potential, Ozone Layer Depletion Potential, Photochemical Ozone Creation Potential, Terrestric Ecotoxicity Potential.

Target audiences of the study are decision-makers of the investigated restaurant, people which are planning to make developments in their food production and serving systems, researchers, and students who work on The Life Cycle Assessment of food serving systems.

Literature survey on Life Cycle Assessment of restaurants and the pollution generated by activities related with restaurants, general information and phases of Life Cycle Assessment Methodology and studies which applied on restaurants were explained in Chapter 2. Materials and methods of the study were explained in Chapter 3. In Chapter 4; explanations of the investigated restaurant, technologies that are used in the system and inventory analysis were given. Results and discussion of the study were given in Chapter 5. Conclusion of the study and recommendations for the system were represented in Chapter 6.

# 2. LITERATURE SURVEY

## 2.1. General Information About Food Sector

According to the Ministry of Customs and Trade Report of 2016, the restaurant number of 2016 was 42,379 in Turkey(T.C. Gümrük ve Ticaret Bakanlığı, 2016a). Along with the rising demand, this number has continuously been growing. In 2016, Ministry of Customs and Trade announced the 20 most increased business lines. According to the report, restaurant business is located in the fourth place(T.C. Gümrük ve Ticaret Bakanlığı, 2016b).

### 2.1.1. Pollution generated by the food industry

According to several Life Cycle Assessments that have been conducted to find out environmental impacts of a restaurant or food service, the most important impact on the environment is occurred due to;

1. fossil fuel usage,
2. greenhouse gases emissions,
3. land use,
4. energy demand.

### 2.1.2. Cleaner Production / Reduction of Pollution Techniques

Some methods that can be used to reduce environmental impacts of restaurants and food systems are;

1. Replacement of electricity with green electricity sources,
2. Energy-saving methods,
3. Reduction of waste production,
4. Changings on the cleaning agents usage for reducing the pollution of the wastewater,
5. Wiping dishes without water before they enter the dishwasher,

6. Arranging portion size(Duursma et al., 2016),
7. Waiting for the dishwasher to get full before start washing,
8. Using a water-saving tap aerator,
9. Implement waste management strategies such as composting, anaerobic digester, incineration, etc rather than sending all the waste to landfill,
10. Energy recovery from anaerobic digester and fertilizer substitution with digestate, fertilizer substitution with composting(Hodge et al., 2016).

## 2.2. LCA

Life Cycle Assessment (LCA) is an approach that is evaluated to obtain possible environmental impacts of a product throughout the products' life cycle by gathering inputs and outputs of the production system(Edelen & Ingwersen, 2016).

### 2.2.1. LCA Framework

ISO 14040 Standards demonstrate four phases of a Life Cycle Assessment Study. Figure 2.1 shows the Life Cycle Assessment Framework that is evaluated with the combination of Goal And Scope Definition, Life Cycle Inventory Analysis, Life Cycle Impact Assessment and Interpretation of Results. Arrows represent that all those four phases are related to each other(Hauschild et al., 2018).

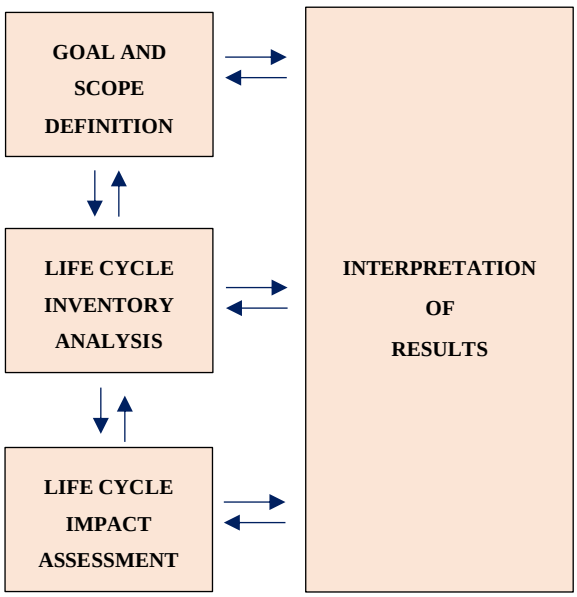


**Figure 2. 1**: Life Cycle Assessment Framework.

### 2.2.2. Goal And Scope Definition

In goal and scope definition phase; aim and coverage of the study are defined. This section also includes functional unit and system boundary definitions(Jolliet et al., 2016).

#### 2.2.2.1. Functional Unit

Functional unit is an important component in a Life Cycle Assessment study which is a quantitive definition of the products' function. After the functional unit of the system is defined; all inputs, outputs and environmental impacts are represented per functional unit. Thus comparison of the impact potentials can be done efficiently and developments for the system can be recommended by arranging inputs(Cucurachi et al., 2019).

#### 2.2.2.2. System Boundary

System boundary of the study is defined in goal and scope definition phase. In this step; it is indicated what is included and what is excluded in the study. LCA can be conducted with four approaches. In a cradle-to-grave approach, Life Cycle Assessment Study starts from the resource extraction and ends with the use phase or waste management. In cradle-to-gate approach, it starts with the resource extraction and ends with the part of the production step(Muralikrishna & Manickam, 2017). If gate-to-gate approach is accepted, LCA is conducted between production steps(gates) or a specific process of the production throughout the life cycle. Gate-to-grave approach covers the activity after production which is transportation, use and waste management(European Commission, 2013).

### 2.2.3. Life Cycle Inventory Analysis

In Life Cycle Inventory Analysis phase; inventory data which include all inputs and outputs of the system according to the accepted Life Cycle Assessment Approach are defined. All the data that are collected from the facility and also obtained during on-site observations are represented per functional unit. An inventory analysis includes all energy and water inputs, material flow, etc. Outputs cover solid wastes, wastewater, by-products and emissions to the atmosphere (Roy et al., 2009).

### 2.2.4. Life Cycle Impact Assessment

The data that is collected in the Life Cycle Inventory Analysis phase is used in the Life Cycle Impact Assessment(LCIA) step in order to calculate environmental impacts with the chosen Life Cycle Impact Assessment Method.

There are several Life Cycle Impact Assessment methods such as CML, IMPACT 2002+, TRACI, ReCiPe, USEtox, IPCC 2001, etc.

Many impact categories can be calculated in a Life Cycle Assessment study such as; Global Warming Potential (GWP), Photochemical Ozone Creation Potential(POCP), Ozone Layer Depletion (ODP), Acidification Potential (AP), Eutrophication Potential (EP), Human Toxicity Potential (HTP), Abiotic Depletion Potential (ADP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Marine Aquatic Ecotoxicity Potential (MAETP), etc (Frischknecht et al., 2007).

Figure 2.2 demonstrates the classification and characterization steps of a Life Cycle Assessment study. In classification step; inventory data are categorized according to environmental impact potential categories. In characterization step; emissions that cause environmental impacts are multiplied with the characterization factor (PE International, 2009).

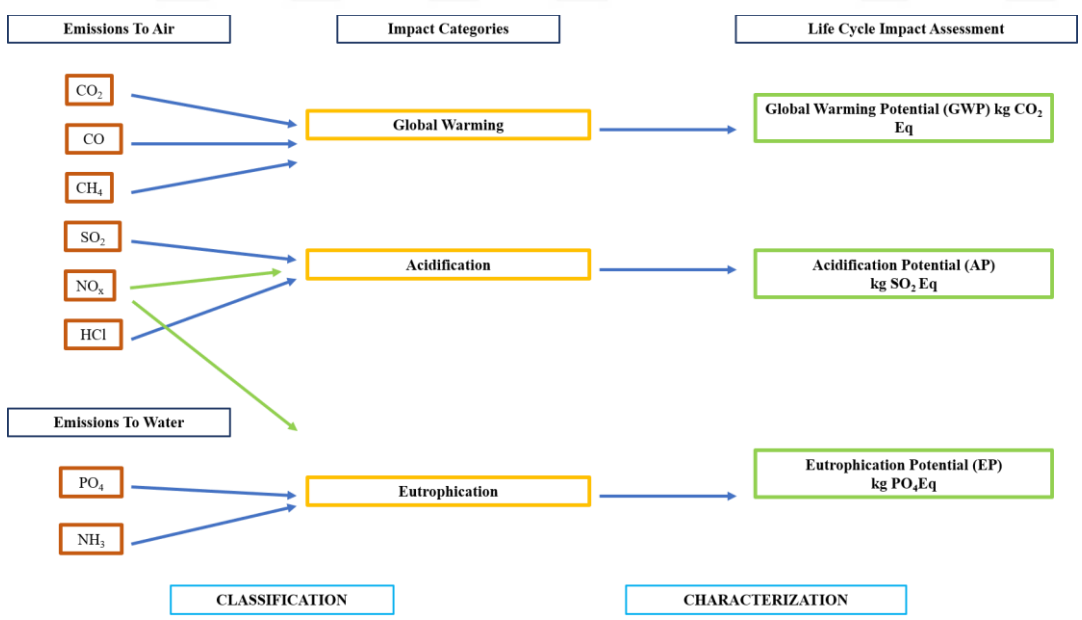


**Figure 2. 2:** Classification and Characterization.

### 2.2.5. Interpretation

Interpretation of the results phase is the last step of a Life Cycle Assessment Study. In this section, results that are calculated in the Life Cycle Impact Assessment step are

interpreted. Interpretations need to respond to the goal and scope of the study and respect the system boundary that is defined in the goal and scope definition phase.

Sensitivity analysis and uncertainty analysis take place in the interpretation section. Those analyses give an opportunity to provide reliable conclusions and recommendations to develop the process (Hauschild et al., 2018).

## 2.3. LCA Studies Applied on Food Sector

A Life Cycle Assessment study had been conducted by gathering data from restaurants in Chicago, USA. The Eco-indicator 99 impact assessment method was used for the Life Cycle Impact Assessment(LCIA) and SimaPro LCA Software was used to conduct the study. Cradle-to-gate Life Cycle Assessment approach was applied. Study covers the activities which take place in four subsystems which are food procurement, food storage, food preparation and cooking, service. Food procurement step includes agricultural activities and processing of food products. Energy-consuming processes were defined as; food storage, preparation of food and cooking, food service and operational support of restaurant (e.g. air conditioning). The most important environmental impact categories in the study were respiratory inorganics, land use and fossil fuels. In figure 2.3, normalized results showed that food production was the leading source of environmental impacts especially for land use and respiratory inorganics. It was mentioned that 15% reduction of meat supply, 7% reduction of energy, 7% reduction of food procurement and 25% replacement of food procurement with organic ones can reduce the negative environmental impacts(Baldwin et al., 2010).

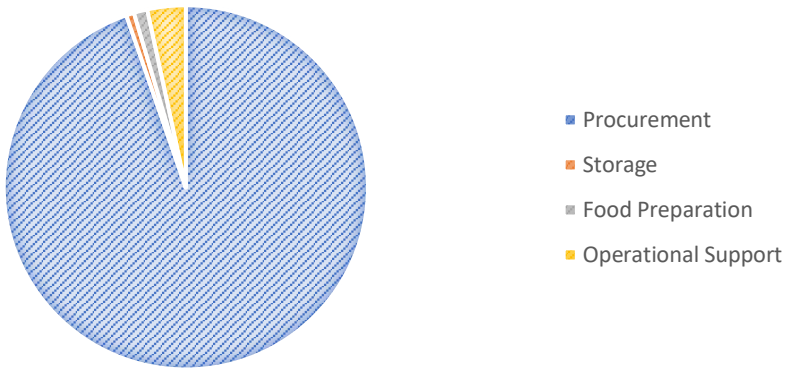


**Figure 2. 3:** Relative Contribution of Environmental Impact Categories(Normalized Results).

In this study, agricultural food production and factory stages were not taken into consideration as Baldwin et al. did. Transportation, Storage, food preparation and cooking, operational support such as cleaning and air conditioning, etc were considered in the system boundary. Also, waste management was considered in the system boundary.

A Life Cycle Assessment Of Food Waste Management Study had been conducted at two restaurants in Singapore. Ecoinvent version 3.4 database and Gabi Software 2017 were used to conduct the study. CML 2001 method was used for life cycle impact assessment. Chosen environmental impact categories were; abiotic depletion element, abiotic depletion fossil fuel, acidification, eutrophication, freshwater aquatic ecotoxicity, global warming, human toxicity, marine aquatic ecotoxicity, ozone layer depletion, photochemical ozone creation and terrestric ecotoxicity. Functional unit of the study was selected as 1000 tones of food wastes. This study was conducted to compare different waste management options: Incineration, anaerobic digester followed by incineration(ADinci), anaerobic digester followed by composting(ADcom) and anaerobic digester followed by gasification(ADgas). According to results, AD scenarios showed the best results except eutrophication potential and photochemical ozone creation potential because of $NO_x$ and CO emissions caused by biogas engine. ADcom performed best for all impact categories except eutrophication potential, global warming potential and photochemical ozone creation. Incineration showed the best results for eutrophication potential(3.63E+01 kg $PO_4$ Eq) and photochemical ozone creation(-2.99E+00 kg Ethene Eq). The best results for GWP were reached in ADgas scenario(3.85E+4 kg $CO_2$ Eq) as a result of the highest electricity production. ADcom showed extra benefits as a result of chemical fertilizer substitution (Tong et al., 2018).

A Life Cycle Assessment study had been conducted at a catering company and a restaurant in Spain. In order to conduct the study; Ecoinvent, LCA Food DK, BUWAL250, IDEMAT 2001 and ETH-ESU 96 databases and SimaPro v7.3.3 LCA Software were used. In order to calculate the environmental impact assessments, Eco-indicator 99 method was used. Stages of the study were defines as; canned food production and consumption at home, catering company that provides food service for schools, restaurants and homemade. Subsystems of the study were agricultural production and meat production, electricity consumption, transportation, packaging

material consumption and solid waste management. Some of the chosen impact categories were; land use, fossil fuels, respiratory inorganics, minerals, carcinogenics, acidification, eutrophication and climate change. Restaurant subsystem was found to have the highest impact on the environment specially on respiratory inorganics, land use and fossil fuel usage categories. Reduction of waste production, reduction of the wastes that are sent to landfill and energy-saving methods are important points to reduce environmental impacts (Calderón et al., 2018).

A study on food waste management strategies was conducted in The USA. SWOLF Model and Ecoinvent v3.01 were used for the study. TRACI and IPCC impact assessment methods were used to calculate environmental impact potentials. Six different scenarios were implemented. Implemented scenarios were;

1. Landfilling of mixed waste,
2. Waste to energy for mixed waste and landfilling of residuals,
3. Anaerobic digester followed by landfill,
4. Anaerobic digester followed by waste to energy plant and landfilling for residuals,
5. Aerobic composting followed by landfill,
6. Aerobic composting followed by waste to energy plant and landfilling for residuals.

All of those scenarios were considered with and without beneficial usages(e.g. implementation of anaerobic digester with and without fertilizer offset). Anaerobic digester followed by landfilling with beneficial usage was found to be the best option to reduce global warming potential. Results showed that energy usage, acidification potential and eutrophication potential had similar impacts on the environment with global warming potential while photochemical oxidation potential didn't follow global warming potential. It was concluded that generally, the logical way is replacement landfill with anaerobic digester, aerobic composting, and waste to energy plant(Hodge et al., 2016).

A Life Cycle Assessment Study conducted to compare municipal solid waste management systems in India. GaBi 8.5.0.79 Software and database were used to conduct the study. CML-1A Impact Assessment Method was used for Life Cycle

Impact Assessment. Functional unit of the study was defined as the management of one metric ton of MSW of Nagpur, India. Scenarios of the study were defined as;

1) Composting followed by landfilling. In this scenario, it was mentioned that only 17% of the waste was treated in composting facility and the rest of the waste was sent to landfilling. There were no landfill gas and leachate collection and treatment system.(COM_LF)
2) Recycling of recyclable materials, composting of organic materials, and landfilling of the remaining part of the waste. In this scenario, the recycling rate and composting rate were 20% and 80%, respectively.
3) Recycling of recyclable materials, sending organics to an anaerobic digester and landfilling of the remaining part of the waste. In this scenario, the recycling rate and anaerobic digester rate were 20% and 80%, respectively. Biogas production from anaerobic digester was taken into account.
4) Recycling of recyclable materials, sending organic part of the waste to composting and anaerobic digester and landfilling of the rest of the waste. In this scenario anaerobic digester-composting and recycle rate were 40% and 20%, respectively. Biogas production from anaerobic digester was taken into account.

Results of the study showed that while composting followed by landfilling(Scenario 1 - COM_LF) gave the highest global warming potential results (1259.69 kg $CO_2$ eq) as a result of no gas treatment system, Scenario 3 showed the lowest global warming potential(721.79 kg $CO_2$ eq). Scenario 1 also gave the highest results on photochemical ozone creation potential(3.04E-01 kg $C_2H_4$ eq) as a result of diesel usage and abiotic depletion potential(fossil)(123.58 MJ). Scenario 3 showed the highest results on acidification potential(6.86E-01 kg $SO_2$ eq), eutrophication potential(7.9E-02 kg $PO_4^{3-}$ eq) and human toxicity potential(8.56E-01 kg DCB eq) as a result of anaerobic digester process and biogas engine. According to results, increasing the recycling rate would decrease environmental burdens (Khandelwal et al., 2019).

# 3. MATERIALS & METHODS

## 3.1. Goal and Scope of The Study

### 3.1.1. Goal

The goal of this study is to evaluate a Life Cycle Assessment study to explore environmental impact potentials of the waste management and energy consumption for a restaurant in Istanbul and develop scenarios to reach environmental benefits.

Data were collected by on-site observations of the restaurant and also gathering information and variables from the restaurant manager. Freshwater provide, wastewater information and solid waste information were provided from Bayrampasa Municipality and Istanbul Metropolitan Municipality Waste Management Department.

### 3.1.2. Scope

The scope of the study covers the transportation of supplies to the restaurant and transportation of wastes to the disposal facility, activities which take place inside the restaurant gate such as storage, preparing, cooking, baking, serving, cleaning, heating, air conditioning, lighting and other electricity consuming devices and waste management. Agricultural activities, meat production and factory stages of the supplies were considered out of the system boundary.

#### 3.1.2.1. Functional Unit

The function of the system is to process the supplies and provide food service. In this study, 1000 services was selected as functional unit (Baldwin et al., 2010). All inputs, outputs and calculated environmental impact potentials were represented for 1000 services.

#### 3.1.2.2. System Boundary

System boundary covers all the activities which take place in the restaurant for 2019. Activities in this study cover the transportation of the purchased supplies from sellers

to the restaurant, storage, food preparation, cooking and baking, waste collection and transportation of wastes and waste disposal.

System boundary excludes raw material production, wastewater treatment of restaurants wastewater, final compost product(Scenario 4) and digestate sludge(Scenario 3) treatment such as landfilling, fertilizer production, and substitution. In the recycling case, for Scenario 2, Scenario 3 and Scenario 4, paper recycling process considered in the system boundary but recycling processes of the rest of the recyclables were sent to a sanitary landfill as their percentages in overall waste(1%-5%) were lower than paper waste percentage(14.76%). Amount of supply inputs**,** water and energy inputs will be given in the inventory analysis chapter. Table shows the overview of Scenarios to clearly see the system boundaries.

**Table 3. 1:** Overview of Scenarios

| | Scenario 0 | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|---|
| Energy Consumption | + | + | + | + | + |
| Water Consumption | + | + | + | + | + |
| Water Reduction | | + | + | + | + |
| Returnables(waste) | + | | | | |
| Returning the returnables | | + | + | + | + |
| Landfill | + | + | + | + | + |
| Paper Recycling | | | + | + | + |
| Anaerobic Digestion | | | | + | |
| Composting | | | | | + |
| Transportation | + | + | + | + | + |

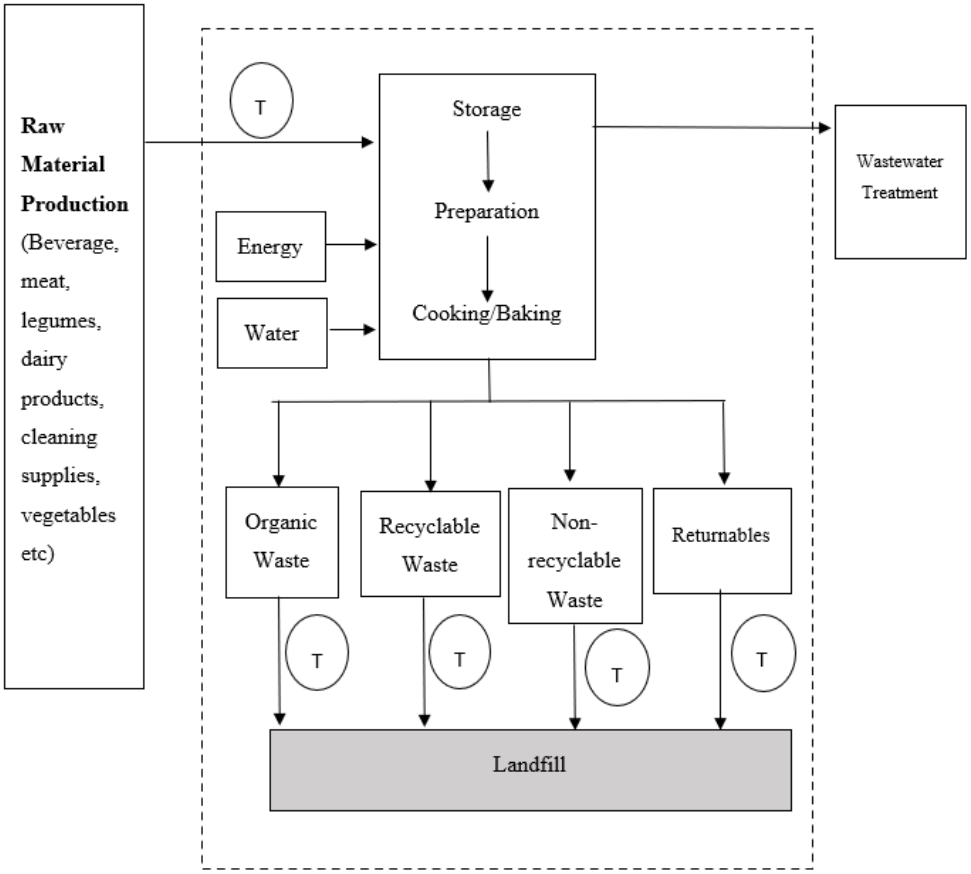


**Figure 3. 1:** System boundary of Scenario 0.

Figure 3.1 shows the system boundary of Scenario 0. In this scenario, the current situation is considered. This scenario includes transportation of inputs, water and energy consumption of the restaurant, waste collection and transportation to the sanitary landfill facility and waste disposal. Returnable products such as HDPE vegetable boxes(22.37 kg) and glass containers(7.5 kg) were considered as waste. All of the solid waste generated by the restaurant is sent to a sanitary landfill facility.

These wastes include organic waste(77.57 kg), recyclable waste and non-recyclable waste. There are no water-saving and renewable energy consumption in this scenario All of the wastes (159.81 kg) are sent to landfill.

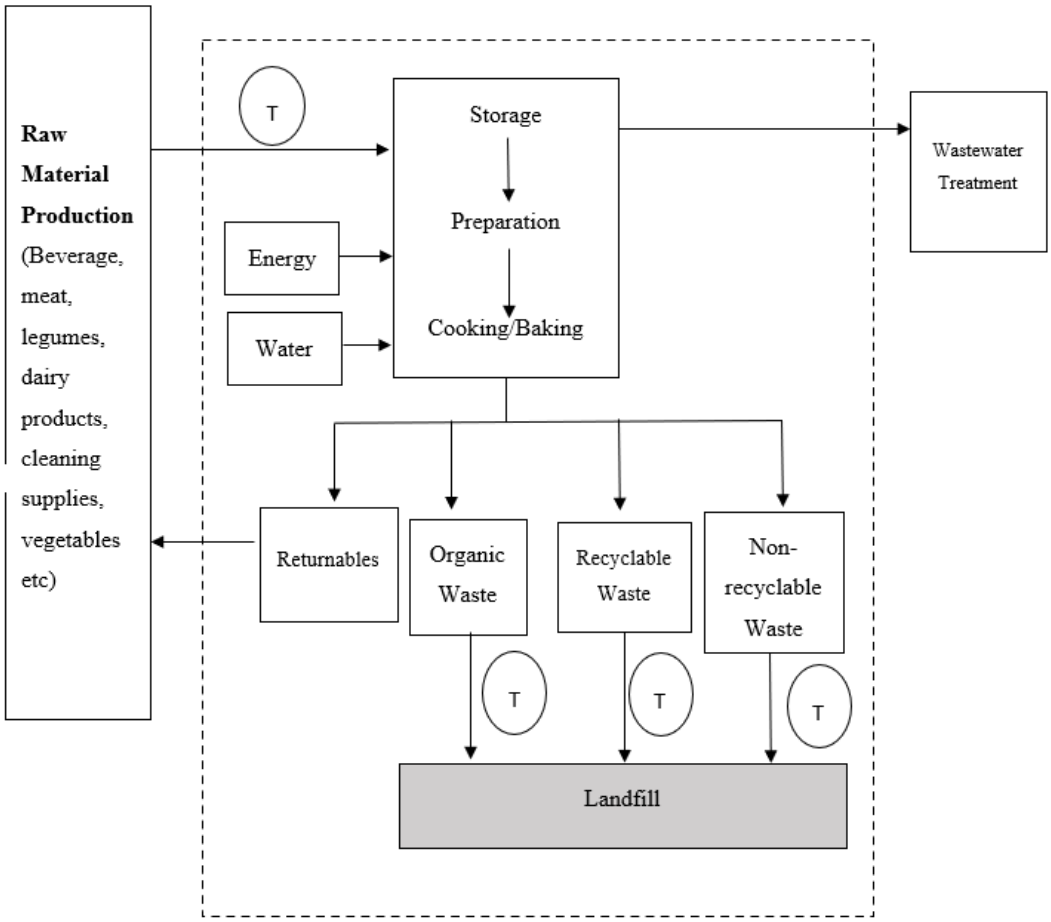


**Figure 3. 2:** System boundary of Scenario 1.

Figure 3.2 shows the system boundary of Scenario 1. In this scenario, returnable HDPE Plastic vegetable boxes(22.37 kg) and glass containers(7.5 kg) are separated from the waste and taken back by the seller. Therefore, in this scenario, the returnable products are given back to the seller during input deliveries. The rest of the wastes are sent to a sanitary landfill facility(129.94 kg).

Water-saving was applied in this scenario. This scenario includes transportation of inputs, water and energy consumption of the restaurant, waste collection and transportation to the sanitary landfill and waste disposal. Transportation of returnable products was excluded in the system boundary.

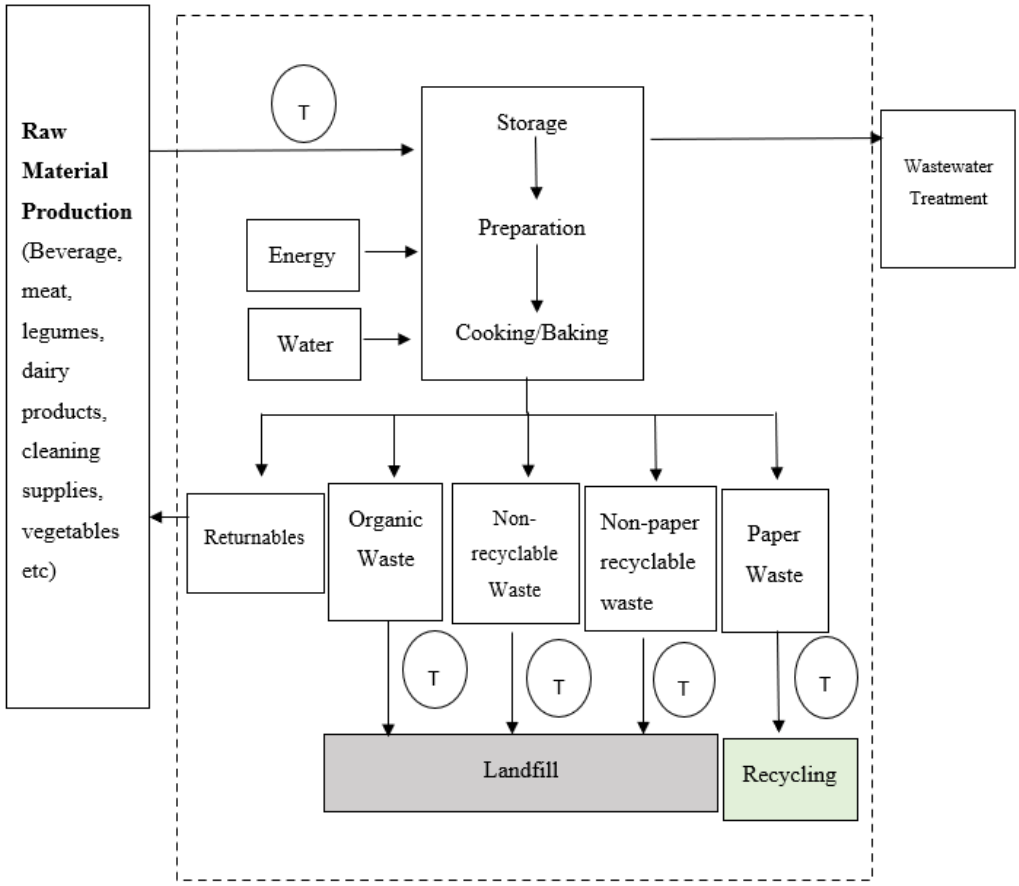


**Figure 3. 3:** System boundary of Scenario 2.

Figure 3.3 shows the system boundary of Scenario 2. In this scenario, returnable HDPE Plastic vegetable boxes(22.37 kg) and glass containers(7.5 kg) are separated from the waste and taken back by the seller during input deliveries. While recyclable paper waste(19.18 kg) is sent to a recycling facility, organic waste(77.57 kg), some of the recyclable waste(14.84 kg) and non-recyclable waste(18.35 kg) are sent to a sanitary landfill facility. Water-saving was applied in this scenario. In this scenario, only paper waste recycling was considered in the system boundary as the paper waste amount and percentage(14.76%) were higher than the other individual recyclable waste amounts(1%-5%).

This scenario includes transportation of inputs, water and energy consumption, waste collection and transportation, paper recycling and disposal of organic waste, non-recyclable waste and recyclable wastes except paper waste at the sanitary landfill facility. Transportation of returnable products was not considered in the system boundary.

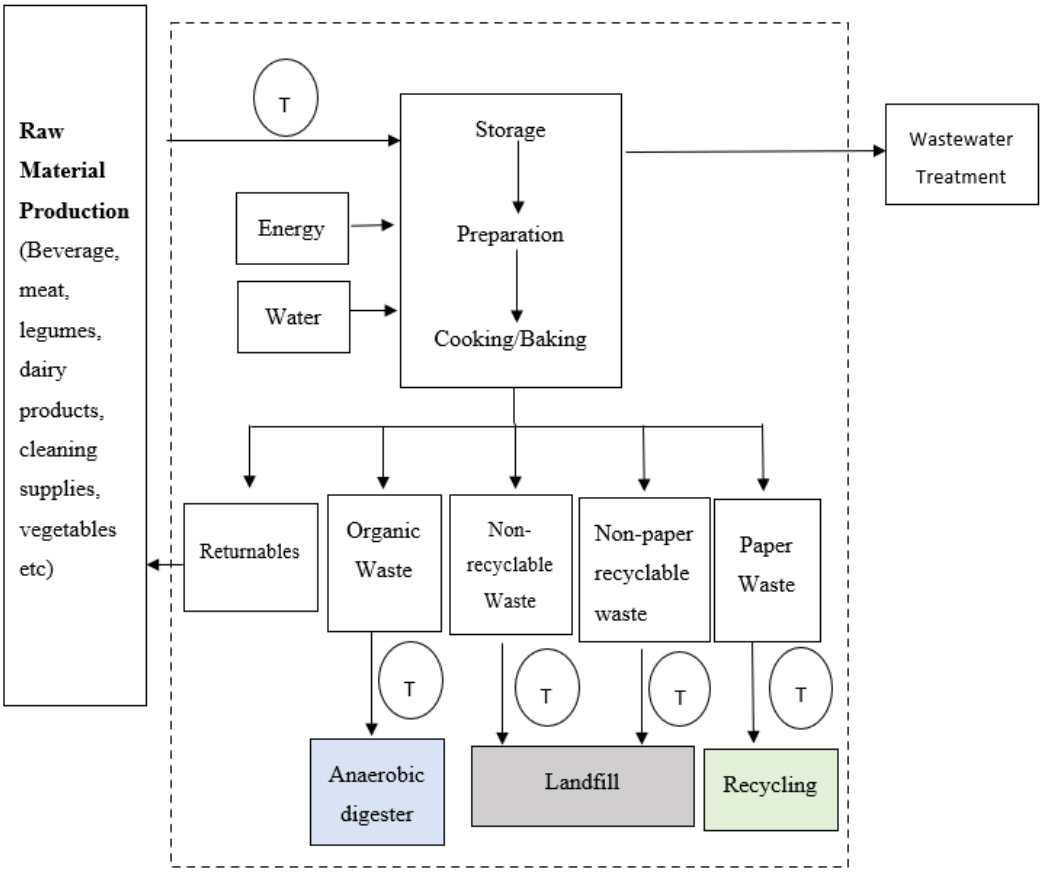


**Figure 3. 4:** System boundary of Scenario 3.

Figure 3.4 shows the system boundary of Scenario 3. In this scenario, returnable HDPE Plastic vegetable boxes(22.37 kg) and glass containers(7.5 kg) are separated from the waste and taken back by the seller during input deliveries. While organic waste(77.57 kg) is sent to anaerobic digestion, paper waste(19.18 kg) is sent to a recycling facility. Non-recyclable waste(18.35 kg) and other recyclables(14.84 kg) are sent to sanitary landfill facility as their individual amounts(1%-5%) were lower than paper waste(14.76%).

Water-saving was applied in this scenario. This scenario includes transportation of inputs, water and energy consumption, waste collection and transportation, disposal of organics at anaerobic digester, non-recyclable and recyclable wastes other than paper waste at the sanitary landfill facility and paper recycling at a recycling facility.

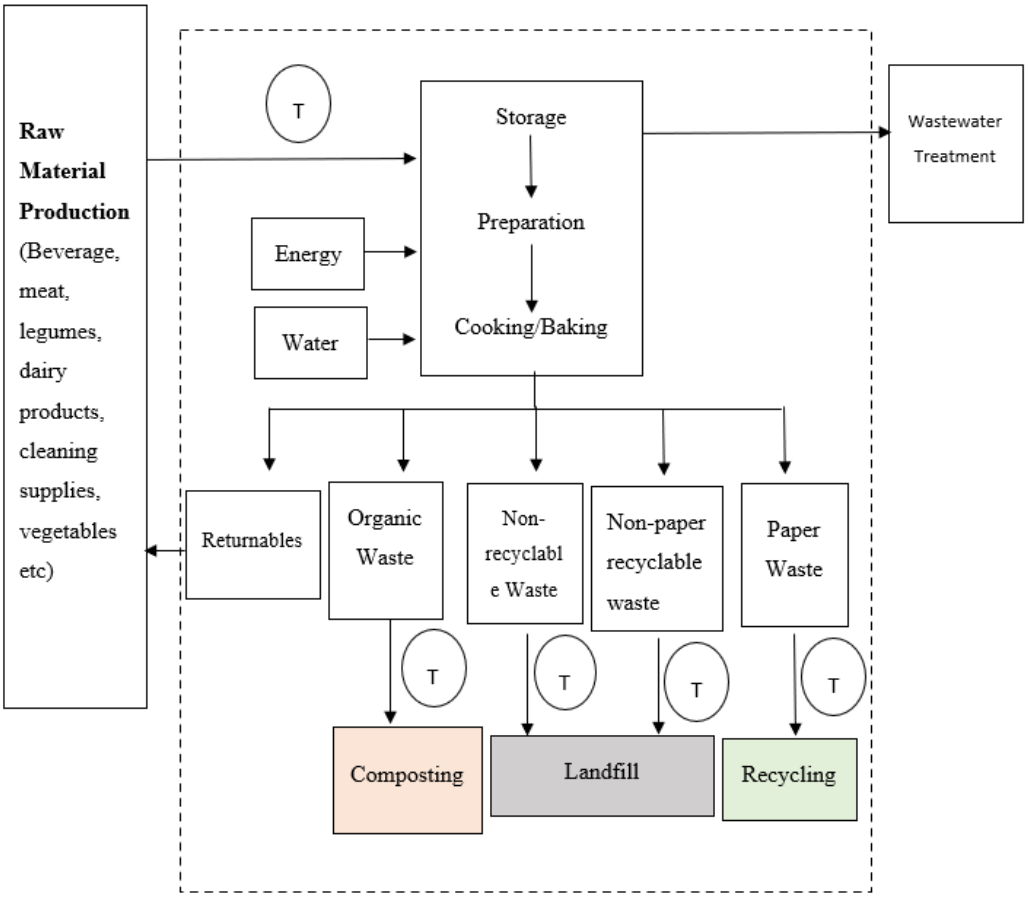


**Figure 3. 5:** System boundary of Scenario 4.

Figure 3.5 shows the system boundary of Scenario 4. In this scenario, returnable HDPE Plastic vegetable boxes(22.37 kg) and glass containers(7.5 kg) are separated from the waste and taken back by the seller during input deliveries. While recyclable paper waste(19.18 kg) is sent to the recycling facility(same as Scenario 2 and 3), organic waste(77.57 kg) is sent to the composting facility. Other recyclables(14.84 kg) and non-recyclable waste(18.35 kg) are sent to a sanitary landfill facility. Water-saving was applied in this scenario. In this scenario, only paper waste recycling was considered in the system boundary(same as Scenario 2 and Scenario 3) as the paper waste amount and percentage(14.76%) were higher than the other recyclable waste amounts(1%-5%)

### 3.1.2.3. Data Quality Requirement

ISO 14040 Standards define requirements to provide data quality of Life Cycle Assessment. Representativeness and completeness are two important needs for establishing data quality. In order to meet these requirements; temporal, geographic and technological aspects need to be defined (Edelen & Ingwersen, 2016).

## 3.2. GaBi Software

In this study, GaBi LCA Software was used. GaBi is a software that calculates environmental impact potentials of a product or production system based on its inventory data and system boundary. Ecoinvent 3.1 Database and CML 2001 Impact Assessment Method were used.

## 3.3. Inventory Analysis

Site-specific data were collected in the restaurant by observing the kitchen and restaurant area and gathering information from the manager.

The information was obtained from the restaurant manager that the daily service number is 180. 7 of these 180 services are packaged and consumed out of the restaurant. Packaging materials and plastic products are only used for services that are consumed out of the restaurant.

All calculations except calculations for products that are only used for services that are consumed out of the restaurant were done with daily 180 services. Calculations for products which only used for services that are consumed out of the restaurant were done with daily 7 services. Waste management of the products which are only used for these 7 services was considered out of the system boundary as it is unknown how end consumers treat their wastes. All values were represented for 1000 services which were calculated with daily service numbers.

Inputs of the restaurant consist of water, electricity, natural gas, beverages, chicken products, red meat products, dairy products, seasonings, legumes, packaging material(aluminum, plastic and paper), kitchen service supplies, vegetables and other food supplies. Cardboards that were delivered as packaging material for supplies were added to the related supplies.

Outputs are waste waster, organic wastes, metal wastes, paper wastes, composite wastes, glass wastes and plastic wastes.

Explanations of some of the input classifications and waste components were listed below;

**Other food supplies:** Lemon juice, oil, sausage, starch, flour, sugar, etc.

**Seasonings:** Seasonings, salt.

**Kitchen and service supplies:** Gloves, paper tissues, wipers, plastic wrap, foil, trash bags, straws, paper cups, plastic forks, etc.

**Aluminium, Plastic, and Paper Packaging Materials for Food:** Packaging material inputs to be used for take-aways.

**Metal waste**: Aluminum beverage cans, a small amount of jar lids.

**Glass waste:** Beverage containers(returnable) and a small amount of jars.

**PET plastic waste**: Beverage containers, lemon juice, etc containers.

**PS plastic waste:** Plastic fork-spoons, meat plates, some lids, salad bowls, etc. In this study, this plastic type is considered non-recyclable as its recycling is rare.

**LDPE plastic waste:** Some beverage packaging materials, plastic wraps, gloves, etc. In this study, this plastic type is considered non-recyclable as its recycling is rare.

**HDPE plastic waste**: Vegetable boxes(returnable), cleaning agent containers.

**PP plastic waste**: Legumes and seasonings packaging, some beverage and yogurt containers, etc. In this study, this plastic type is considered non-recyclable as its recycling is rare.

**Paper waste**: Flour packages, cardboards, supply packagings.

**Other waste**: Used paper tissues, foils, wire wools.

**Composite waste**: Milk and cream boxes and egg trays

In this study, PP Plastic, LDPE Plastic, and PS Plastic wastes are considered as non-recyclable plastics as their recycling is very rare in Turkey(Sifiratik.gov.tr/plastik-atik, 2021).

Supply amounts and seller information were taken from the manager and the transportation distances were collected on the map.

### 3.4. Environmental Impact Potential

Chosen environmental impact potentials to be calculated are; Global Warming Potential, Abiotic Element Depletion Potential, Abiotic Fossil Depletion Potential, Acidification Potential, Eutrophication Potential, Freshwater Aquatic Ecotoxicity Potential, Human Toxicity Potential, Marine Aquatic Ecotoxicity Potential, Ozone

Layer Depletion Potential, Photochemical Ozone Creation Potential, and Terrestic Ecotoxicity Potential. CML 2001 Impact Assessment Method was selected to calculate environmental impact potentials.

# 4. INVESTIGATED RESTAURANT

## 4.1. Location of The Restaurant

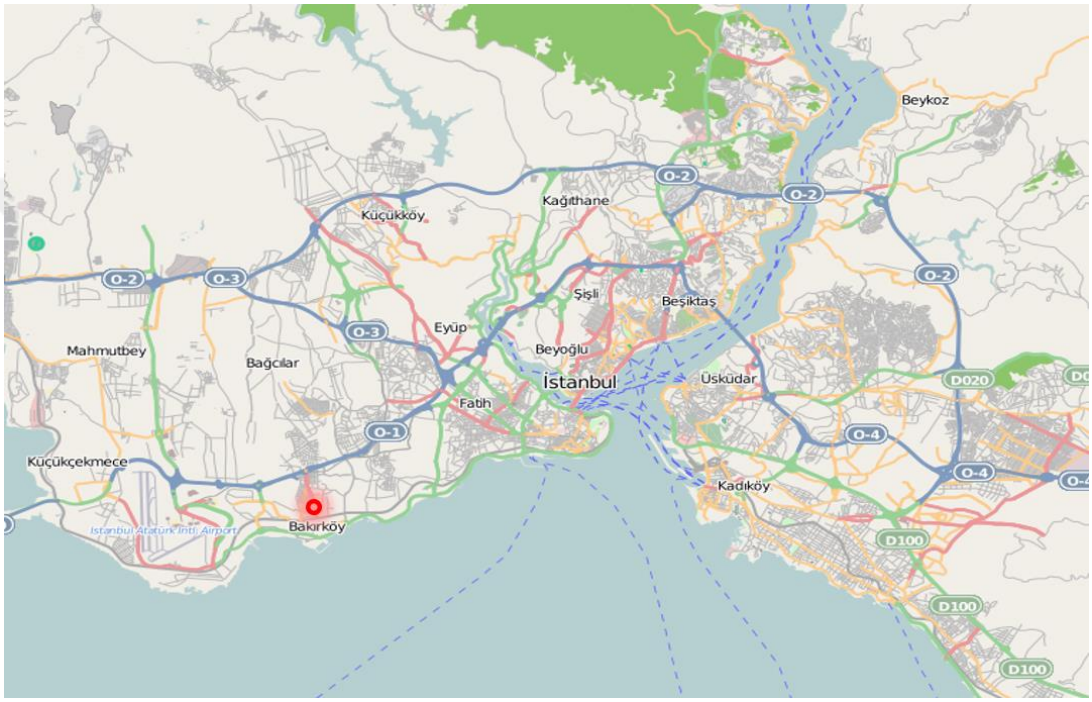


**Figure 4. 1:** Location of the investigated restaurant.

The investigated restaurant is located in a shopping mall in Bakirkoy/Istanbul.

Freshwater for the system is collected from Buyukcekmece Water Treatment Plant. The wastewater is discharged to the municipal system and delivered to Atakoy Advanced Biological Wastewater Treatment Plant.

Solid wastes are collected by municipal services and delivered to Silivri Seymen Sanitary Landfill Facility one time on weekdays and two times on weekends. It was noted that the shopping mall has a project to separate all wastes. All information about waste amounts and distances between disposal facility and restaurant were given in Inventory Analysis Chapter.

## 4.2. Explanation of The Restaurant

The restaurant that was observed serves pita, soup, stews, rice, etc. The daily number of the food service was told by the manager as 180. It was observed and confirmed that there is no usage of plastic tableware in the restaurant and no courier service from the restaurant but there is a takeaway option that causes usage of packaging material. It was told that 7 of these 180 services from the restaurant were packaged and consumed out of the restaurant. Plastic fork and spoons were used only for the daily 7 services.

During restaurant observations; The number and usage of the electricity-consuming devices (dishwasher, refrigerates, ovens, etc.) were noted. Some of the energy-consuming devices are represented below.

### 4.2.1. Equipment of The Restaurant

10 refrigerators (some of them are used as deepfreeze) are used and one benmarie is used to keep foods warm before serving. The dishwasher is used 120 times everyday. It has 3 different modes in terms of operation minutes(40 seconds, 90 seconds, and 180 seconds). In the restaurant that was observed, the dishwasher is operated 3 minutes per operation and it consumes 2.8 L per operation. Water consumption of dishwasher for 1000 services was calculated with this information. Hand wash is applied before dishes enter the dishwasher.

There are three washbasins in the restaurant. One of them is used for hand wash of the dishes before the dishwasher. One of them is used for preparing food and the last one is used for hand wash. After the water consumption of dishwasher for 1000 services was calculated, the result was subtracted from overall water consumption for 1000 services. Tap water consumption for the washing process was assumed to be 80% of the remaining part. Stone oven consumes natural gas and it is operated between 10 am and 10 pm everyday. The stove that is used in the kitchen is operated between 8 am and 12 am every morning. It is operated once in a day every morning. The stove consumes natural gas. There are two range hoods in the kitchen. Cleaning of range hoods is done once in a month. There are 46 led lighters in the restaurant area. 9 led lighters that are placed on the terrace are not included in electricity consumption as they belonged to the shopping mall. There are 3 flashing signs in front of the restaurant. 12 V white leds are used for the lighting system of the restaurant.

### 4.3. Inventory Analysis

Consumptions for water, electricity and natural gas were gathered as TL from the restaurant manager and they were converted to $m^3$, kWh and $m^3$, respectively.(Table 4.1) As a result of very low water usages for January and February, they were not added to the average calculations in this section.

Average water, electricity and natural gas usages belong to 2019 were calculated for 1000 services and represented in Table 4.2.

**Table 4. 1:** Electricity, water and natural gas consumption for 2019.

| Months | Electricity (kWh) | Water ($m^3$) | Natural gas ($m^{3)}$ |
|---|---|---|---|
| January | 4238.98 | ND | 1032.43 |
| February | 3841.32 | ND | 1303.61 |
| March | 4417.61 | 34.79 | 1024.32 |
| April | 4277.19 | 35.60 | 1112.75 |
| May | 4452.19 | 37.91 | 1126.02 |
| Jun | 4888.82 | 43.00 | 1408.25 |
| July | 4961.12 | 48.00 | 910.10 |
| August | 5288.38 | 52.00 | 1297.71 |
| September | 4473.34 | 42.86 | 956.74 |
| October | 4551.71 | 39.15 | 1023.08 |
| November | 4731.91 | 55.00 | 1137.93 |
| December | 4689.07 | 50.00 | 1190.34 |
| **Monthly Avarage** | 4567.64 | 43.83 | 1126.94 |

ND: No data

**Table 4. 2:** Consumption of electricity, water and natural gas for 1000 services.

| Electricity Usage for 1000 Services | Water Usage for 1000 Services | Natural Gas Usage for 1000 Services |
|---|---|---|
| 846 kWh | 8.12 $m^3$ | 208.69 $m^3$ |

Natural gas usage was represented for $m^3$. It was converted for kWh to compare with electricity usage. Calculations showed that 2220.4 kWh natural gas was used for 1000 services.(1 $m^3$=10.64 kWh)

Consumption of dishwasher was calculated and found 1.86 $m^3$ for 1000 services. This value was subtracted from the water input. While 80% of the remaining part of the

water input was assumed to be used for washing and cleaning(5.01 $m^3$), 20% of it was assumed to be consumed for food(1.25$m^3$). Wastewater was calculated by subtracting water consumption for food from the overall water input. Results showed that wastewater for 1000 services was 6.87 $m^3$ in the base scenario(Scenario 0). It was concluded that 84.6% of the water was left the system as wastewater(Calderón et al., 2018).

The number of daily service was 180 and amount of packaged food services that are consumed out of the restaurant were 7 of 180. All inputs except packaging materials and plastic fork-spoon products were calculated with daily 180 services. Packaging materials and plastic forks and spoons were calculated with daily 7 services as they were bought from the restaurant only for consumption out of the restaurant. Cardboard input comes with the supplies as packaging material. For this reason, cardboard weights were calculated and added to the related supplies in input tables.

Table 4.3 shows inventory data of Scenario 0. The total amount of inputs and outputs were calculated for Scenario 0 are 1487.9 kg and 159.81 kg for 1000 services respectively. (Except water, electricity and natural gas consumptions). Returnable products( 22.37 kg HDPE Plastic and 7.5 kg glass containers) were considered as waste in Scenario 0 and included in Table 4.3.

**Table 4. 3:** Inputs and outputs for 1000 services for Scenario 0.

| | Amount | Unit |
|---|---|---|
| **Inputs** | | |
| Water | 8.12 | m3 |
| Electricity | 846 | kWh |
| Natural gas | 208.7 | m3 |
| Beverages | 683.73 | kg |
| Chicken Products | 37.09 | kg |
| Red Meat Products | 60.33 | kg |
| Dairy Products | 89.33 | kg |
| Seasonings | 8.81 | kg |
| Other Food Supplies | 175.52 | kg |
| Legumes | 73.77 | kg |
| Aluminum Packaging Material For Food | 15.9 | kg |
| Plastic Packaging Material For Food | 3.01 | kg |
| Paper Packaging Material For Food | 15.95 | kg |
| Kitchen and service supplies | 8.38 | kg |
| Chemical Cleaning Agents | 17.64 | kg |
| Groceries | 298.23 | kg |
| **Outputs** | | |
| Waste Water | 6.87 | m3 |
| Organic Waste | 77.57 | kg |
| Returnable Products | | |
| Glass Waste | 7.5 | kg |
| HDPE Plastic Waste | 22.37 | kg |
| Recyclable Waste | | |
| Metal and Aluminum Waste | 5.93 | kg |
| Glass waste | 0.02 | kg |
| PET Plastic Waste | 6.21 | kg |
| HDPE Plastic Waste | 2.68 | kg |
| Paper Waste | 11.22 | kg |
| Card board Waste(Paper) | 7.96 | kg |
| Non-recyclable Waste | | |
| PS Plastic Waste | 1.41 | kg |
| PP Plastic Waste | 7.95 | kg |
| LDPE Plastic Waste | 5.36 | kg |
| Non-recyclable Waste | 2.85 | kg |
| Composite Waste | 0.78 | kg |

Table 4.4 shows inventory data of Scenario 1, Scenario 2, Scenario 3 and Scenario 4. Returnable products were not considered as waste in those scenarios and not included

in Table 4.4. Returnable products were assumed to be given back to the seller during input deliveries in Scenario 1, Scenario 2, Scenario 3 and Scenario 4. Also water reduction was applied in Scenario 1, Scenario 2, Scenario 3 and Scenario 4. As a result, water input and output were changed and represented in Table 4.4.

Results show that 10.74% of the inputs were wasted in Scenario 0(Betz et al., 2015). For Scenario 1, Scenario 2, Scenario 3 and Scenario 4, results show that 8.73% of the inputs were wasted. This difference was caused by giving returnable products back to the seller and not considered as waste in all scenarios except Scenario 0. It was calculated that 34.3% of the organic waste comes from the plate waste and 65.7% of the organic waste comes from the preparation step. Preparation waste includes eggshells, unavoidable vegetable wastes(peals, uneatable parts, etc). Plate waste includes leftovers(vegetables, meat bones) (Malefors et al., 2017; Cucurachi et al., 2019).

**Table 4. 4:** Inputs and outputs for 1000 services for Scenario 1, Scenario 2, Scenario 3 and Scenario 4.

| Material | Amount | Unit |
|---|---|---|
| **Inputs** | | |
| Water | 5.12 | m3 |
| Electricity | 846 | kWh |
| Natural gas | 208.69 | m3 |
| Beverages | 683.73 | kg |
| Chicken Products | 37.09 | kg |
| Red Meat Products | 60.33 | kg |
| Dairy Products | 89.33 | kg |
| Seasonings | 8.81 | kg |
| Other Food Supplies | 175.52 | kg |
| Legumes | 73.77 | kg |
| Aluminum Packaging Material For Food | 15.9 | kg |
| Plastic Packaging Material For Food | 3.01 | kg |
| Paper Packaging Material For Food | 15.95 | kg |
| Kitchen and service supplies | 8.38 | kg |
| Cleaning Agents | 17.64 | kg |
| Groceries | 298.23 | kg |
| **Outputs** | | |
| Waste Water | 3.87 | m3 |
| Organic Waste | 77.57 | kg |
| Recyclable Waste | | |
| Metal and Aluminum Waste | 5.93 | kg |
| Glass waste | 0.02 | kg |
| PET Plastic Waste | 6.21 | kg |
| HDPE Plastic Waste | 2.68 | kg |
| Paper Waste | 11.22 | kg |
| Card board Waste(Paper) | 7.96 | kg |
| Non-recyclable Waste | | |
| PS Plastic Waste | 1.41 | kg |
| PP Plastic Waste | 7.95 | kg |
| LDPE Plastic Waste | 5.36 | kg |
| Other Waste | 2.85 | kg |
| Composite Waste | 0.78 | kg |

**Table 4. 5:** Amounts for 1000 services and transportation distances for inputs.

| | **Amount (kg)** | **Distances (km)** |
|---|---|---|
| Beverage, Chicken, Legumes. | 343.94 | 20 |
| Cleaning Agents For Dishwasher | 483.31 | 17 |
| Red Meat | 60.33 | 24 |
| Legumes | 63.43 | 19 |
| Butter | 5.18 | 1107 |
| Food additives, Dairy and Cleaning Supplies(Wholesale market) | 189.07 | 10 |
| Kitchen, cleaning and Service Supplies(wipers, paper cups, etc) | 14.94 | 11 |
| Packaging Materials For Food Services | 29.26 | 18 |
| Vegetables | 298.23 | 29 |
| | **Total** | |
| | 1487.69 | |

Inputs that have the same transportation distances were summed and represented in Table 4.5. Table 4.5 is valid for all of the scenarios in this study.

All inputs which have the same seller and sellers which have the same distance to the restaurant were categorized after input weights, type of wastes and weights of wastes were measured. In beverages section; LDPE type of plastic is used as packaging material and it was assumed that 24 products can be placed in a package. Wastes that were generated by this packaging material were added to LDPE plastic waste section. In vegetable section; HDPE type of plastic is used for vegetable boxes. It was assumed that one vegetable box can contain 20 kg of vegetables and one empty vegetable box weight is 1.5 kg. For other inputs, cardboards that have 0.3 kg of empty weight were used. Waste calculations were done with this information. Waste management for wastes which were generated by packaging materials for food and plastic fork-spoon products were considered out of the system boundaries as the fate of those wastes were unknown as a result of consumption out of the restaurant.

**Table 4. 6:** Transportation distances and waste management of the current system(Scenario 0).

| Outputs | Amount (kg) | Waste Management | Waste Transportation Distances(km) |
|---|---|---|---|
| **Organic Waste** | 77.57 | Landfill | 100 |
| **Returnable Products** | | | |
| Glass waste (Beverage containers) | 7.5 | Landfill | 100 |
| HDPE Plastic Waste (Vegetable box) | 22.37 | Landfill | 100 |
| **Recyclable Waste** | | | |
| Metal and Aluminum Waste | 5.93 | Landfill | 100 |
| Glass Waste | 0.02 | Landfill | 100 |
| PET Plastic Waste | 6.21 | Landfill | 100 |
| Paper Waste | 11.22 | Landfill | 100 |
| Card board (paper) | 7.96 | Landfill | 100 |
| **Non-recyclable waste** | | | |
| PS Plastic Waste | 1.41 | Landfill | 100 |
| LDPE Plastic Waste | 5.36 | Landfill | 100 |
| HDPE Plastic Waste | 2.68 | Landfill | 100 |
| PP Plastic Waste | 7.95 | Landfill | 100 |
| Other Waste | 2.85 | Landfill | 100 |
| Composite Waste | 0.78 | Landfill | 100 |
| **TOTAL** | 159.81 | | |

Waste amounts and waste management information were given in Table 4.6 for Scenario 0. In this scenario, all of the wastes generated by the restaurant were collected together in the shopping mall and gathered by the municipality. Returnable products such as 22.37 kg HDPE Plastic vegetable box and 7.5 kg glass container were considered as waste. Collected wastes were sent to Silivri Seymen Sanitary Landfill Facility with a distance of 100 km. The information about the waste management was taken from the environmental engineer of Bakirkoy Municipality.

Waste characterization of Scenario 0 was indicated in Figure 4.2 and detailed in Table 4.7.

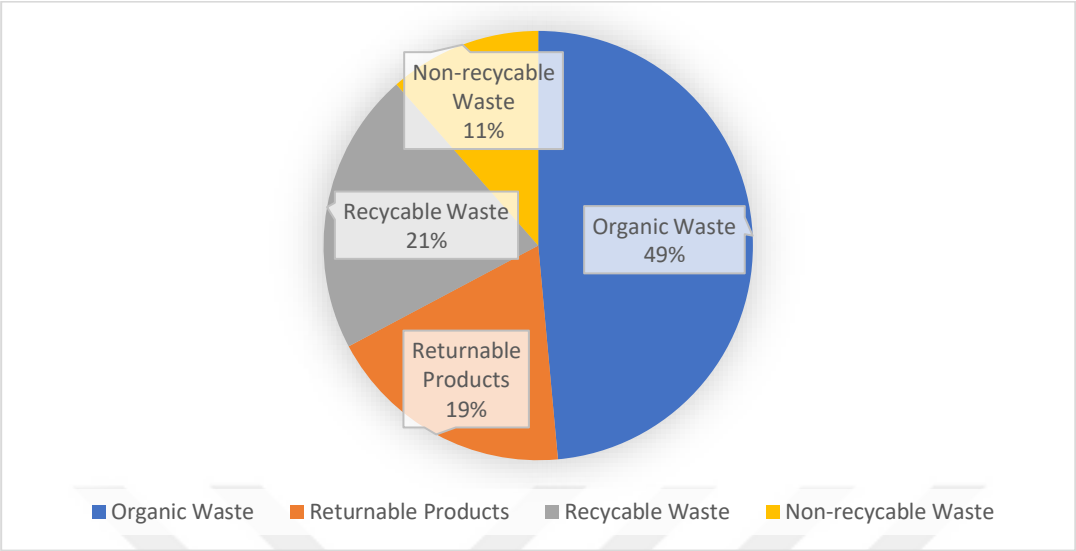


**Figure 4. 2:** Waste characterization of Scenario 0.

**Table 4. 7:** Detailed waste characterization of Scenario 0.

| WASTE CHARACTERIZATION | % | AMOUNT(KG) |
|---|---|---|
| **Organic Waste** | 48.52 | 77.57 |
| **Returnable Products** | | |
| Glass Waste (beverage container) | 4.69 | 7.5 |
| HDPE Plastic Waste (vegetable box) | 13.99 | 22.37 |
| **Recyclable Waste** | | |
| Metal and Aluminum Waste | 4.00 | 5.93 |
| Glass waste | 0.01 | 0.02 |
| PET Plastic Waste | 3.89 | 6.21 |
| HDPE Plastic Waste | 1.68 | 2.68 |
| Paper Waste | 11.99 | 19.18 |
| **Non-recyclable Waste** | | |
| PS Plastic Waste | 0.91 | 1.41 |
| PP Plastic Waste | 4.97 | 7.95 |
| LDPE Plastic Waste | 3.35 | 5.36 |
| Other Waste | 1.50 | 2.85 |
| Composite Waste | 0.49 | 0.78 |

Waste characterization of Scenario 1, Scenario 2, Scenario 3 and Scenario 4 was indicated in Figure 4.3 and detailed in Table 4.8.

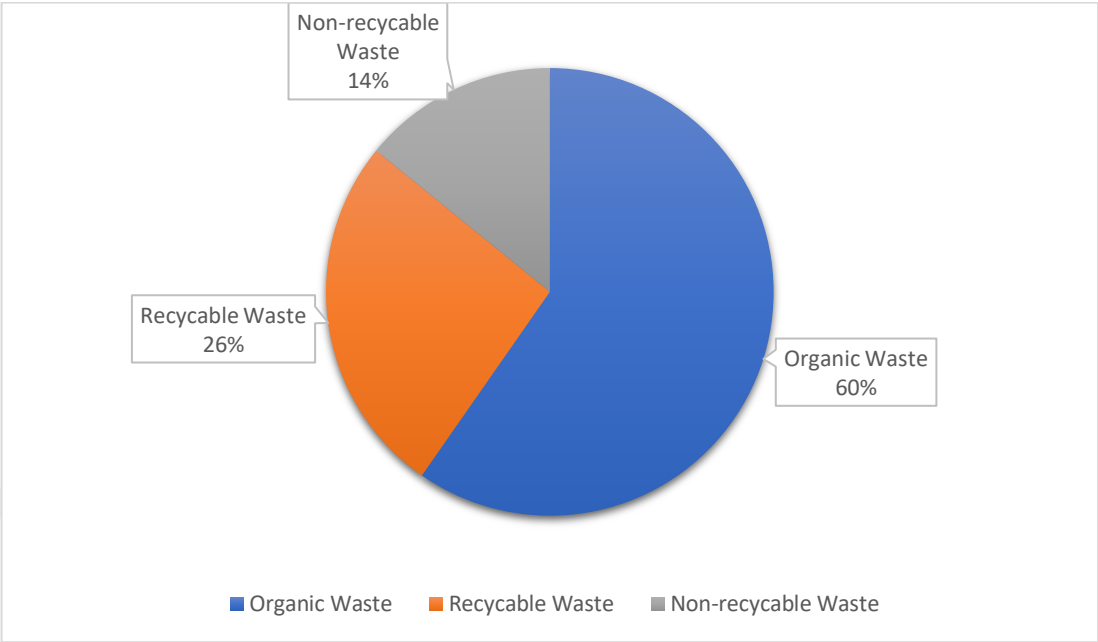


**Figure 4. 3:** Waste characterization of Scenario 1, Scenario 2, Scenario 3 and Scenario 4

**Table 4. 8:** Detailed waste characterization of Scenario 1, Scenario 2, Scenario 3 and Scenario 4.

| WASTE CHARACTERIZATION | % | AMOUNT(KG) |
|---|---|---|
| **Organic Waste** | 59.67 | 77.57 |
| **Recyclable Waste** | | |
| Metal and Aluminum Waste | 4.57 | 5.93 |
| Glass waste | 0.02 | 0.02 |
| PET Plastic Waste | 4.78 | 6.21 |
| HDPE Plastic Waste | 2.06 | 2.68 |
| Paper Waste | 14.76 | 19.18 |
| **Non-recyclable Waste** | | |
| PS Plastic Waste | 1.08 | 1.41 |
| PP Plastic Waste | 6.12 | 7.95 |
| LDPE Plastic Waste | 4.12 | 5.36 |
| Other Waste | 2.20 | 2.85 |
| Composite Waste | 0.60 | 0.78 |

**Table 4. 9:** Transportation distances and waste managements of Scenario 1.

| Outputs | Amount (kg) | Waste Management | Waste Transportation Distances(km) |
|---|---|---|---|
| **Organic Waste** | 77.57 | Landfill | 100 |
| **Recyclable Waste** | | | |
| Metal and Aluminum Waste | 5.93 | Landfill | 100 |
| Glass Waste | 0.02 | Landfill | 100 |
| PET Plastic Waste | 6.21 | Landfill | 100 |
| Paper Waste | 11.22 | Landfill | 100 |
| Card board | 7.96 | Landfill | 100 |
| **Non-recyclable waste** | | | |
| PS Plastic Waste | 1.41 | Landfill | 100 |
| LDPE Plastic Waste | 5.36 | Landfill | 100 |
| HDPE Plastic Waste | 2.68 | Landfill | 100 |
| PP Plastic Waste | 7.95 | Landfill | 100 |
| Other Waste | 2.85 | Landfill | 100 |
| Composite Waste | 0.78 | Landfill | 100 |
| **TOTAL** | 129.94 | | |

Waste management information for Scenario 1 was given in Table 4.9. Returnable products were given back to the seller during input deliveries and not included in Table 4.9. The rest of the wastes were sent to Silivri Seymen Sanitary Landfill Facility with a distance of 100 km.

**Table 4. 10:** Transportation distances and waste managements of Scenario 2.

| Outputs | Amount (kg) | Waste Management | Waste Transportation Distances(km) |
|---|---|---|---|
| **Organic Waste** | 77.57 | Landfill | 100 |
| **Recyclable Waste** | | | |
| Metal and Aluminum Waste | 5.93 | Landfill | 100 |
| Glass Waste | 0.02 | Landfill | 100 |
| PET Plastic Waste | 6.21 | Landfill | 100 |
| Paper Waste | 11.22 | Recycling | 20 |
| Card board | 7.96 | Recycling | 20 |
| **Non-recyclable waste** | | | |
| PS Plastic Waste | 1.41 | Landfill | 100 |
| LDPE Plastic Waste | 5.36 | Landfill | 100 |
| HDPE Plastic Waste | 2.68 | Landfill | 100 |
| PP Plastic Waste | 7.95 | Landfill | 100 |
| Other Waste | 2.85 | Landfill | 100 |
| Composite Waste | 0.78 | Landfill | 100 |
| **TOTAL** | 129.94 | | |

Waste management information for Scenario 2 was given in Table 4.10. In this scenario, Returnable products were returned back to the seller during input deliveries and not represented in Table 4.10. Paper waste was separated and sent to a recycling facility with a distance of 20 km. The remaining waste was sent to a sanitary landfill facility with a distance of 100 km. As it can be seen from Table 4.8, individual amounts of other recyclable wastes were less than paper waste. Therefore recyclables except paper waste were not sent to a recycling facility.

**Table 4. 11:** Transportation distances and waste managements of Scenario 3.

| Outputs | Amount (kg) | Waste Management | Waste Transportation Distances(km) |
|---|---|---|---|
| Organic Waste | 77.57 | Anaerobic digester | 39 |
| Recyclable Waste | | | |
| Metal and Aluminum Waste | 5.93 | Landfill | 100 |
| Glass Waste | 0.02 | Landfill | 100 |
| PET Plastic Waste | 6.21 | Landfill | 100 |
| Paper Waste | 11.22 | Recycling | 20 |
| Card board | 7.96 | Recycling | 20 |
| Non-recyclable waste | | | |
| PS Plastic Waste | 1.41 | Landfill | 100 |
| LDPE Plastic Waste | 5.36 | Landfill | 100 |
| HDPE Plastic Waste | 2.68 | Landfill | 100 |
| PP Plastic Waste | 7.95 | Landfill | 100 |
| Other Waste | 2.85 | Landfill | 100 |
| Composite Waste | 0.78 | Landfill | 100 |
| **TOTAL** | 129.94 | | |

Waste management information for Scenario 3 was given in Table 4.11 In this scenario, Returnable products were returned back to the seller during input deliveries and not represented in Table 4.11. Paper waste was separated and sent to a recycling facility with a distance of 20 km. Organic waste was separated and sent to anaerobic digestion with a distance of 39 km. The remaining waste was sent to a sanitary landfill facility with a distance of 100 km. As it can be seen from the table, individual amounts of other recyclable wastes were less than paper waste. Therefore recyclables except paper waste were not sent to a recycling facility.

**Table 4. 12:** Transportation distances and waste managements Scenario 4.

| Outputs | Amount (kg) | Waste Management | Waste Transportation Distances(km) |
|---|---|---|---|
| Organic Waste | 77.57 | Composting | 39 |
| Recyclable waste | | | |
| Metal and Aluminum Waste | 5.93 | Landfill | 100 |
| Glass Waste | 0.02 | Landfill | 100 |
| PET Plastic Waste | 6.21 | Landfill | 100 |
| Paper Waste | 11.22 | Recycling | 20 |
| Card board | 7.96 | Recycling | 20 |
| Non-recyclable waste | | | |
| PS Plastic Waste | 1.41 | Landfill | 100 |
| LDPE Plastic Waste | 5.36 | Landfill | 100 |
| HDPE Plastic Waste | 2.68 | Landfill | 100 |
| PP Plastic Waste | 7.95 | Landfill | 100 |
| Non-recyclable Waste | 2.85 | Landfill | 100 |
| Composite Waste | 0.78 | Landfill | 100 |
| **TOTAL** | 129.94 | | |

Waste management information for Scenario 4 was given in Table 4.12. In this scenario, returnable products were returned back to the seller during input deliveries and not represented in Table 4.12. Paper waste was separated and sent to a recycling facility with a distance of 20 km. Organic waste was separated and sent to a composting facility with a distance of 39 km. The remaining waste was sent to a sanitary landfill facility with a distance of 100 km. As it can be seen from the table, individual amounts of other recyclable wastes were less than paper waste. Therefore recyclables except paper waste were not sent to a recycling facility

# 5. RESULTS

## 5.1. Applying to Gabi Software

In this study, Gabi Software was used in order to calculate environmental impact potentials.

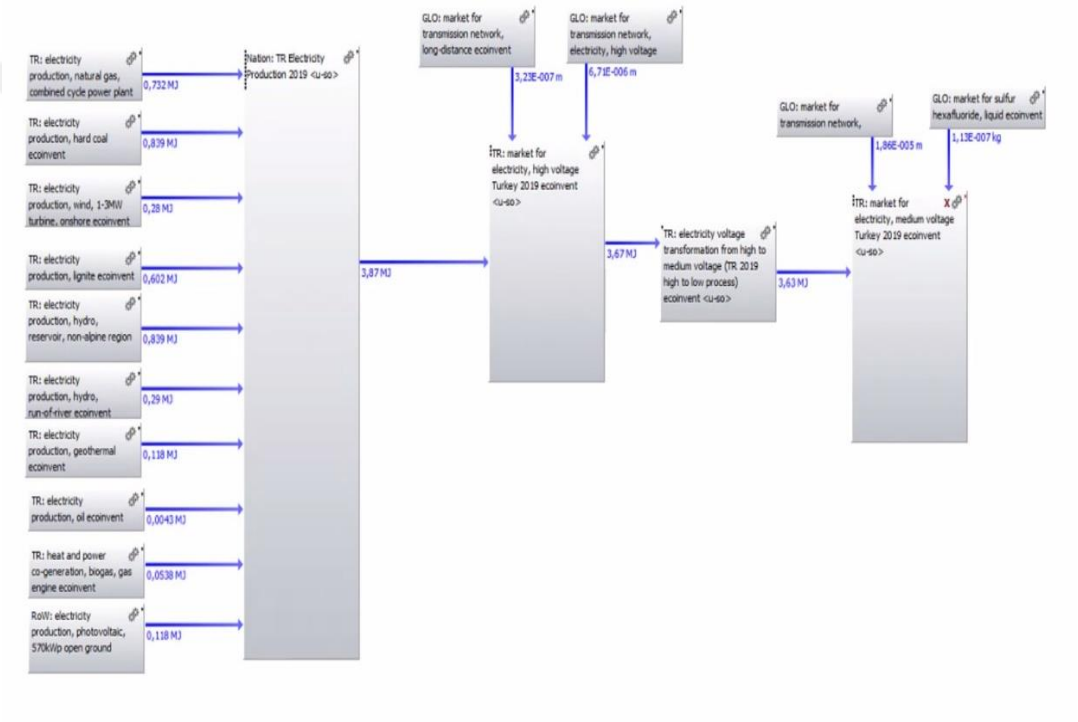


**Figure 5. 1:** Turkey's medium voltage electricity mix(2019) model in Gabi 7.3

Figure 5.1 shows medium voltage electricity mix for Turkey(2019). Medium voltage electricity mix model was created from 2019 data belong to Turkey(TEİAS). TR Electricity production mix was modelled, high voltage electricity is converted to medium voltage with "electricity voltage transformation from high voltage to medium voltage". "Market for electricity, medium voltage" process was fixed for 1 kWh medium voltage electricity production. Then results were multiplied with the electricity consumption taken from inventory data(846 kWh). Market for low voltage and market for high voltage models were created in the same way to be used in other electricity-consuming models.

Market for heat, natural gas process from Ecoinvent 3.1 was used for natural gas consumption(Baldwin et al., 2010).


**Figure 5. 2**: Sanitary landfill model in Gabi 7.3

Sanitary landfill process and composting process were taken from Ecoinvent 3.1 Database and flows were connected. Figure 5.2 and Figure 5.3 represent landfill and composting processes, respectively. Anaerobic digester process was taken from Ecoinvent 3.7 Database and flows were connected. Anaerobic digester process was shown in Figure 5.4. Processes were fixed for 1 kg of waste. Tkm(ton-kilometer) values were entered to models individually according to the waste disposal facility distance between restaurant and facility. Results were multiplied with individual waste amounts to reach environmental impact potentials. Tkm values for 1 kg waste in landfill, anaerobic digester and compost were 0.1 tkm, 0.039 tkm and 0.039 tkm, respectively.


**Figure 5. 3:** Composting model in Gabi 7.3

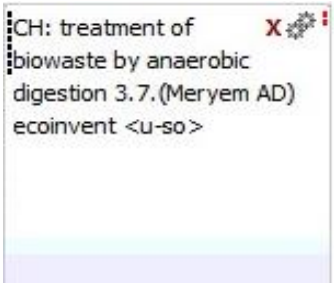


**Figure 5. 4:** Anaerobic digester model in Gabi 7.3

This study includes input transportations in the system boundary. Three different transportation processes were used in order to calculate environmental impacts of input transportation. While “Transport, freight, lorry 3.5-7.5 metric ton, EURO5” process was selected for inputs that come from a close distance(Istanbul), “Transport, freight, lorry 7.5-16 metric ton, EURO5” was selected for inputs that come from Trabzon(>1000 km). For the inputs that are bought from the wholesale market, there is no delivery system from the seller. Therefore “Transport, passenger car, large size, diesel, EURO 5” were used for inputs that were bought from the wholesale market.

## 5.2. Impact Assessment

### 5.2.1. Impact Assessment Methods

CML 2001 Impact Assessment Method was used to calculate environmental impact potentials. Select environmental impact potentials were Abiotic Depletion Potential, Acidification Potential, Eutrophication Potential, Freshwater Aquatic Ecotoxicity Potential, Global Warming Potential, Human Toxicity Potential, Marine Aquatic Ecotoxicity Potential, Ozone Layer Depletion Potential, Photochemical Ozone Creation Potential, Terrestric Ecotoxicity Potential.

### 5.2.2. LCIA Results

Environmental impact assessment of the restaurant was represented in Table 5.1 Results were represented for 1000 services.

**Table 5. 1:** Environmental impact assessment of the restaurant(Scenario 0).

| Environmental Impact Category | Unit | Total |
|---|---|---|
| **ADP Elements** | kg Sb-Equiv. | 6.78E-04 |
| **ADP Fossil** | MJ | 1.43E+04 |
| **AP** | kg SO2-Equiv. | 5.44E+00 |
| **EP** | kg Phosphate-Equiv. | 3.35E+00 |
| **FAETP** | kg DCB-Equiv. | 7.08E+02 |
| **GWP** | kg CO2-Equiv. | 1.26E+03 |
| **HTP** | kg DCB-Equiv. | 4.32E+02 |
| **MAETP** | kg DCB-Equiv. | 1.35E+06 |
| **ODP** | kg R11-Equiv. | 4.88E-05 |
| **POCP** | kg Ethene-Equiv. | 3.80E-01 |
| **TETP** | kg DCB-Equiv. | 2.74E+00 |

Table 5.2 shows the most important sources of environmental impact categories in this study.

**Table 5. 2:** Environmental impact potential sources and their contribution for Scenario 0.

| SCENARIO 0 | Important Factor/Factors in Scenario 0 | Most important impact sources, their contribution and important factors | Impact percentages |
|---|---|---|---|
| **ADP Elements** | Electricity | Non-renewable element consumption (99%) (Copper, gold, silver, cadmium, lead, etc) | 39.81% |
| | Natural Gas | Non-renewable element consumption(96%) (Copper, cadmium, lead, etc) | 36.02% |
| **ADP Fossil** | Natural gas | Non-renewable energy source(96%) (Natural gas) | 60.12% |
| **AP** | Electricity | Inorganic emissions to air(99%) (Sulphur dioxide) | 56.73% |
| | Natural gas | Inorganic emissions to air(91%) (Sulphur dioxide) | 38.87% |
| **EP** | Electricity | Emissions to freshwater (91%) (Phosphate) | 57.66% |
| | Landfill | Emissions to freshwater (98%) (TOC, COD) | 36.49% |
| **FAETP** | Electricity | Emissions to freshwater(99%) (nickel, beryllium, cobalt, copper, etc) | 48.74% |
| | Landfill | Emissions to freshwater(99%) (Copper, nickel) | 43.95% |
| **GWP** | Natural gas | Inorganic emissions to air(88%) ($CO_2$) | 47.57% |
| | Electricity | Inorganic emissions to air(94%) ($CO_2$) | 39.01% |
| **HTP** | Electricity | -Emissions to freshwater(70%) (Selenium, barium, nickel, etc), -Heavy metals to air(15%) (Chromium, arsenic) | 63.23% |
| **MAETP** | Electricity | Emissions to fresh water(68%) (beryllium, nickel, etc) | 78.50% |
| **ODP** | Natural gas | Halogenated organic emissions to air(99.99%) (Halon) | 71.42% |
| **POCP** | Natural gas | -Inorganic emissions to air(54%) (Sulphur dioxide) -Organic emissions to air(46%) (NMVOC) | 45.91% |
| | Electricity | Inorganic emisisons to air(86%) (sulphur dioxide, nitrogen oxides) | 40.96% |
| **TETP** | Electricity | -Heavy metals to air(54%) (mercury, chromium) -Heavy metals to industrial soil(39%) ( Chromium (+VI)) | 62.79% |

## 5.3. Environmental Impact Potential Categories Comparison

**Table 5. 3:** Literature comparison.

| | ADP Element | ADP Fossil | AP | EP | FAETP | GWP | HTP | MAETP | ODP | POCP | TETP | Refence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LF** | 1.26E-07 | 2.16 | 9.13E-04 | 7.79E-03 | 1.95E+00 | 8.96E-01 | 2.22E-01 | 9.65E+02 | 2.65E-08 | 2.51E-04 | 1.64E-03 | This study |
| **LF** | 2.61E-08 | 2.68E-01 | 2.66E-04 | 7.62E-03 | 1.94E+00 | 7.63E-01 | 1.95E-01 | 9.43E+02 | 3.44E-09 | 1.40E-04 | 1.50E-03 | Ecoinvent(agg) |
| **LF** | | | 3.40E-04 | 3.00E-04 | 2.00E-05 | 5.93E-01 | 3.20E-04 | 4.92E-03 | | 1.60E-04 | 1.00E-05 | (Zhang et al., 2019) |
| **LF** | | | 2.60E-03 | 2.50E-03 | | 1.53 | | | 3.60E-09 | 5.00E-04 | | (Righi et al., 2013) |
| **LF** | 1.99E-09 | 0.136 | 1.69E-04 | 6.62E-05 | 2.08E-02 | 1.83 | 4.79E-02 | 7.16E+01 | 3.83E-09 | 4.05E-04 | 1.28E-03 | (Erses Yay, 2015) |
| **COM** | 6.92E-08 | 9.24E-01 | 1.73E-03 | 3.54E-04 | 8.46E-03 | 5.38E-01 | 1.79E-02 | 1.97E+01 | 1.11E-08 | 8.97E-05 | 1.94E-04 | This study |
| **COM** | 3.25E-08 | 2.21E-01 | 1.48E-03 | 2.82E-04 | 4.58E-03 | 4.88E-01 | 6.94E-03 | 7.30E+00 | 2.96E-09 | 4.92E-05 | 1.31E-04 | Ecoinvent (agg) |
| **COM** | | | 2.90E-04 | 7.14E-03 | | 0.031 | | | | 2.00E-05 | | (Padeyanda et al., 2016) |
| **AD** | 5.91E-08 | 1.14 | 8.49E-04 | 1.82E-04 | 5.08E-03 | 3.67E-01 | 1.60E-02 | 1.23E+01 | 1.44E-08 | 6.72E-05 | 1.67E-04 | This study |

**Table 5.3(Continued):** Literature comparison

| | ADP Element | ADP Fossil | AP | EP | FAETP | GWP | HTP | MAETP | ODP | POCP | TETP | Refence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AD(3.1)** | 2.20E-07 | 1.11 | 6.99E-04 | 2.52E-04 | 2.87E-02 | 2.95E-01 | 3.80E-02 | 3.55E+01 | 1.64E-08 | 8.22E-05 | 3.09E-03 | Ecoinvent(agg) |
| **AD** | | | 1.40E-04 | 1.00E-05 | 6.00E-05 | 0.023 | 1.60E-04 | | | | | (Jin et al., 2015) |
| **COM_LF** | 8.62E-08 | 1.29 | 1.48E-03 | 2.59E-03 | 5.91E-01 | 6.45E-01 | 7.91E-02 | 3.03E+02 | 1.57E-08 | 1.38E-04 | 6.28E-04 | This study |
| **COM_LF** | | 0.123 | 1.92E-04 | | | 1.259 | | | | 3.04E-04 | | (Khandelwal et al., 2019) |
| **COM_LF** | | | 2.20E-03 | 1.90E-03 | | 1.16 | | | -1.13E-09 | 4.00E-04 | | (Righi et al., 2013) |
| **COM_LF** | 7.20E-09 | 2.71E-01 | 4.63E-03 | 2.08E-03 | 6.54E-03 | 4.92 | 5.61E-03 | 1.86E+01 | 2.73E-09 | 1.20E-03 | 3.36E-05 | (Yadav & Samadder, 2018) |
| **AD_LF** | 7.92E-08 | 1.45E+00 | 8.68E-04 | 2.47E-03 | 5.89E-01 | 0.5 | 7.78E-02 | 2.98E+02 | 1.80E-08 | 1.22E-04 | 6.09E-04 | This study |
| **AD_LF** | | | 4.66E-07 | 6.33E-04 | | 0.28 | | | -6.00E-09 | 1.36E-04 | | (Righi et al., 2013) |

Table 5.3 shows the literature comparison. Zhang et al. (2019) mentioned that waste characterization contains high water and organic contents. Fertilizer production and substitution were included. In our study, fertilizer production and substitution are not included.

Righi et al. (2013) mentioned that waste characterization contains sludge and organic waste. Dewatering of sludge, gas and leachate treatment, transport were included. Biogas recovery was included. Also in our study, leachate treatment and transportation were included, but gas treatment and dewatering were not included. In our study, the landfill facility is 3 times further than the landfill facility in Righi's study.

Erses Yay (2015) mentioned that waste mostly contains paper, organic and plastic waste, 52%, 42.4%, and 13.4%, respectively. For the landfill scenario, no leachate treatment and no energy recovery were applied. Transportation of waste is included in the system boundary but transportation distance was 5 times lower than our study.

Khandelwal et al. (2019) studied with the waste that mostly contains organic, plastic, and paper waste, 60.10%, 15.50%, and 11.20%, respectively. All of the waste was sent to a landfill and 17% of the waste was sent to the composting. No landfill gas treatment and leachate treatment were applied. In our study, leachate treatment was considered for the landfill scenario. In Khandelwal's study, landfill and composting facility was located in the same distance:7 km. This distance is very below from our distances between restaurant, landfill and composting (39 km for composting, 100 km for landfill).

In another scenario in Righi et al. (2013), sludge was sent to a landfill after dewatering. Organic part was sent to composting. Gas and leachate treatment, transportation, fertilizer production and biogas recovery were included. Leachate treatment and transportation were included in our study as well but gas treatment, dewatering and fertilizer substitution were not included. The landfill facility was located 3 times further than the landfill facility in Righi's study.

Yadav and Samadder (2018) assumed that waste characterization mostly contains inert waste. As a result, landfill gas production was very low. No energy recovery was applied. Organic waste was sent to composting, transportation was included.

In another scenario in Righi et al. (2013), transportation, anaerobic digester operation, combined heat and power unit, leachate treatment, waste collection and disposal of digested matter in the landfill were included. Also in our study, leachate treatment and transportation were included. However, gas treatment, combined heat and power unit, disposal of digested matter were not included.

Padeyanda et al. (2016) mentioned that 80% of the waste contains moisture and 14.4% includes organic matter. Composting facility was located at a close distance. Transportation, leachate treatment was included. The residual matter was landfilled.

Jin et al. (2015) mentioned that higher than 87% of the waste contains organic matter. Pretreatment, anaerobic digester operation, sorting, dewatering, biogas generation, waste collection and transportation were included. Sorting and dewatering were not included in our study.

Life cycle assessment studies that applied on a restaurant were researched. There are a few studies that applied on a restaurant. They were not shown in Table 5.4 as their functional unit and impact assessment methods were considerably different from our study. Those papers and this study were compared. Calderón et al. (2018) studied on several subsystems which include a traditional restaurant were examined. 80% of the waste consists of organic matter. Results showed that energy consumption was the most contributed factor in the restaurant. Baldwin et al. (2010) includes operational support subsystem includes energy consumption and this subsystem gave the highest results in most of the environmental impact potentials.

### 5.3.1. Abiotic element depletion potential (ADP Element)

Figure 5.5 shows abiotic elements depletion potential of the restaurant. ADP elements were represented with the unit of kg Sb-Equiv. According to the figure, the total ADP Elements of the restaurant was 6.78E-04 kg Sb-Equiv for 1000 services.

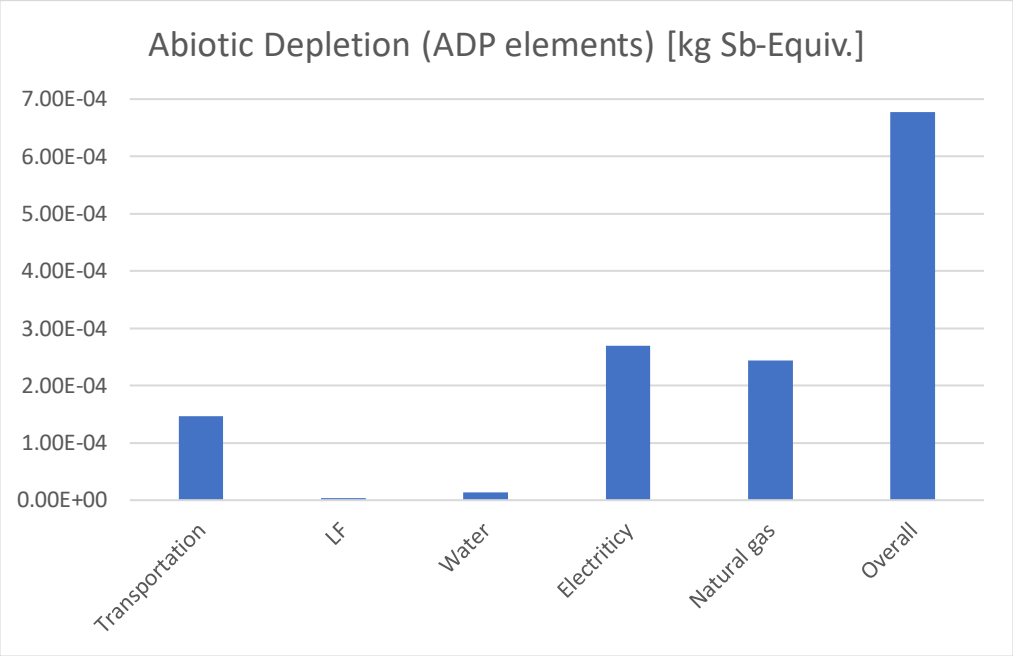


**Figure 5. 5:** Abiotic depletion potential(ADP Elements) of the restaurant.

As it can be seen from Figure 5.5, in ADP Elements case, electricity has the highest impact on the environment. Electricity contribution(39.81%) is followed by natural gas(36%) and transportation(21.54%) as high amount of non-renewable element(cadmium, lead, etc) consumption take place in those processes. Figure 5.6 shows the percentages contribution of factors to ADP Elements.

This ADP Elements result in transportation was mainly caused by non-renewable element consumption such as cadmium(30%), lead(21%), gold(17%) and copper(8%).

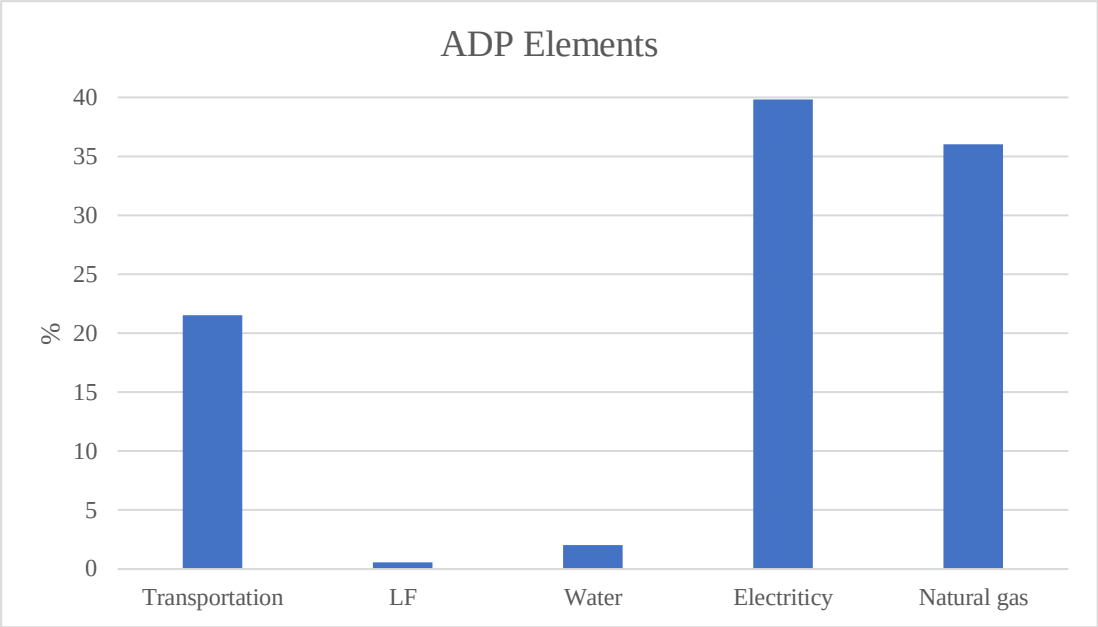


**Figure 5. 6:** Percentages contribution of factors to abiotic element depletion potential (ADP Elements).

Figure 5.7 shows the contribution of electricity mix to ADP Elements. Most contributed factors were shown in the figure. As it can be seen, impact caused by electricity came from non-renewable element consumption such as copper, gold, silver, cadmium and lead, specilally in transmission network, photovoltaic electricity production and wind power production(35%, 32% and 7%, respectively). Copper consumption is mainly caused by transmission network.

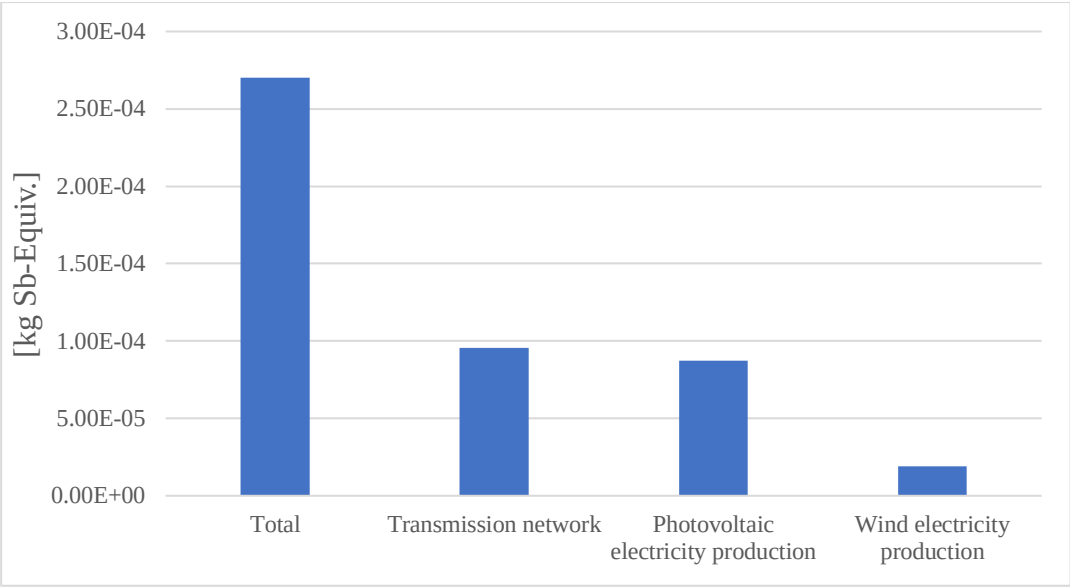


**Figure 5. 7:** Contribution of electricity to abiotic element depletion potential(ADP Elements).

### 5.3.2. Abiotic fossil depletion potential (ADP Fossil)

Figure 5.8 shows abiotic fossil depletion potential of the restaurant. ADP Fossil was represented with the unit of MJ. According to the figure, the total ADP Fossil of the restaurant was 1.43E+04 MJ for 1000 services.

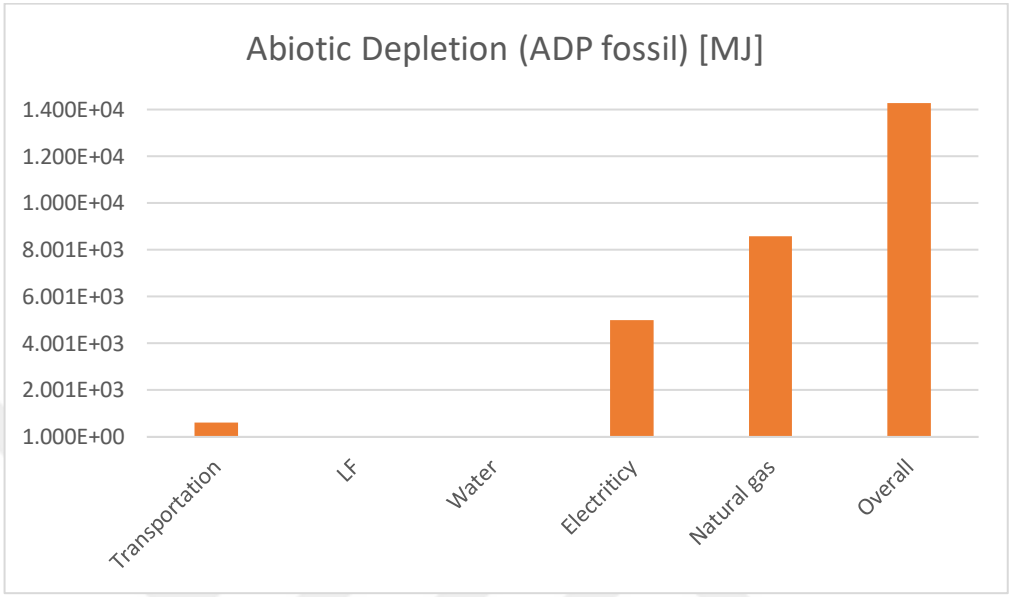


**Figure 5. 8:** Abiotic fossil depletion potential (ADP Fossil) of the restaurant.

As it can be seen from Figure 5.8, in ADP Fossil case, natural gas has the highest impact on the environment with 8.59E+3 MJ. Natural gas contribution is followed by electricity contribution(4.99E+03 MJ). Figure 5.9 shows the percentages contribution of factors to ADP Fossil. It can be seen from the figure that transportation, water and landfill contributions were lower than 10%.

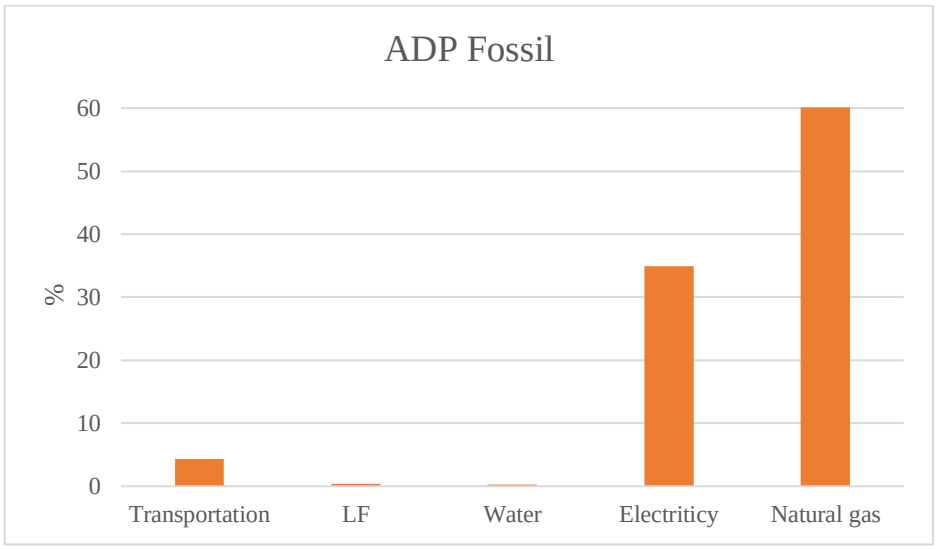


**Figure 5. 9:** Percentage contributions of factors to abiotic fossil depletion potential (ADP Fossil).

Figure 5.10 shows the contributions of factors that affect the impact caused by electricity in ADP Fossil case. Most important factors were represented in the table. Hard coal(41.6%), lignite(31.6%) and natural gas(24.3%) contributed the most in this case as percentages of those factors are higher in Turkey's 2019 production mix.

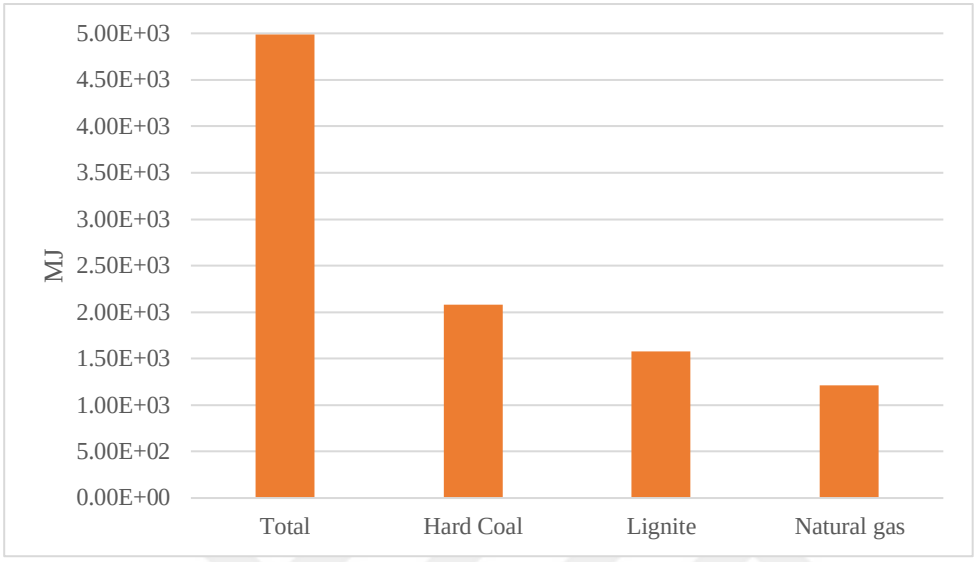


**Figure 5. 10:** Contribution of electricity on ADP Fossil.

### 5.3.3. Acidification potential (AP)

Figure 5.11 shows acidification potential of the restaurant. Acidification potential was represented with the unit of kg $SO_2$-Equiv. According to the figure, the total AP of the restaurant was 5.44 kg $SO_2$-Equiv for 1000 services.

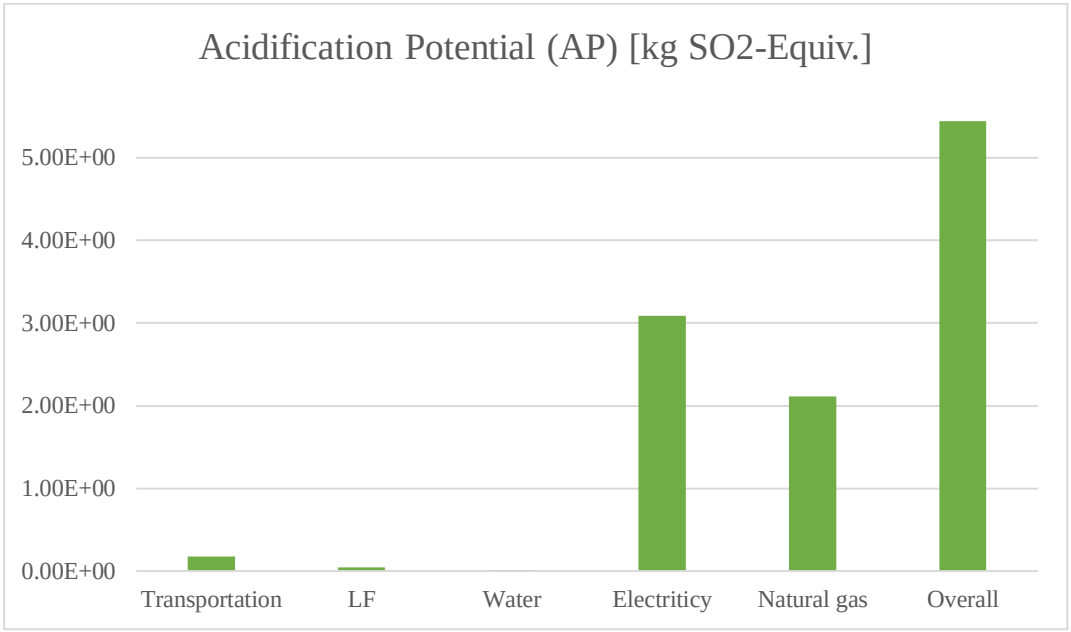


**Figure 5. 11:** Acidification potential (AP) of the restaurant.

As it can be seen from Figure 5.11, in AP case, electricity has the highest impact on the environment. Electricity contribution is followed by natural gas contribution. Figure 5.12 shows the percentages contribution of factors to AP. While 56.73% contribution comes from electricity, 38.87% contribution comes from natural gas consumption.

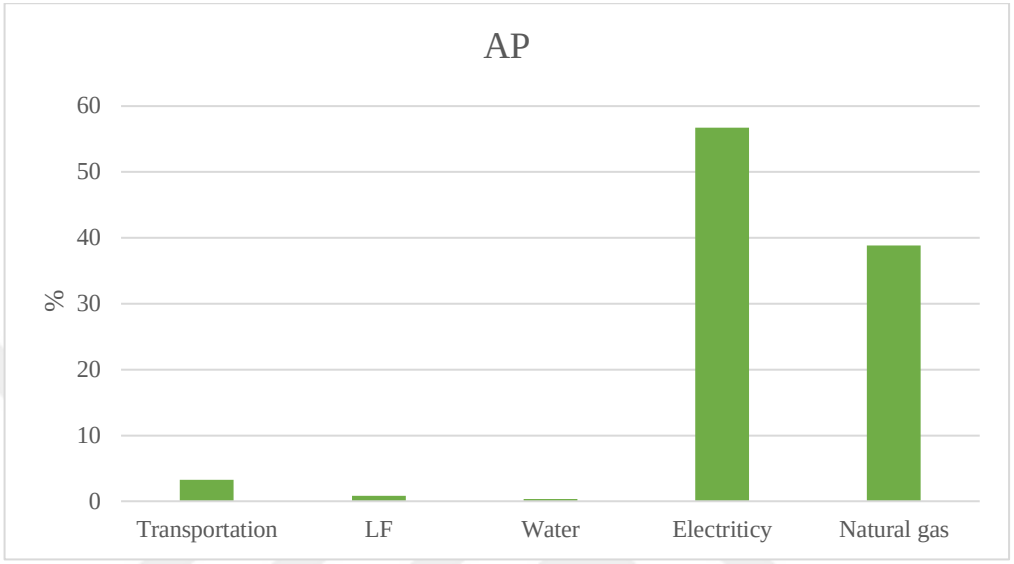


**Figure 5. 12:** Percentages contribution of factors to acidification potential (AP).

Figure 5.13 shows the electricity contribution to AP in this study. Electricity contribution is mainly caused by inorganic emissions to air. $SO_x$ and $NO_x$ emissions to air from "electricity production, hard coal" and "electricity production, lignite" processes were the main contributors in this case.

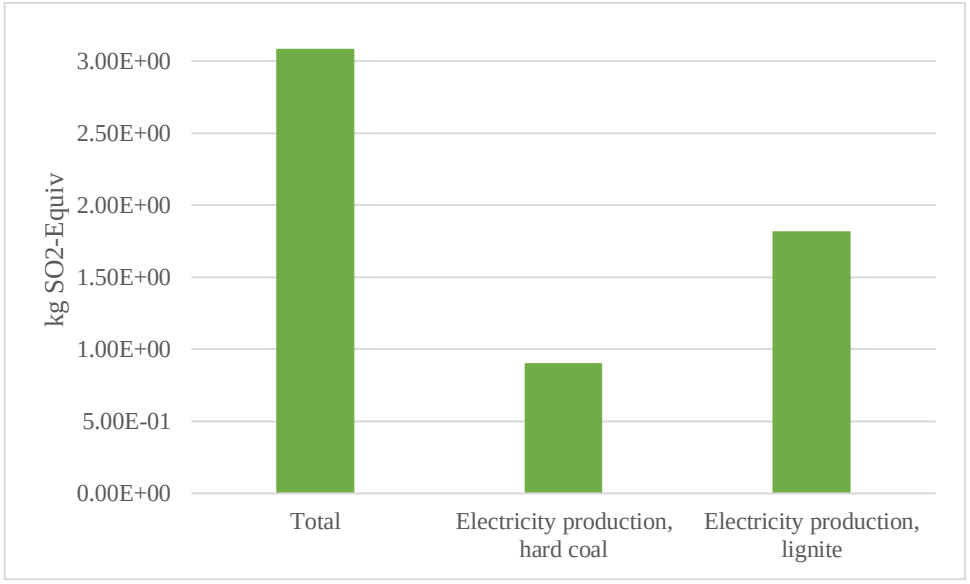


**Figure 5. 13:** Electricity contribution to AP.

### 5.3.4. Eutrophication potential (EP)

Figure 5.14 shows eutrophication potential of the restaurant. Eutrophication potential was represented with the unit of kg Phosphate-Equiv. According to the figure, the total EP of the restaurant was 3.35 kg Phosphate-Equiv. for 1000 services.

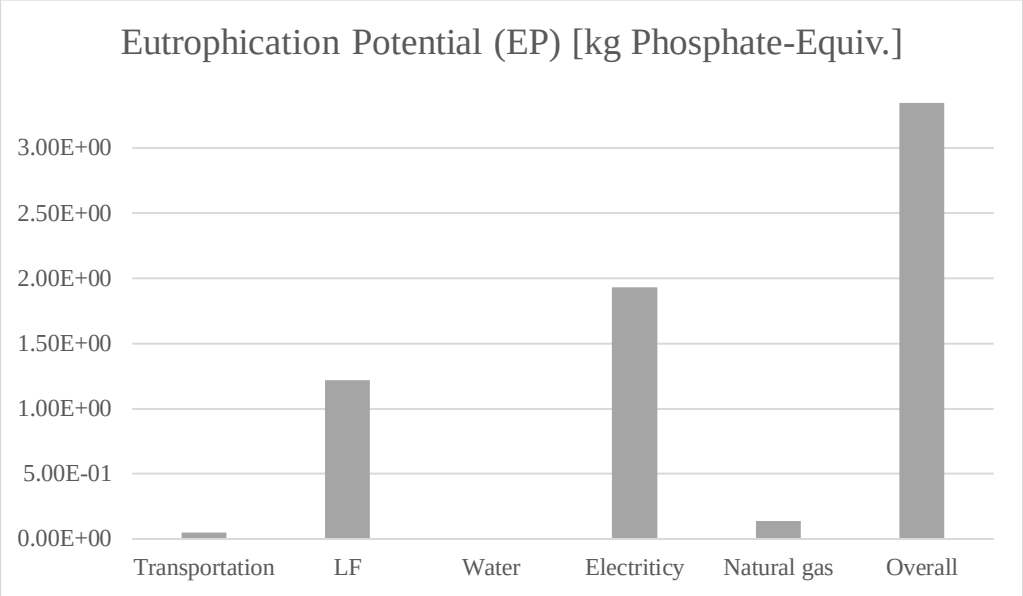


**Figure 5. 14:** Eutrophication potential(EP) of the restaurant.

Figure 5.14 shows that, in EP case, electricity has the highest impact on the environment. Electricity contribution is followed by landfill contribution. Figure 5.15 shows the percentages contribution of factors to EP. While 57.66% contribution comes from electricity consumption, 36.49% contribution comes from sanitary landfill application.

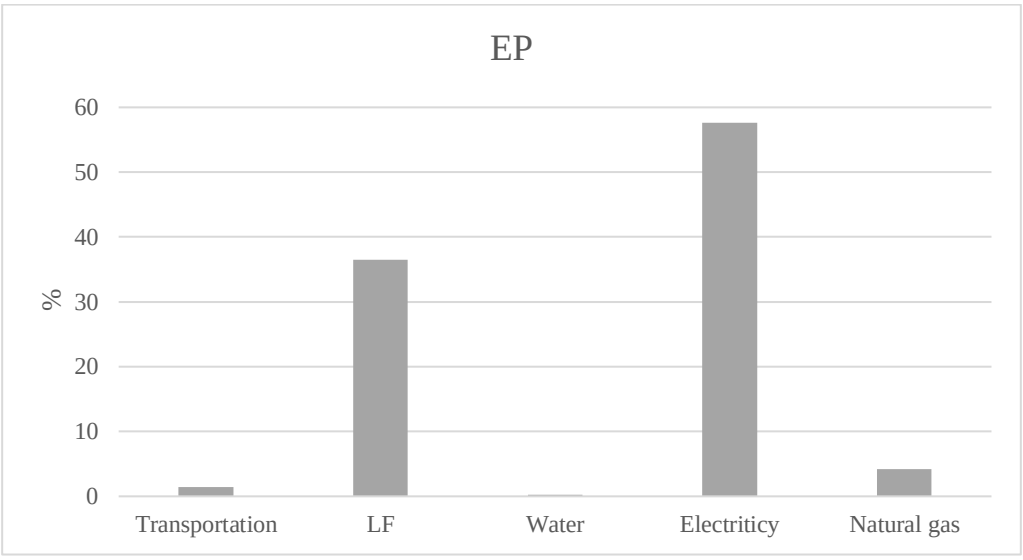


**Figure 5. 15:** Percentages contribution of factors to EP.

Figure 5.16 shows the electricity contribution to EP in this study. Electricity contribution is mainly caused by emissions to freshwater. Phosphate emissions to freshwater from "electricity production, hard coal" and "electricity production, lignite" processes were the main contributors in this case.

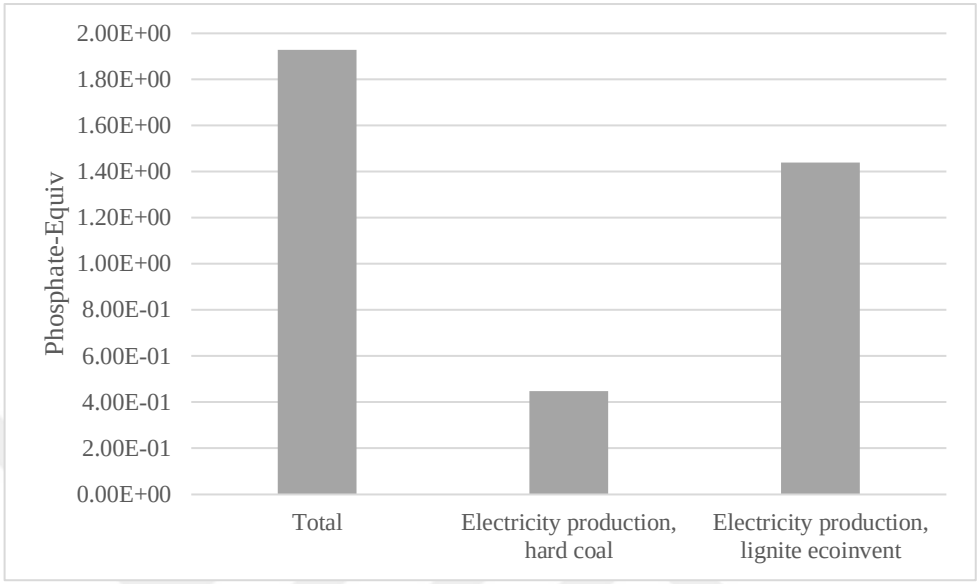


**Figure 5. 16:** Electricity contribution to EP.

Figure 5.17 shows the landfill contribution to EP. According to results, landfill contribution mainly comes from emissions to freshwater from treatment of municipal solid waste process. Treatment of municipal solid waste process was responsible for 99% of the COD and TOC emissions to freshwater in landfill case.

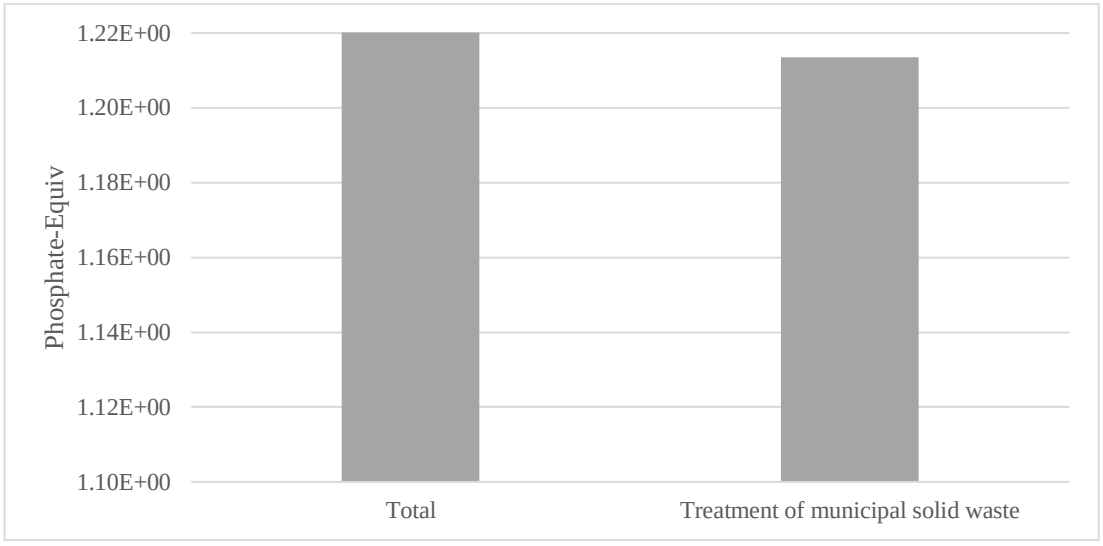


**Figure 5. 17:** Landfill contribution to EP.

### 5.3.5. Freshwater aquatic ecotoxicity potential (FAETP)

Figure 5.18 shows freshwater aquatic ecotoxicity potential of the restaurant. FAETP was represented with the unit of kg DCB-Equiv. According to the figure, the total FAETP of the restaurant was 7.08E+02 kg DCB-Equiv. for 1000 services.

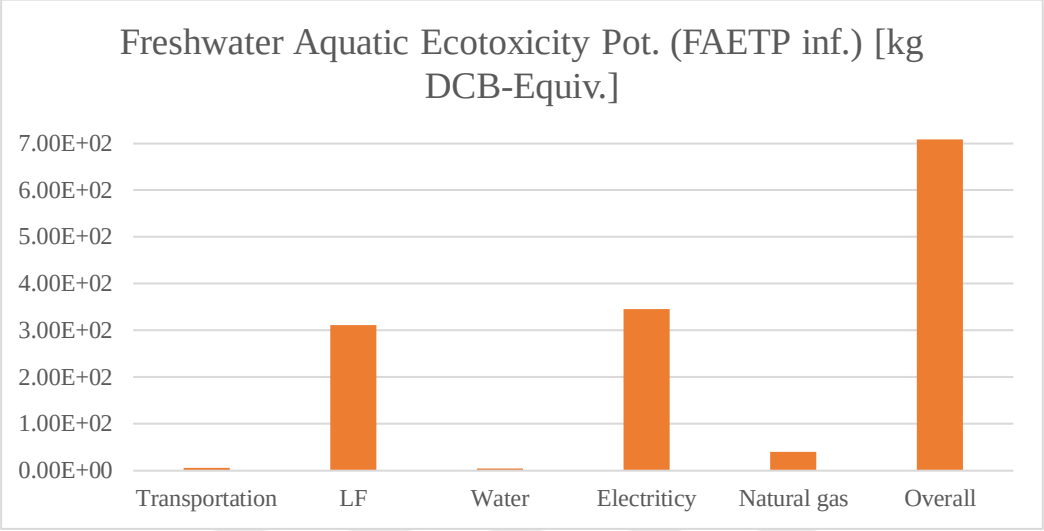


**Figure 5. 18:** Freshwater aquatic ecotoxicity potential (FAETP) of the restaurant.

Figure 5.18 shows that, in FAETP case, electricity has the highest impact on the environment. Electricity contribution is followed by landfill contribution. Figure 5.19 shows the percentages contribution of factors to EP. While 48.74% contribution comes from electricity consumption, 43.95% contribution comes from sanitary landfill application.

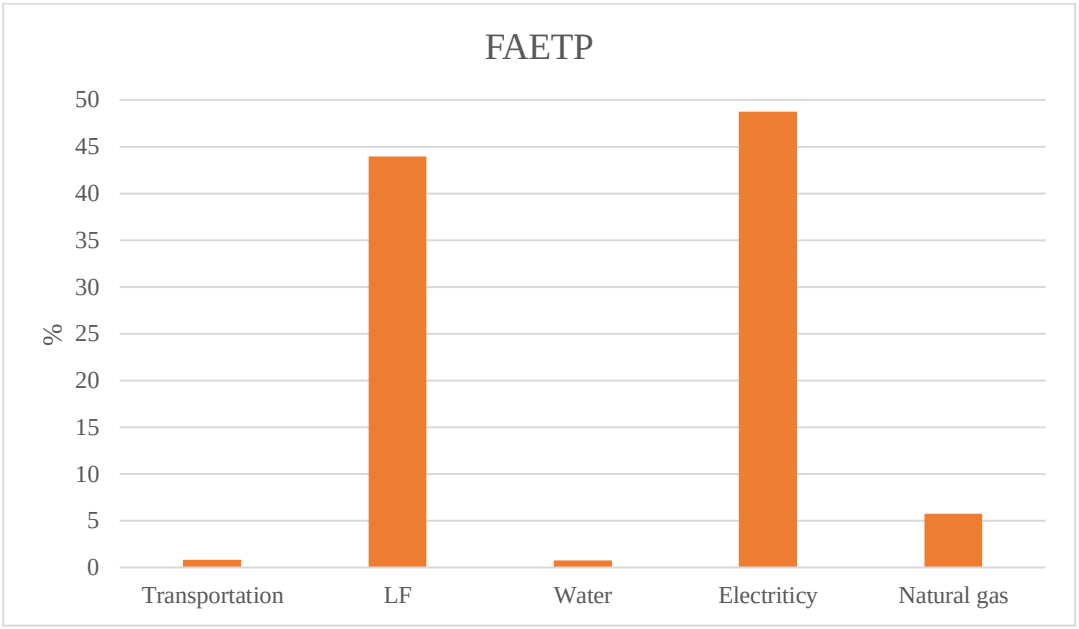


**Figure 5. 19:** Percentages contribution of factors to FAETP.

Figure 5.20 shows the electricity contribution of FAETP. Electricity contribution is mainly caused by emissions to freshwater(copper, cobalt, beryllium, etc) from electricity production from lignite(70%), electricity production from hard coal(18%) and transmission network(6%).

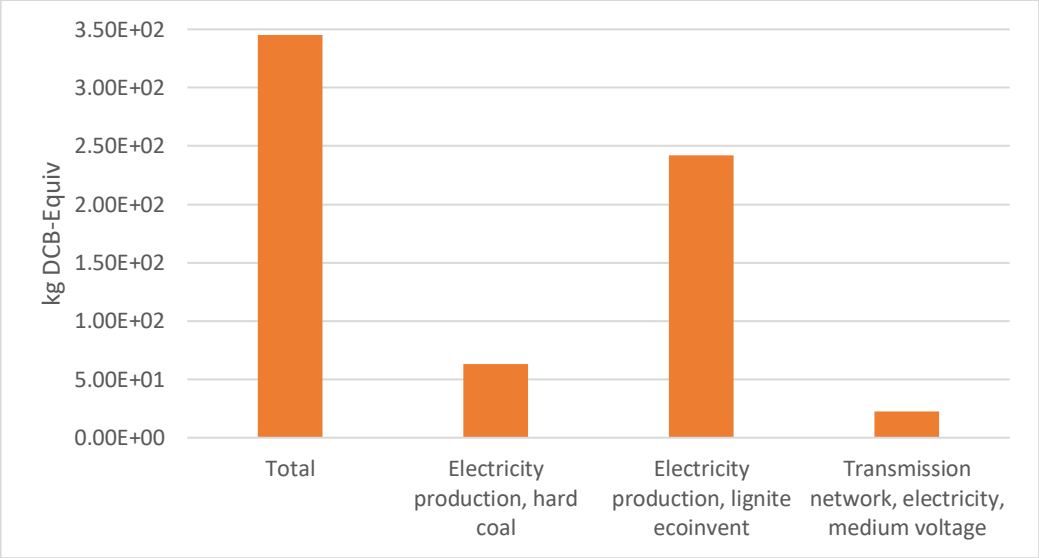


**Figure 5. 20:** Electricity contribution to FAETP.

Figure 5.21 shows the landfill contribution to FAETP. According to results, landfill contribution mainly comes from emissions to freshwater from treatment of municipal solid waste process. Treatment of municipal solid waste process was responsible for 99% of the emissions to freshwater such as COD and TOC.

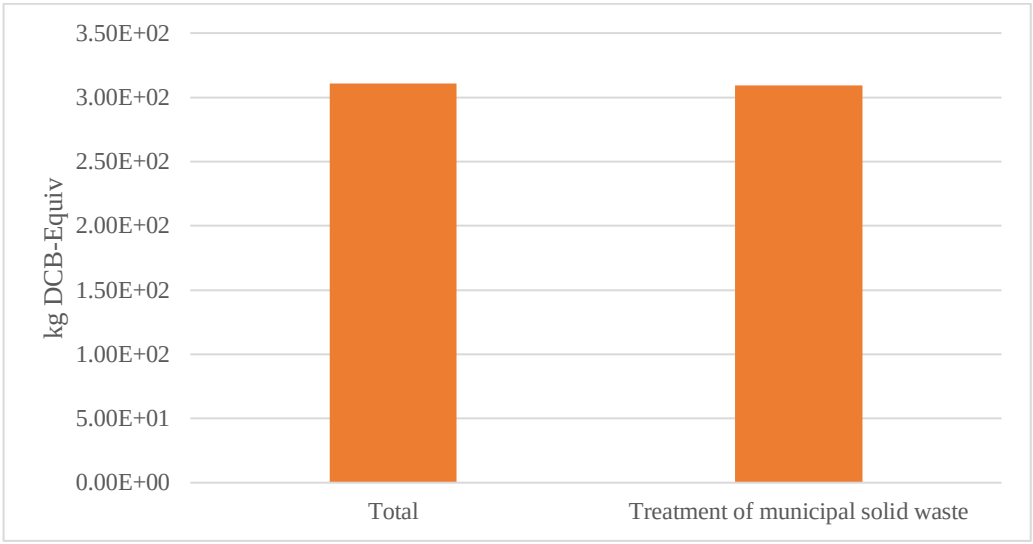


**Figure 5. 21:** Landfill contribution to FAETP.

### 5.3.6. Global warming potential (GWP)

Figure 5.22 shows global warming potential of the restaurant. GWP was represented with the unit of kg $CO_2$-Equiv. According to the figure, the total GWP of the restaurant was 1.26E+03 kg $CO_2$-Equiv. for 1000 services.

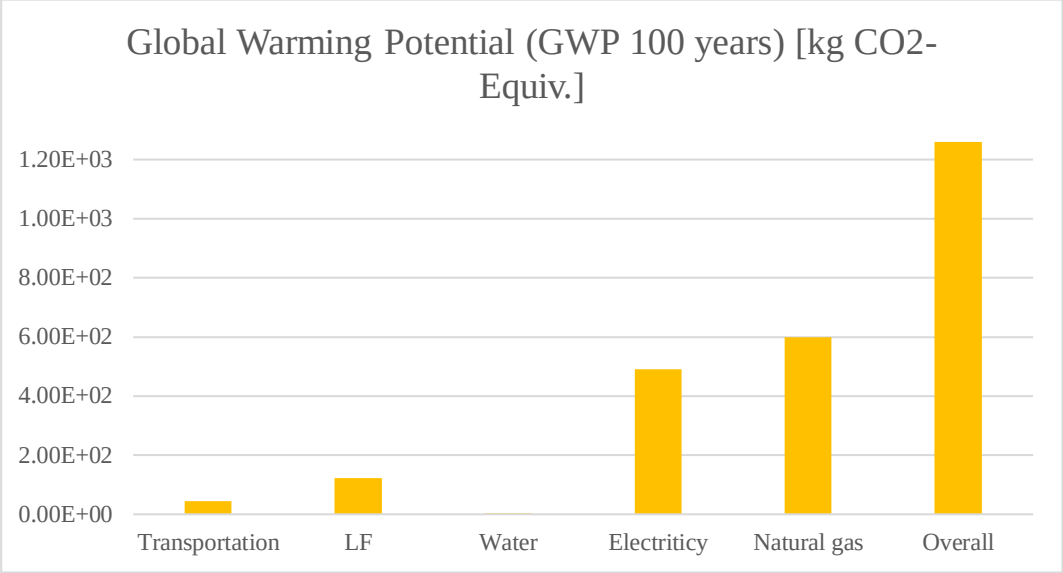


**Figure 5. 22:** Global warming potential (GWP) of the restaurant.

Figure 5.22 shows that, in GWP case, natural gas has the highest impact on the environment. Natural gas contribution is followed by electricity and landfill contributions. Figure 5.23 shows the percentages contribution of factors to GWP. While 47.57% contribution comes from natural gas consumption, 39.01% contribution comes from electricity and 9.71% contribution comes from landfill application.

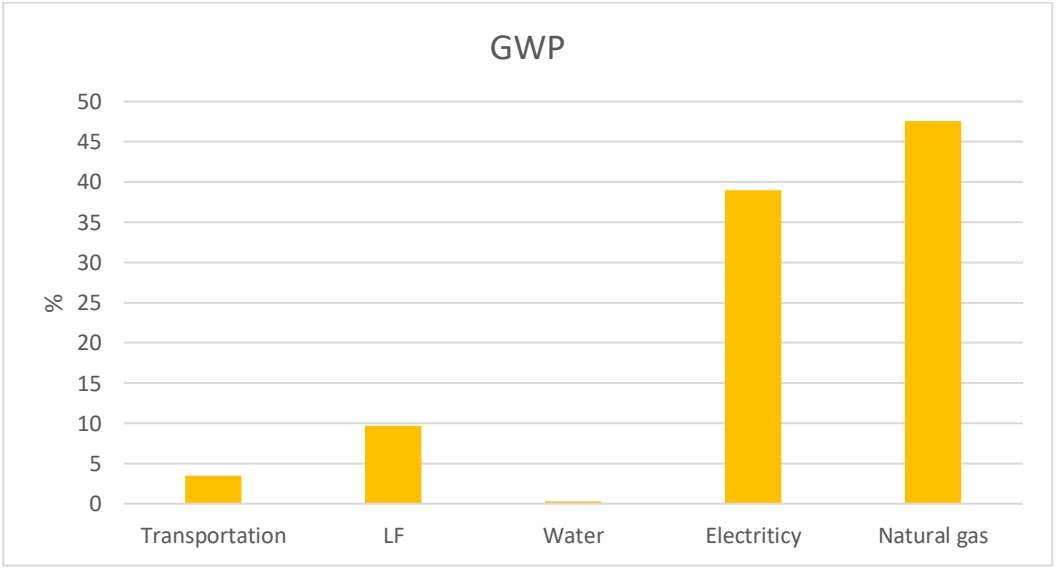


**Figure 5. 23:** Percentages contribution of the factors to GWP.

Figure 5.24 shows the electricity contribution to GWP. According to the figure, electricity production from hard coal, electricity production from lignite and electricity production from natural gas have the biggest contributions of electricity-related GWP. These results were mainly caused by inorganic emissions to air(94%), specially carbon dioxide(92%).

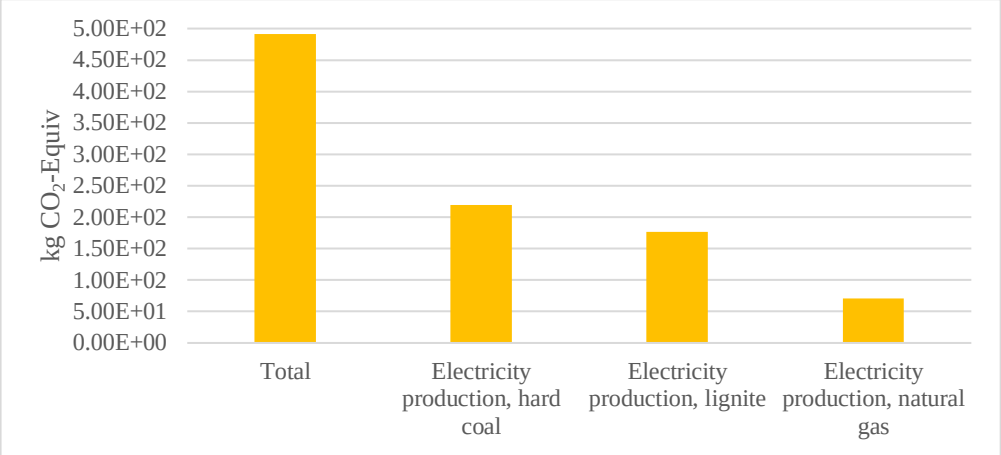


**Figure 5. 24:** Electricity contribution to GWP.

Figure 5.25 shows the landfill application contribution to GWP results. According to the figure, treatment of municipal solid waste contributed to the almost total amount (97%) as a result of inorganic and organic emissions to air such as carbon dioxide and methane, respectively.

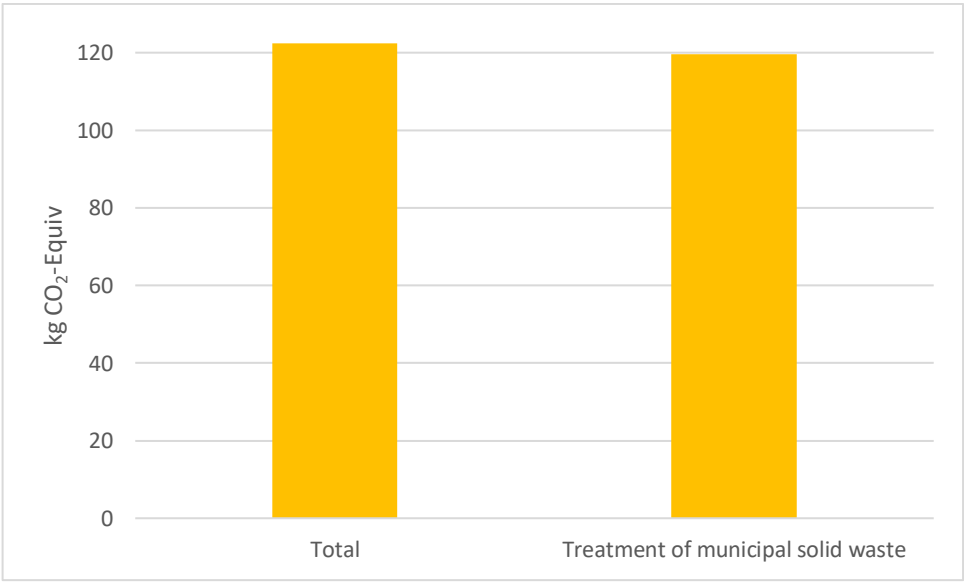


**Figure 5. 25:** Landfill contribution to GWP.

### 5.3.7. Human toxicity potential (HTP)

Figure 5.26 shows human toxicity potential of the restaurant. HTP was represented with the unit of kg DCB-Equiv. According to the figure, the total HTP of the restaurant was 4.32E+02 kg DCB-Equiv. for 1000 services. Figure 5.26 shows that, in HTP case, electricity has the highest impact on the environment. Natural gas contribution is followed by electricity contribution.

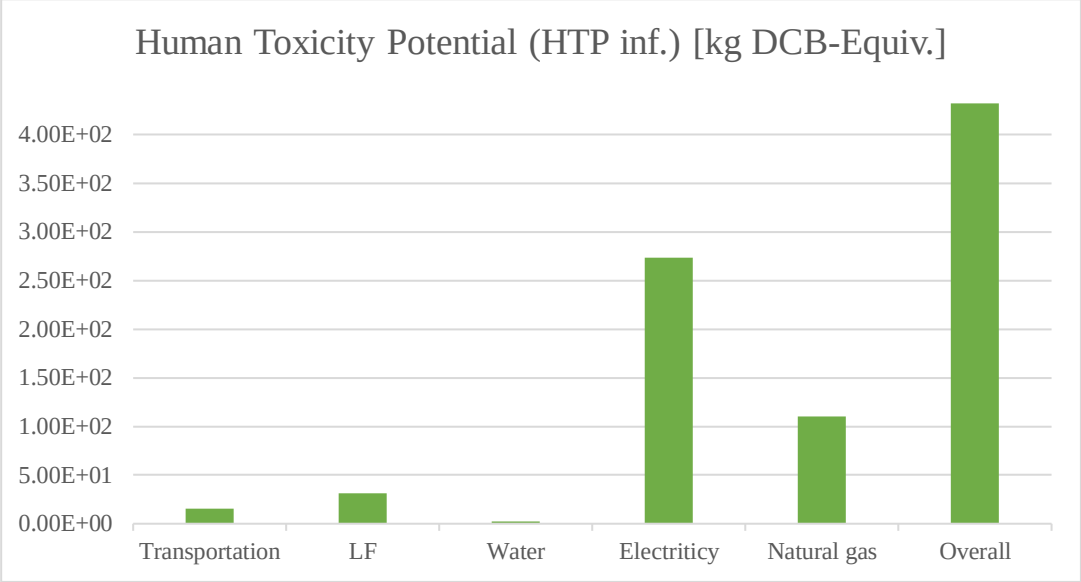


**Figure 5. 26:** Human toxicity potential(HTP) of the restaurant.

Figure 5.27 shows the percentages contribution of factors to HTP. While 65.23% contribution comes from electricity, 25.43% contribution comes from natural gas consumption.

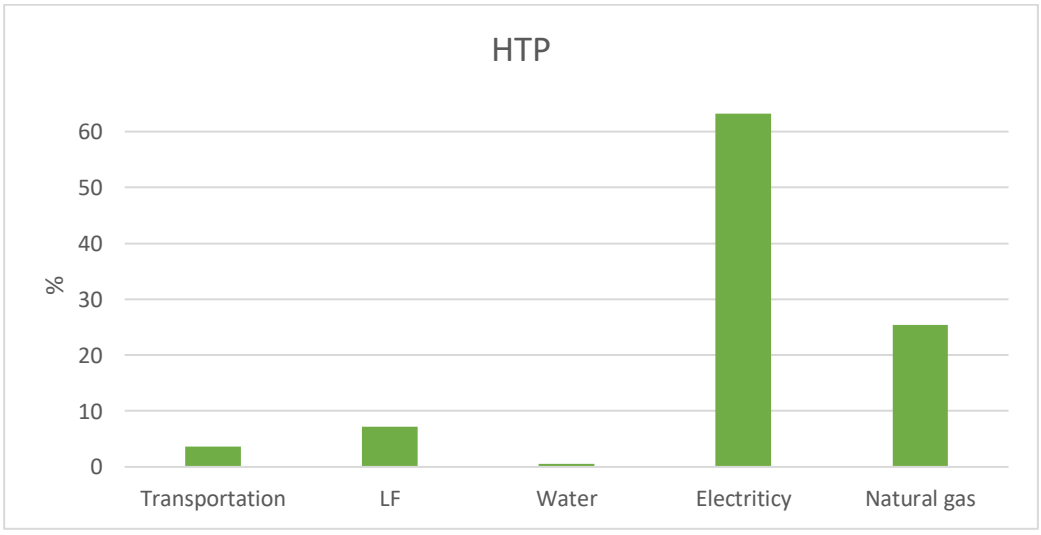


**Figure 5. 27:** Percentages contributions of factors to HTP.

Figure 5.28 shows the electricity contribution to HTP. According to the results, 59% of the impact of the electricity comes from “electricity production, lignite” and 29% comes from “electricity production, hard coal”. Electricity contribution of this category is mainly caused by heavy metals to air such as arsenic, chromium, nickel and emissions to freshwater such as selenium.

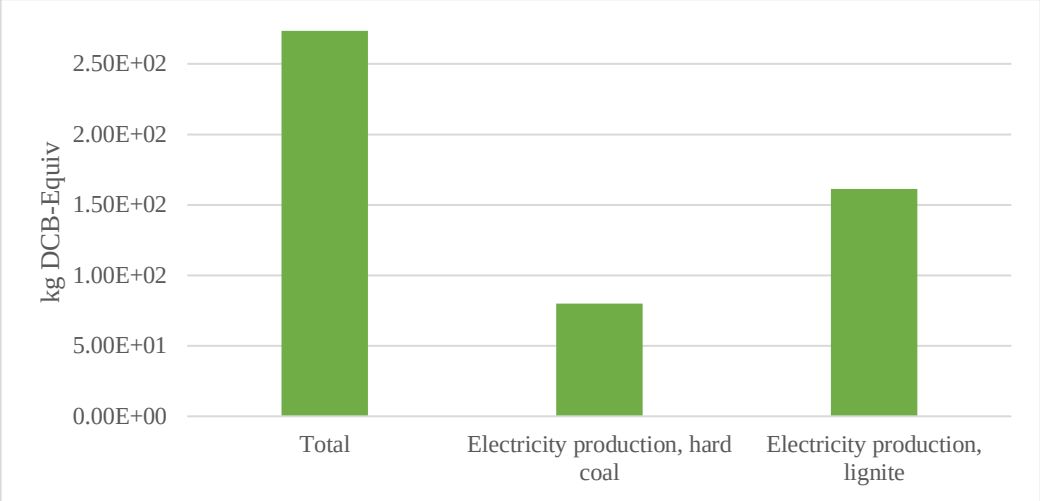


**Figure 5. 28:** Electricity contribution to HTP.

### 5.3.8. Marine aquatic ecotoxicity potential (MAETP)

Figure 5.29 shows marine aquatic ecotoxicity potential of the restaurant. MAETP was represented with the unit of kg DCB-Equiv. According to the figure, the total MAETP of the restaurant was 1.35E+06 kg DCB-Equiv. for 1000 services. Figure 5.29 shows that, in MEATP case, electricity has the highest impact on the environment.

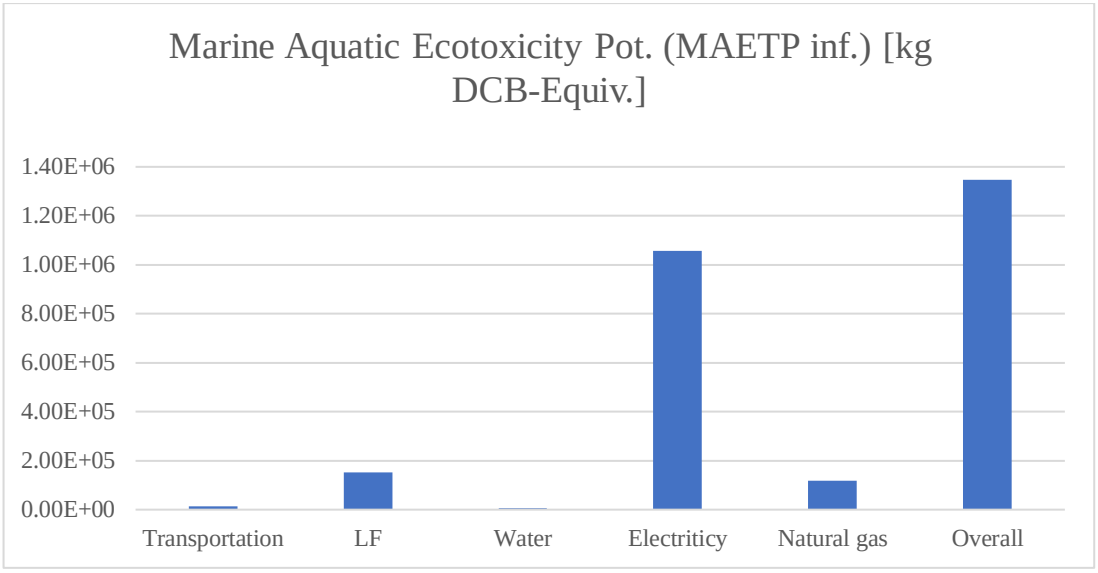


**Figure 5. 29:** Marine aquatic ecotoxicity potential(MAETP) of the restaurant.

Figure 5.30 shows the percentages contribution of factors to MAETP. According to the figure, 78.50 % contribution comes from electricity consumption of the restaurant.

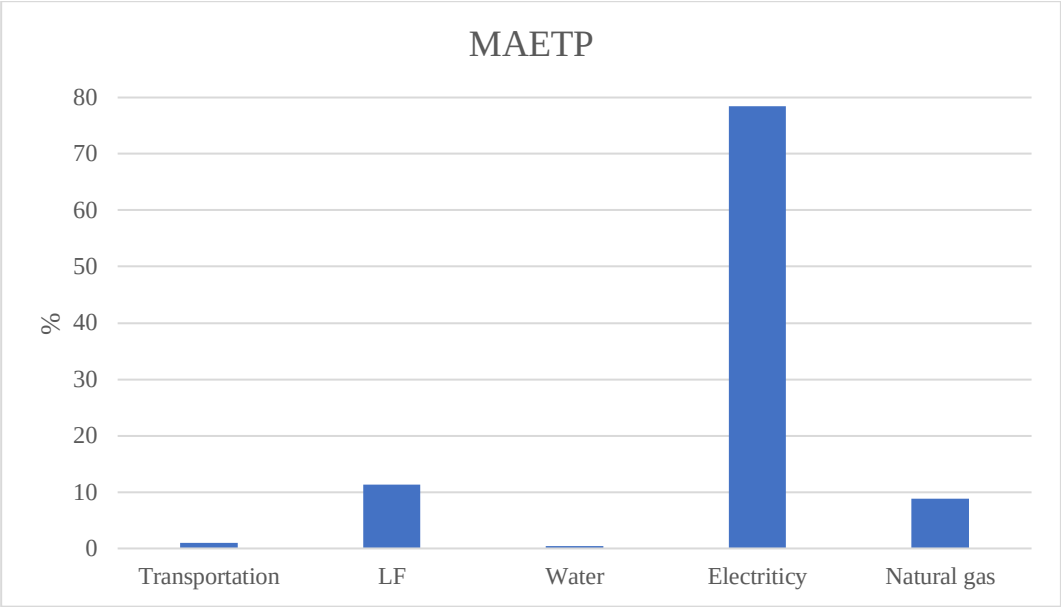


**Figure 5. 30:** Percentages contributions of the factors to MAETP.

Figure 5.31 shows the electricity consumption contribution to MAETP. According to the results, 60% of the impact of the electricity comes from "electricity production, lignite" and 35% comes from "electricity production, hard coal". Electricity contribution of this category is mainly caused by emissions to freshwater such as beryllium, nickel and selenium.

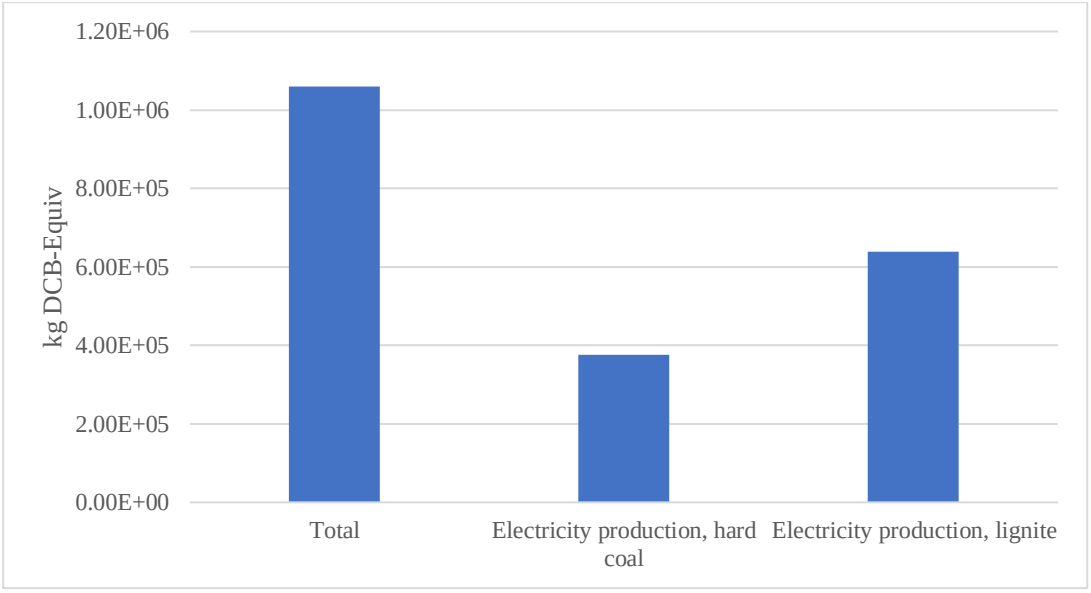


**Figure 5. 31:** Electricity contribution to MAETP.

### 5.3.9. Ozone layer depletion potential (ODP)

Figure 5.32 shows ozone layer depletion potential of the restaurant. ODP was represented with the unit of kg R11-Equiv. According to the figure, the total ODP of the restaurant was 4.88E-05 kg R11-Equiv. for 1000 services. Figure 5.32 shows that, in ODP case, natural gas consumption has the highest impact on the environment.

Figure 5.33 shows the percentages contribution of factors to ODP. According to the figure, while 71.42% contribution comes from natural gas consumption of the restaurant, 15.55% comes from transportation and 11.41% comes from electricity consumption.

ODP result in transportation is mainly caused by halogenated organic emissions to air(99%).

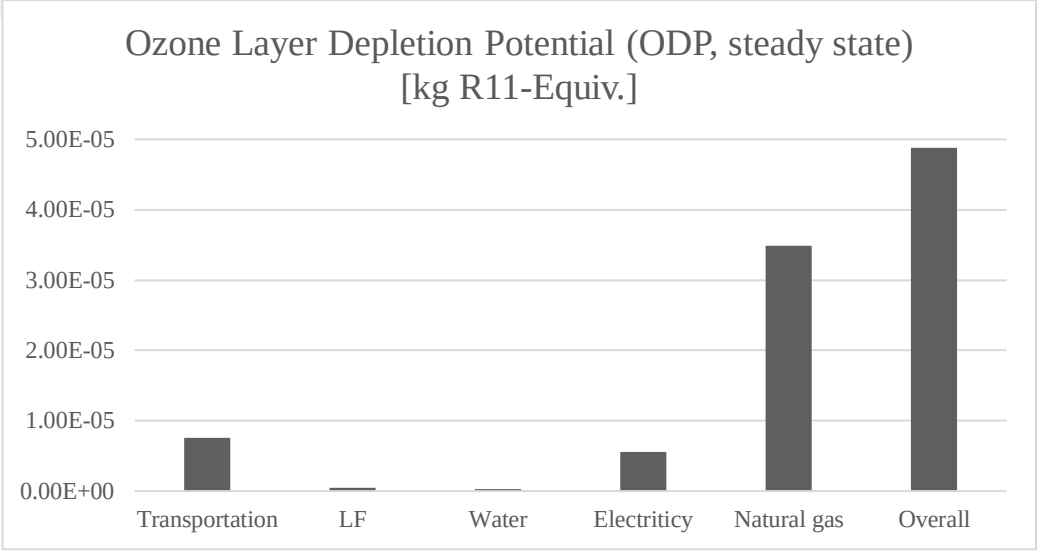


**Figure 5. 32:** Ozone layer depletion potential (ODP) of the restaurant.

The reason why natural gas gave a considerably high result in ODP is the high amount of refrigerant usage in natural gas pipelines(Atilgan & Azapagic, 2017).

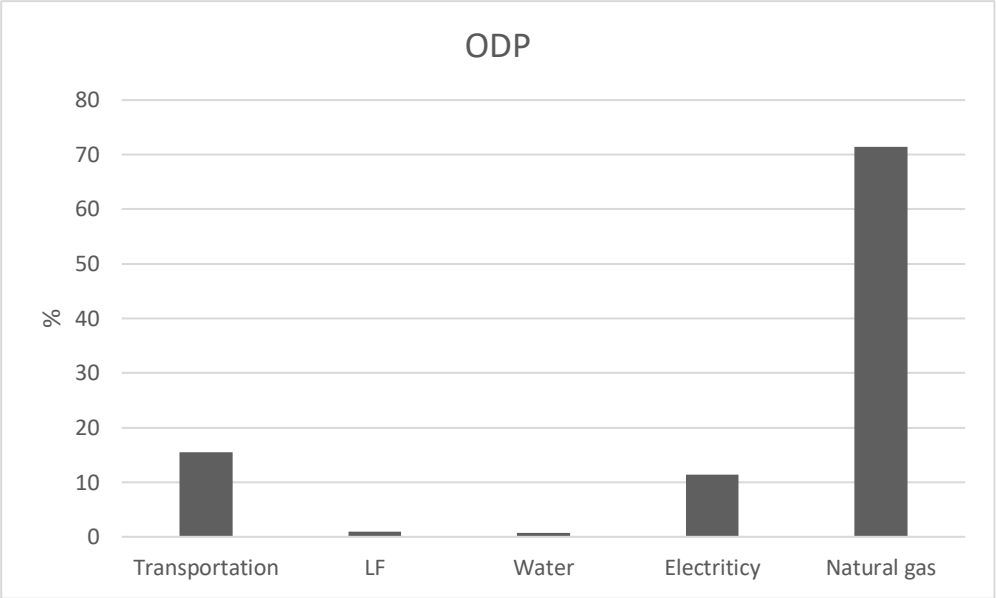


**Figure 5. 33:** Percentages contributions of the factors to ODP.

### 5.3.10. Photochemical ozone creation potential (POCP)

Figure 5.34 shows photochemical ozone creation potential of the restaurant. POCP was represented with the unit of kg Ethene-Equiv. According to the figure, the total POCP of the restaurant was 3.80E-01 kg Ethene-Equiv. for 1000 services. Figure 5.34 shows that, in POCP case, natural gas consumption has the highest impact on the environment. Natural gas consumption-related POCP is followed by electricity consumption-related POCP.

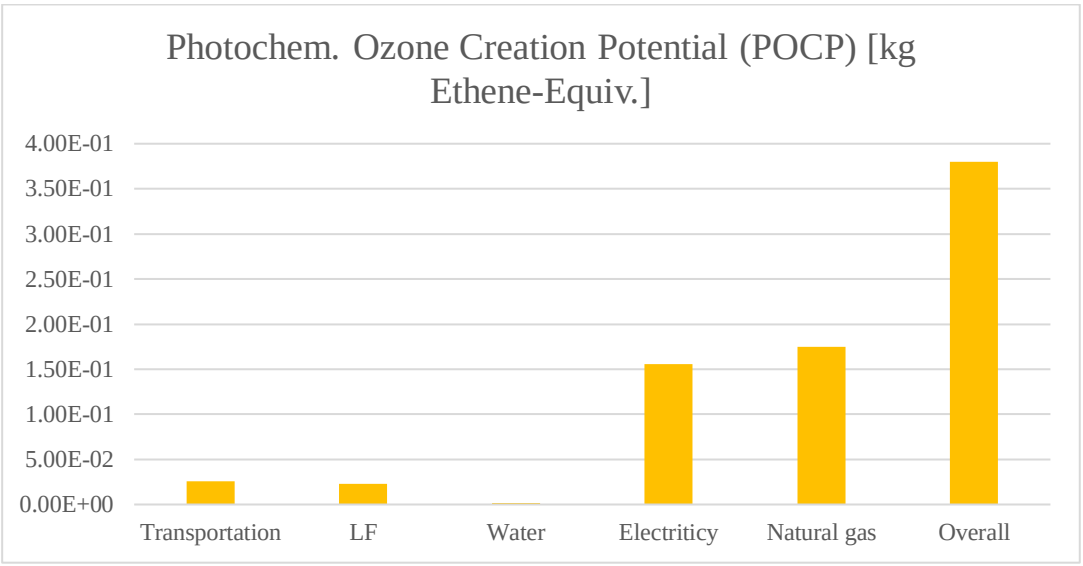


**Figure 5. 34:** Photochemical ozone creation potential (POCP) of the restaurant.

Figure 5.35 shows the percentages contribution of factors to POCP. According to the figure, while 45.91% contribution comes from natural gas consumption of the restaurant, 40.96% comes from electricity consumption.

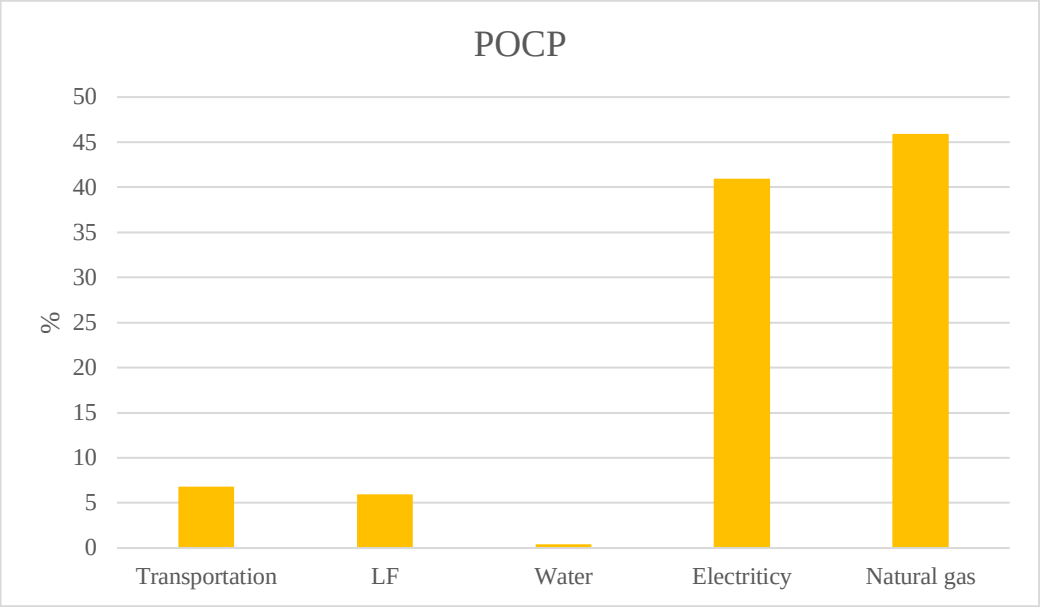


**Figure 5. 35:** Percentages contributions of the factors to POCP.

Figure 5.36 shows the electricity consumption contribution to POCP. According to the results, 51.4% of the impact of the electricity comes from "electricity production, lignite" and 30.8% comes from "electricity production, hard coal". Electricity contribution of this category is mainly caused by inorganic emissions to air such as $SO_2$ and $NO_x$.

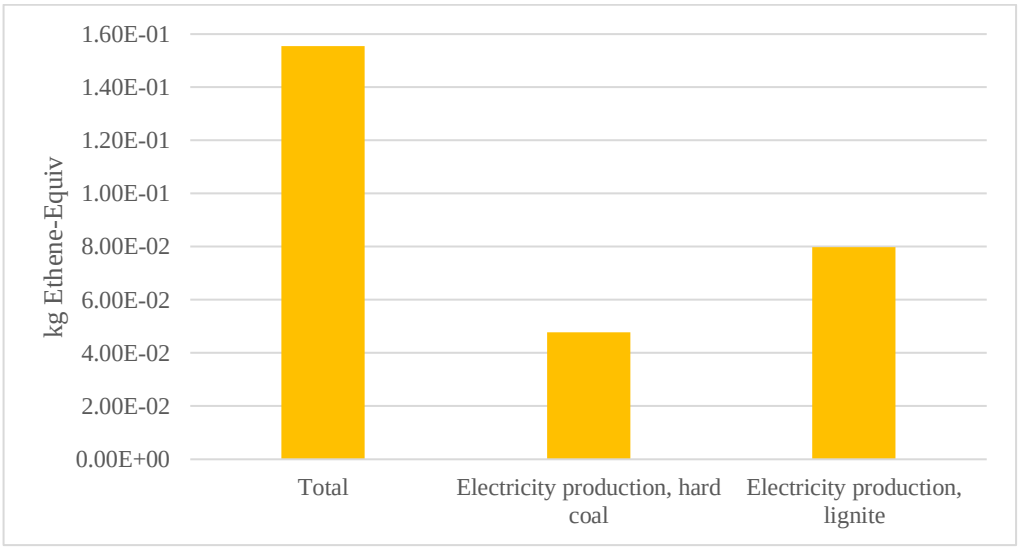


**Figure 5. 36:** Electricity contribution to POCP.

### 5.3.11. Terrestric ecotoxicity potential (TETP)

Figure 5.37 shows terrestric ecotoxicity potential of the restaurant. TETP was represented with the unit of kg DCB-Equiv. According to the figure, the total TETP of the restaurant was 2.74 kg DCB-Equiv. for 1000 services. Figure 5.37 shows that, in TETP case, electricity consumption has the highest impact on the environment. Electricity consumption-related TETP is followed by natural gas consumption-related POCP.

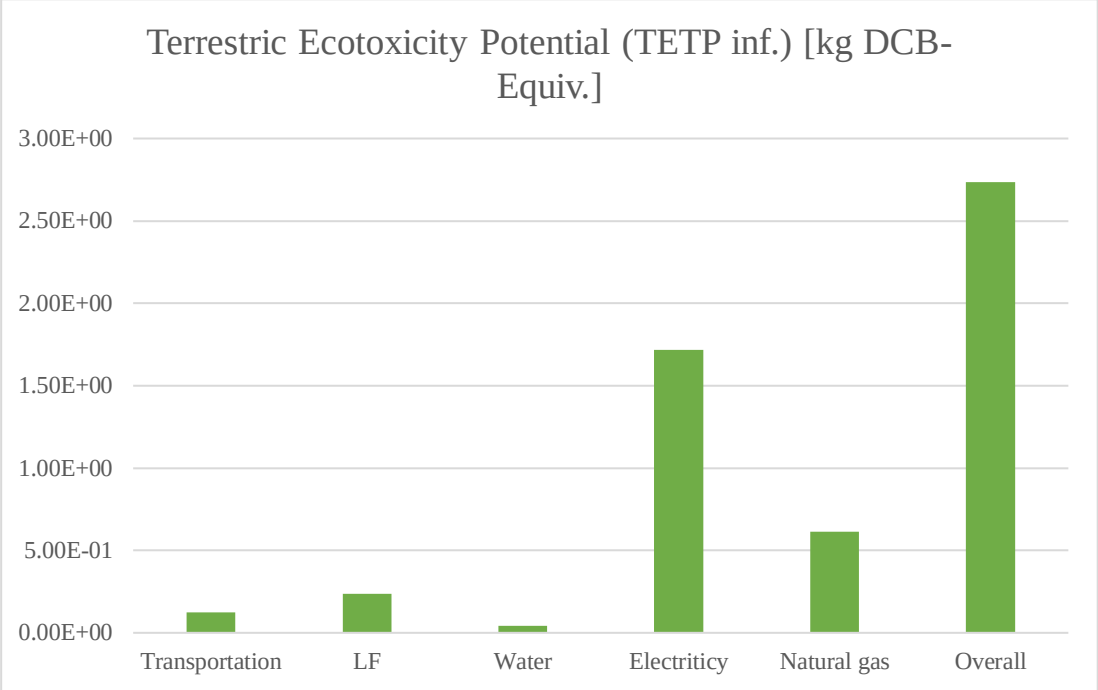


**Figure 5. 37:** Terrestric ecotoxicity potential (TETP) of the restaurant.

Figure 5.38 shows the percentages contribution of factors to TETP. According to the figure, while 62.79% comes from electricity consumption, 22.48% contribution comes from natural gas consumption of the restaurant.

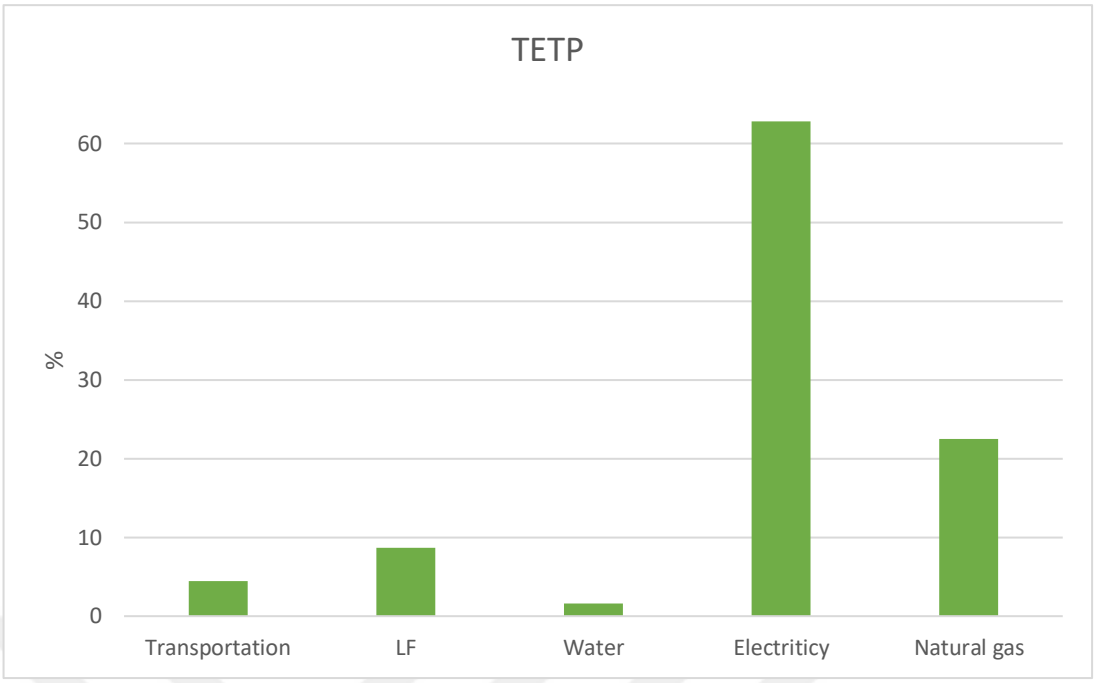


**Figure 5. 38:** Percentage contribution of factors to TETP.

Figure 5.39 shows the electricity consumption contribution to TETP. According to the results, while 34.5% of the electricity-related TETP comes from "transmission network", 22.9% comes from "electricity production, lignite" and 21.1% comes from "electricity production, hard coal". Results show that electricity contribution in TETP was mainly caused by heavy metal to air(52.6%) and heavy metals to industrial soil(38.4%) in this study. Heavy metals to industrial soil is mainly caused by transmission network(85.75%). According to the studies, installation of the network may be the main contributor(Turconi et al., 2014).

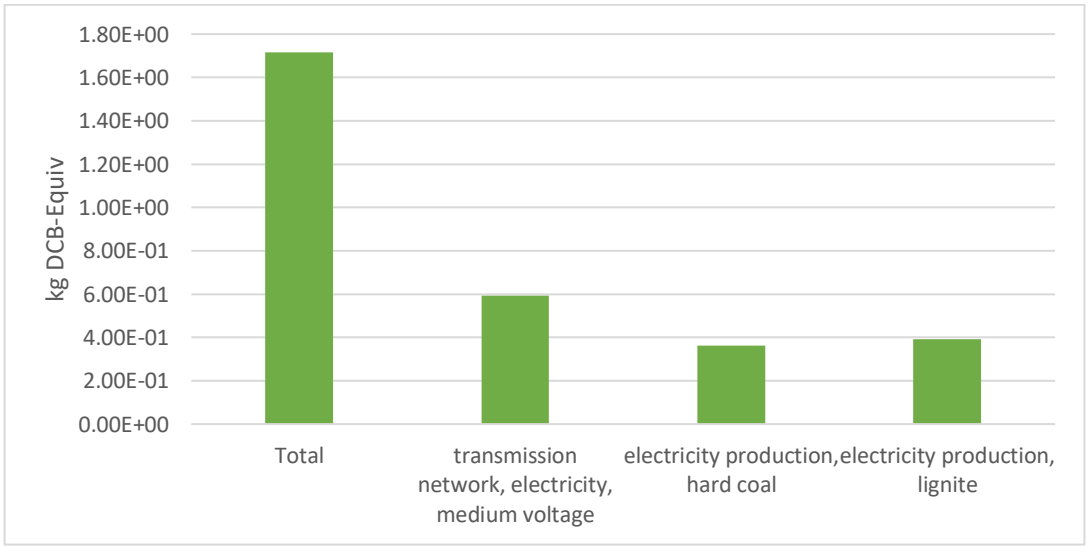


**Figure 5. 39:** Electricity contribution to TETP.

Results showed that transportation has a low impact on the environment in this study as a result of close distance transportation. Only for ADP Element and ODP, transportation resulted higher than 10% contribution to the overall impact. Landfill mainly contributes to EP and FAETP. While energy consumption of the restaurant has the biggest impact on the environment (Atilgan & Azapagic, 2017), water consumption does not show a considerable impact.

## 5.4. Water Reduction Scenario

In the current system(Scenario 0), water consumption is 8.12 $m^3$. This water consumption includes dishwasher consumption, consumption with food(tap), washing(tap), etc. With 60% tap water reduction, water input can be reducted to 5.12 $m^3$. In this study, "Market for Tap Water" process was used in order to calculate environmental impact potentials. Results showed 36.95% reduction for all environmental impact categories. Water reduction was applied to Scenario 1, Scenario 2, Scenario 3 and Scenario 4.

Table 5.4 shows the environmental impact potentials of both current water consumption and reducted water consumption.

**Table 5. 4:** Environmental impact potentials of water scenarios.

| Environmental Impact Category | Unit | Current water consumption | Tap water reducted water consumption |
|---|---|---|---|
| **ADP Elements** | kg Sb-Equiv. | 1.38E-05 | 8.70E-06 |
| **ADP Fossil** | MJ | 3.70E+01 | 2.33E+01 |
| **AP** | kg SO2-Equiv. | 1.65E-02 | 1.04E-02 |
| **EP** | kg Phosphate-Equiv. | 7.64E-03 | 4.82E-03 |
| **FAETP** | kg DCB-Equiv. | 5.10E+00 | 3.22E+00 |
| **GWP** | kg CO2-Equiv. | 3.25E+00 | 2.05E+00 |
| **HTP** | kg DCB-Equiv. | 2.22E+00 | 1.40E+00 |
| **MAETP** | kg DCB-Equiv. | 5.70E+03 | 3.59E+03 |
| **ODP** | kg R11-Equiv. | 3.26E-07 | 2.06E-07 |
| **POCP** | kg Ethene-Equiv. | 1.50E-03 | 9.47E-04 |
| **TETP** | kg DCB-Equiv. | 4.38E-02 | 2.76E-02 |

## 5.5. Electricity Scenarios

### 5.5.1. Electricity grid mix scenario

Medium voltage electricity mix model was created from 2019 data belong to Turkey. All impact categories were calculated with CML2001 for 1 kWh electricity production, results were multiplied with the inventory data gathered from the investigated restaurant.

### 5.5.2. Photovoltaic electricity scenario

"ROW electricity production, photovoltaic, 3kWp flat-roof installation, multi-Si" was chosen for Electricity Production From Solar Power Scenario from Ecoinvent 3.1 Database. All impact categories were calculated with CML2001 for 1 kWh electricity production, results were multiplied with the inventory data gathered from the investigated restaurant.

### 5.5.3. Wind turbine electricity scenario

"TR electricity production, wind, 1-3MW turbine, onshore" was chosen for Electricity Production From Wind Power Scenario from Ecoinvent 3.1 Database. All impact categories were calculated with CML2001 for 1 kWh electricity production, results were multiplied with the inventory data gathered from the investigated restaurant.

### 5.5.4. Environmental ımpact potential results for energy scenarios

All environmental impact potential categories were calculated for electricity grid mix usage, wind power usage and solar power usage for 1 kWh electricity in GaBi Software. Results were multiplied by the electricity consumption for 1000 services.

It's clearly seen from Table 5.5, that all impact categories except ADP Elements and ODP are decreased with switching from electricity grid mix to solar or wind power. On the other hand, ADP Elements gave the highest results on solar power. This result is mainly caused by high consumption of non-renewable elements(Stamford, 2012).

For Ozone Layer Depletion Potential, solar power gave comparatively high results. The reason of this is the usage of certain materials, such as teflon, in producing solar cells(Atilgan & Azapagic, 2016). Freshwater Aquatic Ecotoxicity, Human Toxicity

and Terrestic Ecotoxicity Potentials gave considerable results on wind and solar power as a result of metal requirements and emissions for production of the systems.

**Table 5. 5:** Environmental impact potentials of electricity mix, wind and solar-based electricity production.

| Environmental Impact Category | Unit | Electricity mix | Wind power | Solar power |
|---|---|---|---|---|
| **ADP Elements** | kg Sb-Equiv. | 2.70E-04 | 2.49E-04 | 2.59E-03 |
| **ADP Fossil** | MJ | 4.99E+03 | 1.24E+02 | 7.09E+02 |
| **AP** | kg SO2-Equiv. | 3.09E+00 | 6.55E-02 | 5.17E-01 |
| **EP** | kg Phosphate-Equiv. | 1.93E+00 | 3.11E-02 | 2.19E-01 |
| **FAETP** | kg DCB-Equiv. | 3.45E+02 | 6.83E+01 | 1.57E+02 |
| **GWP** | kg CO2-Equiv. | 4.92E+02 | 1.05E+01 | 6.28E+01 |
| **HTP** | kg DCB-Equiv. | 2.73E+02 | 3.44E+01 | 1.36E+02 |
| **MAETP** | kg DCB-Equiv. | 1.06E+06 | 3.77E+04 | 2.61E+05 |
| **ODP** | kg R11-Equiv. | 5.57E-06 | 7.58E-07 | 1.06E-05 |
| **POCP** | kg Ethene-Equiv. | 1.56E-01 | 7.10E-03 | 4.07E-02 |
| **TETP** | kg DCB-Equiv. | 1.72E+00 | 7.62E-01 | 6.43E-01 |

## 5.6. Waste Management Scenarios

### 5.6.1. Organic waste management

#### 5.6.1.1. Anaerobic Digestion

Anaerobic digester process was taken from Ecoinvent 3.7 Database. Proces was fixed for 1 kg of waste. Tkm(ton-kilometer) values for 1 kg (0.039 tkm) were entered to the model according to the waste disposal facility distance. Results were multiplied by the organic waste amount to reach environmental impact potentials of anerobic digestion in this study. Anaerobic digestion of organic waste(77.57 kg) was applied in Scenario 3.

#### 5.6.1.2. Composting

Composting process was taken from Ecoinvent 3.1 Database. Proces was fixed for 1 kg of waste. Tkm(ton-kilometer) values for 1 kg (0.039 tkm) were entered to the model according to the waste disposal facility distance. Results were multiplied by the organic waste amount to reach environmental impact potentials of composting in this study. Composting of organic waste(77.57 kg) was applied in Scenario 4.

### 5.6.2. Paper recycling

Paper recycling process was taken from Ecoinvent 3.1. Process was fixed for 1 kg of waste. Recycling process was connected with paper/ cardboard production. Results were multiplied by paper waste amount to reach environmental impact potentials of paper recycling. 19.18 kg paper waste was sent to paper recycling in Scenario 2, Scenario 3 and Scenario 4.

### 5.6.3. Waste management results

Table 5.6 shows environmental impact potentials of anaerobic digester, composting and paper recycling in this study. Results were gathered for anaerobic digester, composting and paper recycling. 77.57 kg, 77.57 kg and 19.17 kg, respectively. Transportation was included in Table 5.6. Distances from the restaurant were 39 km, 39 km and 20 km for anaerobic digester, composting and paper recycling, respectively.

**Table 5. 6:** Environmental impact potentials of anaerobic digester, composting and paper recycling.

| Environmental Impact Category | Unit | Anaerobic Digestion (77.57 kg) | Composting (77.57 kg) | Paper Recycling (19.17 kg) |
|---|---|---|---|---|
| **ADP Elements** | kg Sb-Equiv. | 4.58E-06 | 5.37E-06 | -4.12E-05 |
| **ADP Fossil** | MJ | 8.84E+01 | 7.17E+01 | -2.19E+02 |
| **AP** | kg SO2-Equiv. | 6.59E-02 | 1.34E-01 | -1.17E-01 |
| **EP** | kg Phosphate-Equiv. | 1.41E-02 | 2.75E-02 | -6.31E-02 |
| **FAETP** | kg DCB-Equiv. | 3.94E-01 | 6.56E-01 | -7.19E+00 |
| **GWP** | kg CO2-Equiv. | 2.85E+01 | 4.17E+01 | -8.51E+00 |
| **HTP** | kg DCB-Equiv. | 1.24E+00 | 1.39E+00 | -9.17E+00 |
| **MAETP** | kg DCB-Equiv. | 9.54E+02 | 1.53E+03 | -2.80E+04 |
| **ODP** | kg R11-Equiv. | 1.12E-06 | 8.61E-07 | -1.37E-06 |
| **POCP** | kg Ethene-Equiv. | 5.21E-03 | 6.96E-03 | -8.85E-03 |
| **TETP** | kg DCB-Equiv. | 1.30E-02 | 1.50E-02 | -1.68E-01 |

According to Table 5.6, negative results were gathered for paper recycling. This means paper recycling has environmental benefits.

As it can be seen from Table 5.6, composting gave higher results than anaerobic digester except ADP Fossil and Ozone Layer Depletion Potential(ODP). For Acidification Potential, composting gave considerably higher results than anaerobic

digester as a result of “treatment of biowaste” processes. The most contributed factor is inorganic air emissions(specially ammonia) in this case. Treatment of biowaste process in composting resulted 2.7 times higher inorganic air emissions related acidification potential than treatment of biowaste process in anaerobic digester. For ADP Fossil case, the most effective factor was crude oil consumption. Anaerobic digester process consumes around 1.3 times more crude oil consumption related with ADP Fossil. While crude oil consumption related ADP Fossil in anaerobic digester was caused by transportation(64%) and heat requirements(24.5%), crude oil consumption related ADP Fossil in composting was caused by almost only transportation(84%). Transportation distances and waste amounts were the same for both processes. Therefore, it can be said that the reason why anaerobic digester gave higher results in ADP Fossil than composting is the crude oil consumption for heat requirements.

For Ozone Layer Depletion Potential, anaerobic digester showed 1.3 times higher impacts on the environment caused by halogenated organic emissions to air. ODP of composting was caused by almost only transportation(83%). In anaerobic digester case, transportation(63.8), heat requirements(25.2%) and machine operation(10.5%) play an important role for ODP. Transportation distances and waste amounts were the same for both processes(anaerobic digester and composting). Therefore, it can be said that the reason why anaerobic digester gave higher results in ODP than composting is the halogenated organic emissions to air caused by heat requirements and machine operation.

## 5.7. Overall Scenarios

### 5.7.1. Scenario 1

This Scenario was explained in Figure 3.3. Comparison of Scenario 0 and Scenario 1 was represented in Figure 5.40.

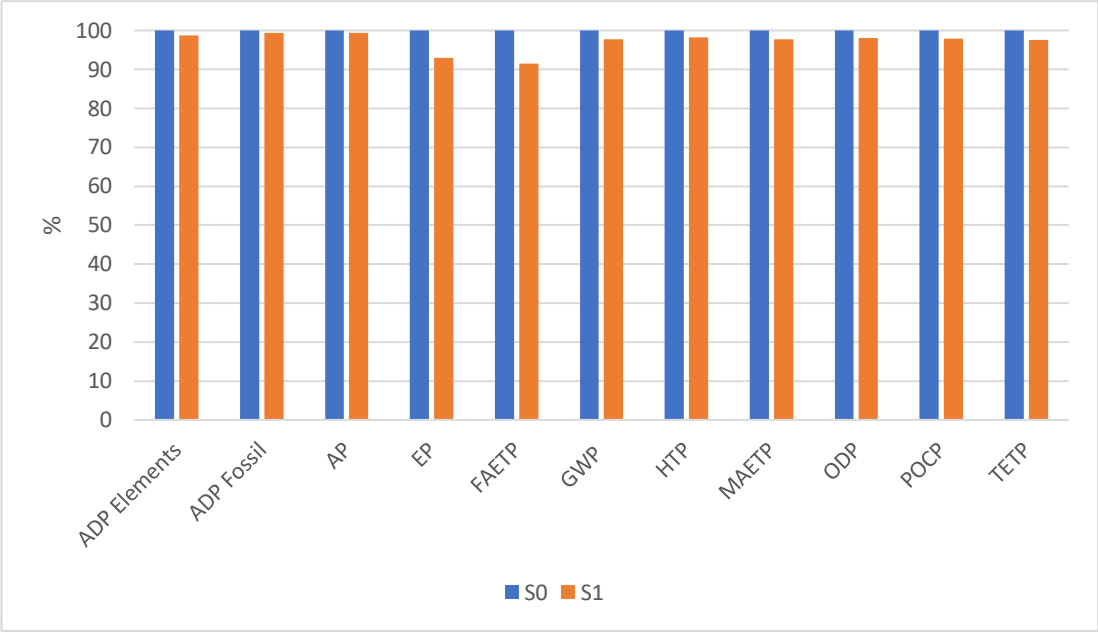


**Figure 5. 40:** Comparison of S0 and S1.

In this scenario, water consumption, amount of waste that is transported to the landfill facility and amount of waste that is landfilled were reduced. Scenario 0 results were fixed to 100 in Figure 5.40. As it can be seen from Figure 5.40, all environmental impact potentials were decreased between 1%-2% except EP and FAETP. 7% decrease for EP and 9% decrease of FAETP were observed. These decreases were caused by sending a lower amount of waste to landfill. The overall result did not show considerable results as a small amount of waste was reduced in the scenario.

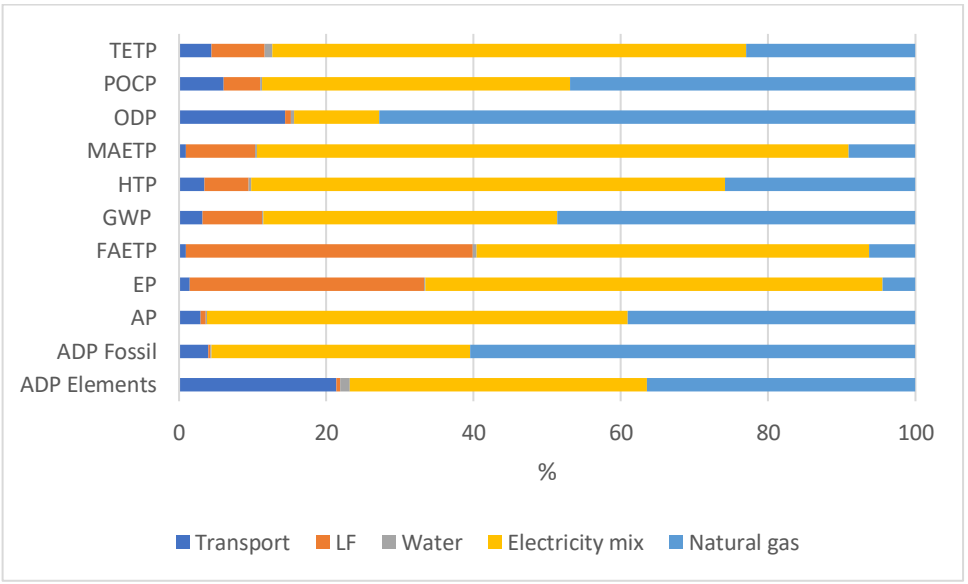


**Figure 5. 41:** Contribution of factors on overall environmental impact potentials of Scenario 1 (%).

Figure 5.41 shows the contributions of factors on overall environmental impact potentials. As it can be seen, energy contributions showed the highest results similar to Scenario 0. Energy-related impact is followed by landfill and transportation impacts. In this study, water consumption-related environmental impacts contribute the least. As a result of it, water reduction didn't give an important reduction in any environmental impact potential in this study.

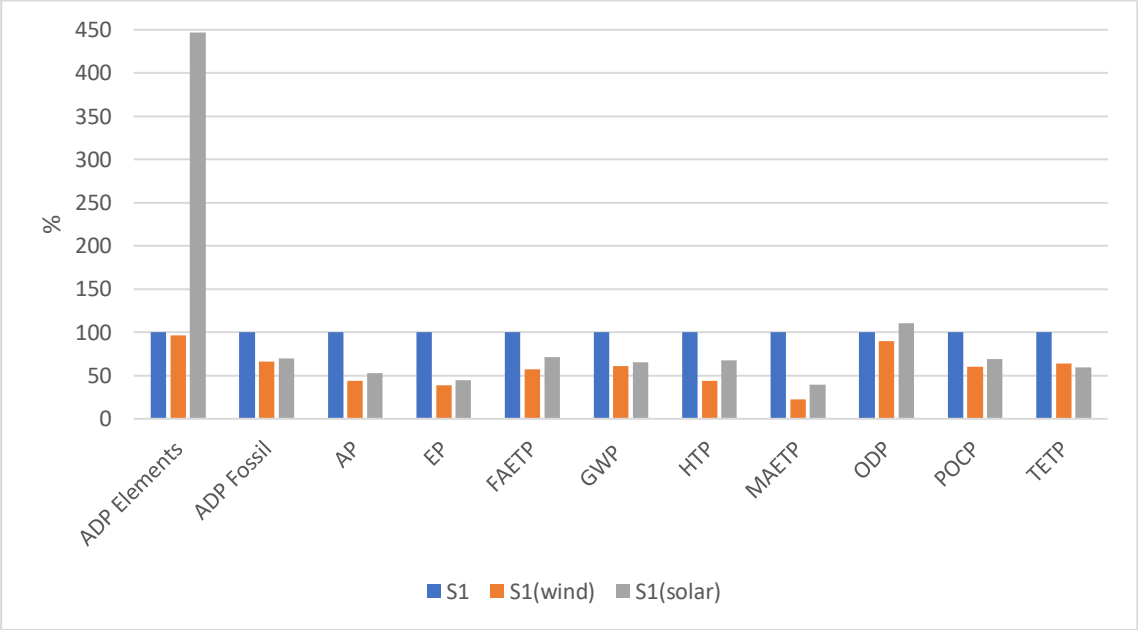


**Figure 5. 42:** Overall results when electricity mix, wind power and solar power are selected in Scenario 1.

Figure 5.42 shows changes in overall results when Turkey's 2019 electricity mix, wind power and solar power were used for electricity consumption. Results from electricity mix usage in Scenario 1 were fixed to 100 in Figure 5.42. According to the figure, decreases for all impact potentials except ADP Element and ODP for solar power were observed. The reason why ADP Elements gave 347% higher results than electricity mix is the high amount of consumption of non-renewable elements in solar power production proses such as gold, silver and copper. For ODP, the reason why solar power gave 10% higher result than electricity mix is halogenated organic emissions to air(R 22, Carbon tetrachloride, Halon, R 12, etc) caused by production of solar cells.

### 5.7.2. Scenario 2

This Scenario was explained in Figure 3.4. Figure 5.43 shows the comparison of Scenario 2 results with Scenario 1 and Scenario 0 results. The lowest environmental impacts were observed in Scenario 2. With comparing results with Scenario 0, the

reason of this decrease was the reduction of the amount of waste that is sent to landfill and adding paper recycling process to the scenario.

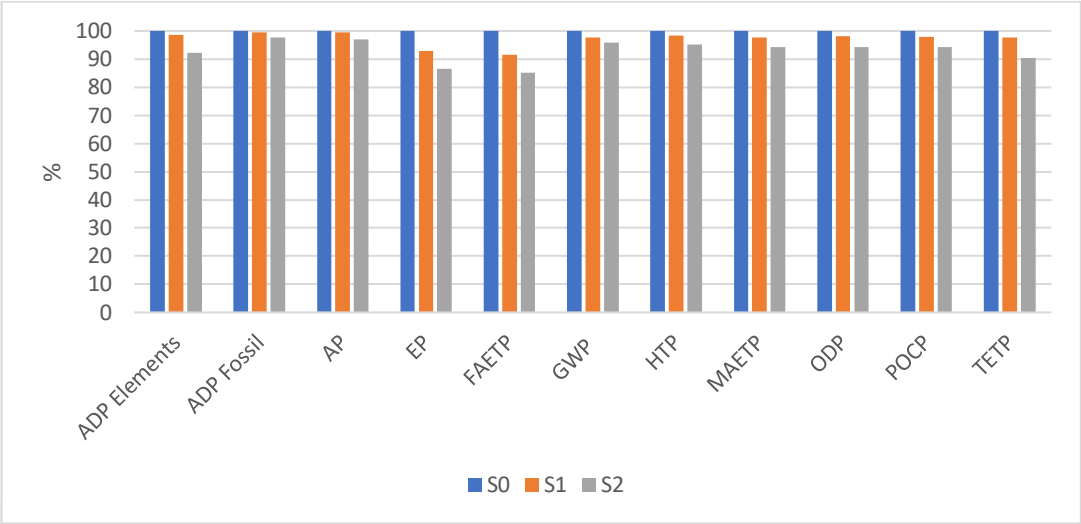


**Figure 5. 43:** Comparison of S0, S1, and S2.

As it can be seen from Figure 5.43, water reduction, reduction of the amount of waste that is sent to landfill and adding recycling process show 8% reduction for ADP Elements, 2% reduction for ADP Fossil, 3% reduction for AP, 13% reduction for EP, 15% reduction for FAETP, 4% reduction for GWP, 5% reduction for HTP, 6% reduction for ODP, POCP and MAETP and 10% reduction of TETP. Reductions higher than 10% were observed only for EP and FAETP.

Figure 5.44 shows factors that cause the decreases in each impact category. In this scenario, recycling has effects mostly on the decrease of ADP Elements, ADP Fossil, AP, HTP, ODP, POCP, and TETP. On the other hand, reducing the amount of wastes that are sent to landfill mostly has effects on the decrease of EP, FAETP, GWP, HTP, and MAETP. Reductions in EP, FAETP were mainly caused by reducing the amount of waste that was landfilled(83% and 91%, respectively.).

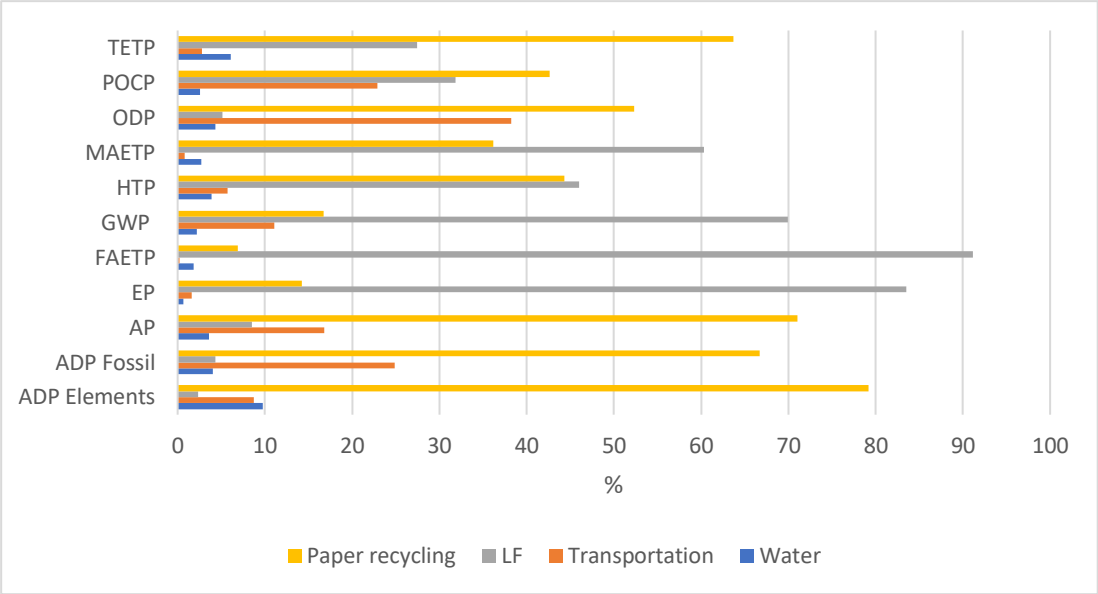


**Figure 5. 44:** Factors that cause reductions in Scenario 2(Comparison with Scenario 0).

Table 5.7 shows the most important environmental impact potential sources and their contribution to Scenario 2. It was seen that the most important parameters remain the same with previous scenarios.

**Table 5. 7:** Most important environmental impact potential sources and their contribution for Scenario 2.

| SCENARIO 2 | Important Factor/Factors in Scenario 0 | Most important impact sources, their contribution and important factors | Impact percentages |
|---|---|---|---|
| **ADP Elements** | Electricity | Non-renewable element consumption (99%) (Copper, gold, silver, cadmium, lead, etc) | 43.15% |
| | Natural Gas | Non-renewable element consumption(96%) (Copper, cadmium, lead, etc) | 39.05% |
| **ADP Fossil** | Natural gas | Non-renewable energy source(96%) (Natural gas) | 61.58% |
| **AP** | Electricity | Inorganic emissions to air(99%) (Sulphur dioxide) | 58.53% |
| | Natural gas | Inorganic emissions to air(91%) (Sulphur dioxide) | 40.10% |
| **EP** | Electricity | Emissions to freshwater (91%) (Phosphate) | 66.60% |
| | Landfill | Emissions to freshwater (98%) (TOC, COD) | 29.19% |
| **FAETP** | Electricity | Emissions to freshwater(99%) (nickel, beryllium, cobalt, copper, etc) | 57.21% |
| | Landfill | Emissions to freshwater(99%) (Copper, nickel) | 35.74% |
| **GWP** | Natural gas | Inorganic emissions to air(88%) ($CO_2$) | 49.69% |
| | Electricity | Inorganic emissions to air(94%) ($CO_2$) | 40.75% |
| **HTP** | Electricity | -Emissions to freshwater(70%) (Selenium, barium, nickel, etc), -Heavy metals to air(15%) (Chromium, arsenic) | 66.44% |
| **MAETP** | Electricity | Emissions to freshwater(68%) (beryllium, nickel, etc) | 83.30% |
| **ODP** | Natural gas | Halogenated organic emissions to air(99.99%) (Halon) | 75.77% |
| **POCP** | Natural gas | -Inorganic emissions to air(54%) (Sulphur dioxide) -Organic emissions to air(46%) (NMVOC) | 48.70% |
| | Electricity | Inorganic emisisons to air(86%) (sulphur dioxide, nitrogen oxides) | 43.44% |
| **TETP** | Electricity | -Heavy metals to air(54%) (mercury, chromium) -Heavy metals to industrial soil(39%) ( Chromium (+VI)) | 69.53% |

Figure 5.45 shows the contributions of each factor to the overall impact of Scenario 2. As it can be seen, energy consumption has the highest impact in this study. Energy consumption-related environmental impacts were followed by landfill and transport-related impacts. Water consumption of the restaurant did not show considerable impact

in this study. Paper recycling showed negative results for all environmental impact potentials. This means that paper recycling had environmental benefits in this scenario.

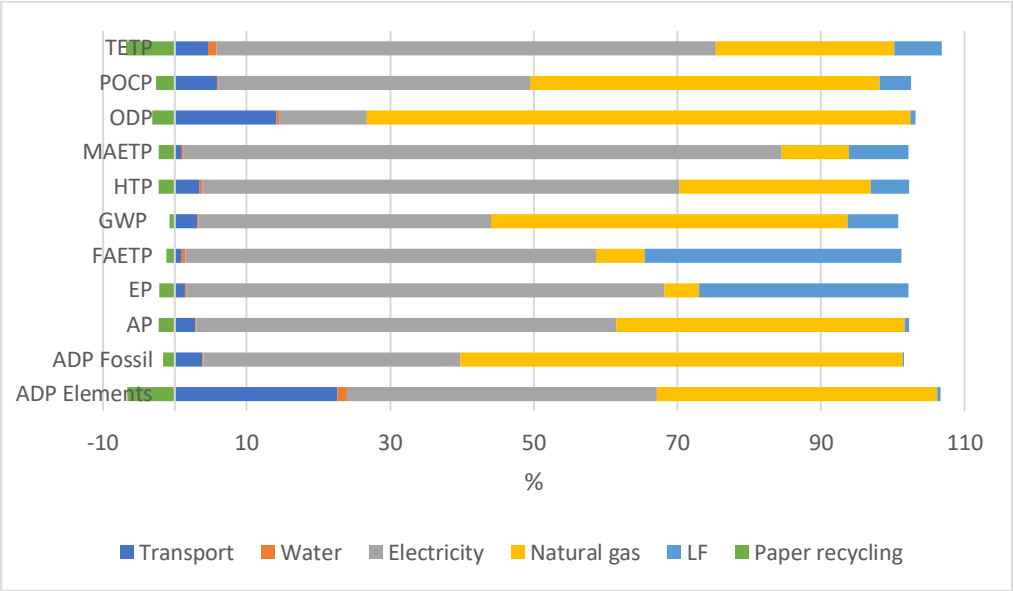


**Figure 5. 45:** Contribution of factors on overall environmental impact potentials of Scenario 2 (%).

Individual decreases were observed for all environmental impact categories in transport, landfill and water factors. These results were caused by reduction of wastes that are transported to landfill facility(100 km) and landfilled. 19.18 kg of paper waste were landfilled in Scenario 0 and Scenario 1. In Scenario 2, paper waste was transported to recycling facility(20 km) and recycled. No changes took place in electricity and natural gas factors as their amounts and sources remain the same for all scenarios.

Table 5.8 shows changes in the overall results when electricity was supplied from wind power and solar power. According to the table, decrease for all impact potentials except ADP Element and ODP for solar power was observed.

The reason why ADP Element gave higher results than electricity mix is the high amount of consumption of non-renewable elements in solar power production proses such as gold, silver, and copper. For ODP, the reason why solar power gave higher result than electricity mix is halogenated organic emissions to air(R 22, Carbon tetrachloride, Halon, R 12, etc) caused by production of solar cells.

**Table 5. 8:** Changings on overall results when electricity was supplied from wind power and solar power in Scenario 2(%).

| | S2 | S2 (wind) | S2 (solar) |
|---|---|---|---|
| **ADP Elements** | 100 | -3% | 371% |
| **ADP Fossil** | 100 | -35% | -31% |
| **AP** | 100 | -57% | -49% |
| **EP** | 100 | -66% | -59% |
| **FAETP** | 100 | -46% | -31% |
| **GWP** | 100 | -40% | -36% |
| **HTP** | 100 | -58% | -33% |
| **MAETP** | 100 | -80% | -63% |
| **ODP** | 100 | -10% | 11% |
| **POCP** | 100 | -41% | -32% |
| **TETP** | 100 | -39% | -43% |

### 5.7.3. Scenario 3

Water-saving was applied in this scenario. Figure 5.46 shows the comparison of Scenario 3 results with Scenario 2, Scenario 1, and Scenario 0 results. The lowest environmental impacts were observed in Scenario 3. With comparing results with Scenario 0, the reason of this decrease was the reduction of the amount of waste that is sent to landfill, adding a recycling process to the scenario and sending organic wastes to anaerobic digester.

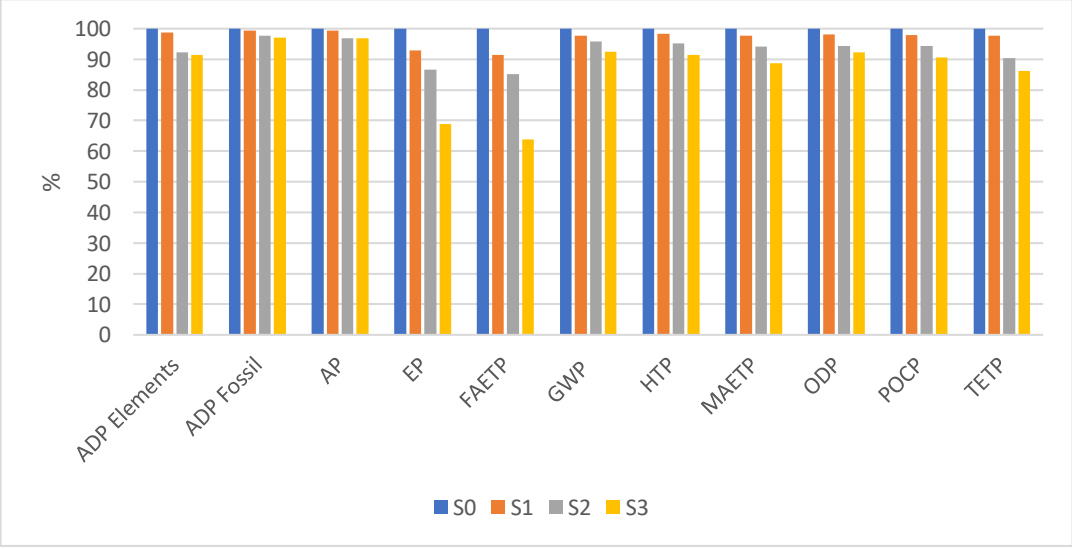


**Figure 5. 46:** Comparison of S0, S1, S2, and S3.

As it can be seen from Figure 5.46, water reduction, reduction of the amount of waste that is sent to landfill and adding recycling process show 9% reduction for ADP Elements, 3% reduction for ADP Fossil, 3% reduction for AP, 31% reduction for EP, 36% reduction for FAETP, 8% reduction for GWP, 9% reduction for HTP, 11% reduction for MAETP, 8% reduction for ODP, 9% reduction for POCP and 14% reduction for TETP. Reductions higher than 10% were observed only for EP, FAETP, MAETP, and TETP.

Figure 5.47 shows factors that cause the decreases in each impact category in Scenario 3. As it can be seen from Figure 5.47, in this scenario recycling has effects mostly on the decrease of ADP Elements, ADP Fossil, AP, and TETP. On the other hand, reducing the amount of waste that is sent to landfill has effects mostly on the decrease of EP, FAETP, GWP, HTP, MAETP, POCP, and TETP. Reduction in ODP is mainly caused by transportation. Reductions in EP, FAETP, and MAETP were mainly caused by reducing the amount of waste that was landfilled(93%, 96.3%, and 79.6%, respectively.). Reduction in TETP was mainly caused by reducing the amount of waste that was sent to landfill(49.40%) and paper waste recycling(44.54%). Adding anaerobic digester to the scenario did not cause an overall increase in any category. But it mostly had an increasing effect on AP and GWP mainly caused by inorganic emissions to air, such as $SO_2$ and $CO_2$, from "treatment of biowaste by anaerobic digestion" process.

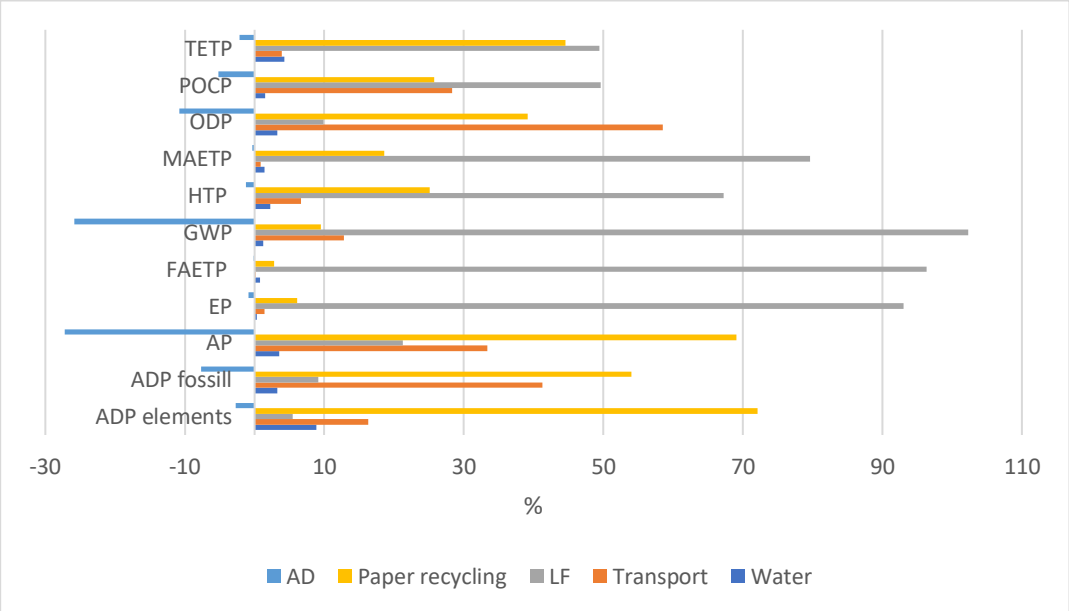


**Figure 5. 47:** Factors that cause reductions in Scenario 3(Comparison with Scenario 0).

Figure 5.48 shows contributions of each factor to the overall impact of Scenario 3. As it can be seen, energy consumption has the highest impact in this study as previous scenarios had.

Energy consumption-related environmental impacts were followed by transportation and landfill-related impacts. Water consumption and anaerobic digestion did not show considerable impacts in the scenario. While reducted water-related environmental impacts were range between 0%-2%, anaerobic digestion-related environmental impacts were ranged between 0%-2%. Paper recycling showed negative results for all environmental impact potentials. This means that paper recycling had environmental benefits in the scenario.

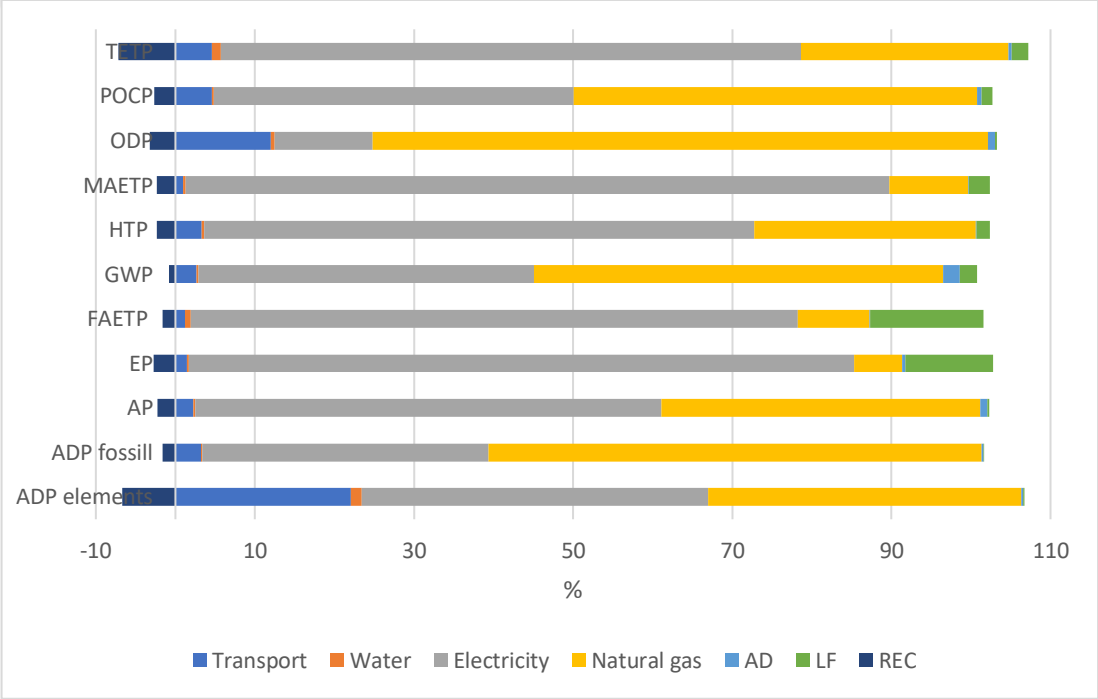


**Figure 5. 48:** Contribution of factors on overall environmental impact potentials of Scenario 3 (%).

Table 5.9 shows changes in the overall results when electricity was supplied from wind power and solar power. According to the table, decrease for all impact potentials except ADP Element and ODP for solar power was observed like previous scenarios. The reason of these results was explained in Scenario 1 and Scenario 2.

**Table 5. 9:** Changings on overall results when electricity was supplied from wind power and solar power in Scenario 3(%).

| | S3 | S3 (wind) | S3 (solar) |
|---|---|---|---|
| **ADP Elements** | 100 | -3% | 374% |
| **ADP Fossil** | 100 | -35% | -31% |
| **AP** | 100 | -57% | -49% |
| **EP** | 100 | -82% | -74% |
| **FAETP** | 100 | -61% | -42% |
| **GWP** | 100 | -41% | -37% |
| **HTP** | 100 | -60% | -35% |
| **MAETP** | 100 | -85% | -67% |
| **ODP** | 100 | -11% | 11% |
| **POCP** | 100 | -43% | -33% |
| **TETP** | 100 | -41% | -46% |

### 5.7.4. Scenario 4

Water-saving was applied in this scenario. Figure 5.49 shows the comparison of Scenario 4 results with Scenario 3, Scenario 2, Scenario 1 and Scenario 0 results. It can be seen that Scenario 3 and Scenario 4 gave close results. In this scenario, the same amount of organic waste(77.57 kg) in Scenario 3 was sent to anaerobic digester. Composting in Scenario 4 and anaerobic digestion in Scenario 3 had the same distance in this study. (39 km).

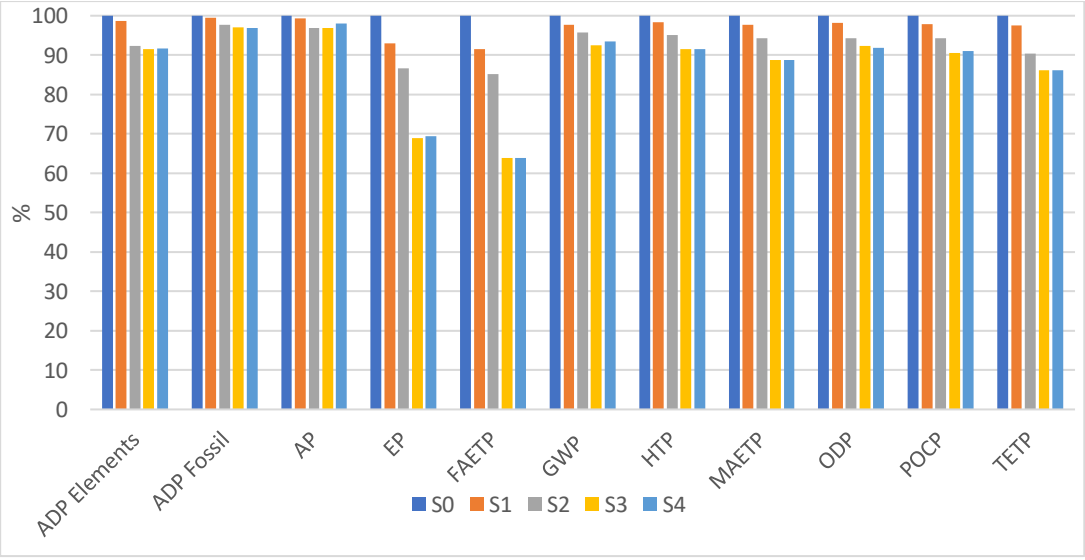


**Figure 5. 49:** Comparison of S0, S1, S2, S3, and S4.

Figure 5.50 shows factors that cause decreases in each impact category in Scenario 4. In this scenario, recycling has effects mostly on the decrease of ADP Elements, ADP Fossil, AP, and TETP. On the other hand, reducing the amount of wastes that are sent to landfill has effects mostly on the decrease of EP, FAETP, GWP, HTP, MAETP, POCP and TETP. Reduction in ODP is mainly caused by transportation. Reductions in EP, FAETP and MAETP were mainly caused by reducing the amount of waste that was landfilled(94.26%, 96.48%, and 79.90%, respectively.). Reduction in TETP was mainly caused by reducing the amount of waste that was sent to landfill(49.67%) and paper waste recycling(44.79%). Adding composting to the scenario did not cause an overall increase in any category. But it mostly had an increasing effect on AP and GWP mainly caused by inorganic emissions to air, such as $SO_2$ and $CO_2$, from "treatment of biowaste by composting" process.

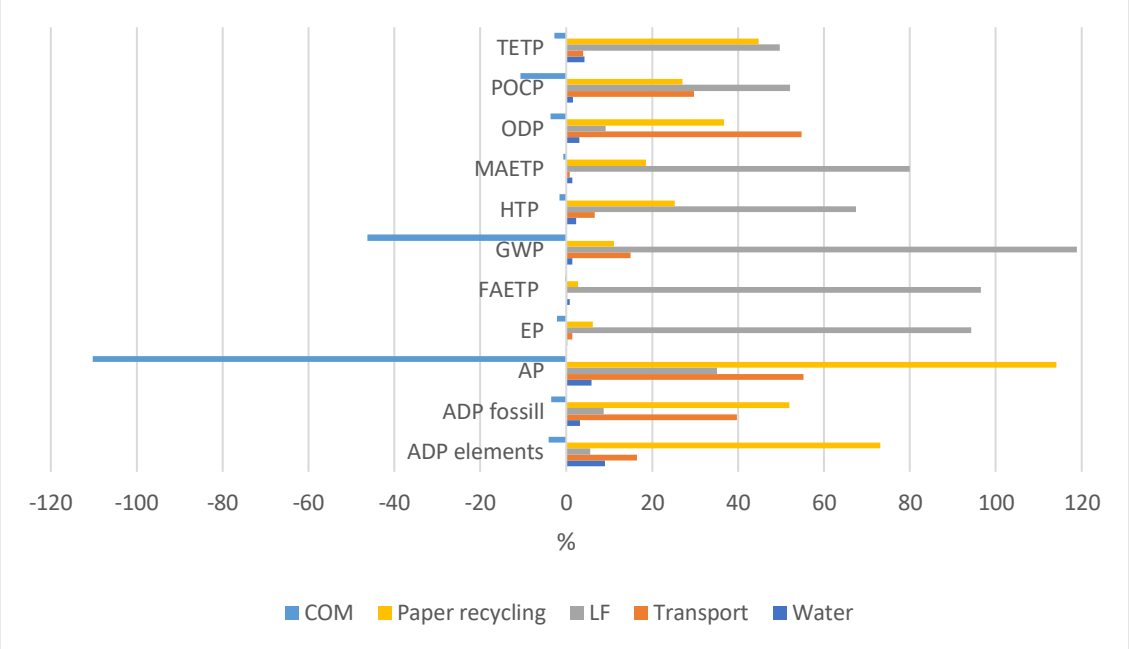


**Figure 5. 50:** Factors that cause reductions in Scenario 4 (Comparison with Scenario 0).

Figure 5.51 shows the contributions of each factor to the overall impact of Scenario 4. As it can be seen, energy consumption has the highest impact in this study as previous scenarios had. Energy consumption-related environmental impacts were followed by transportation and landfill-related impacts. Water consumption and composting did not show considerable impacts in this study.

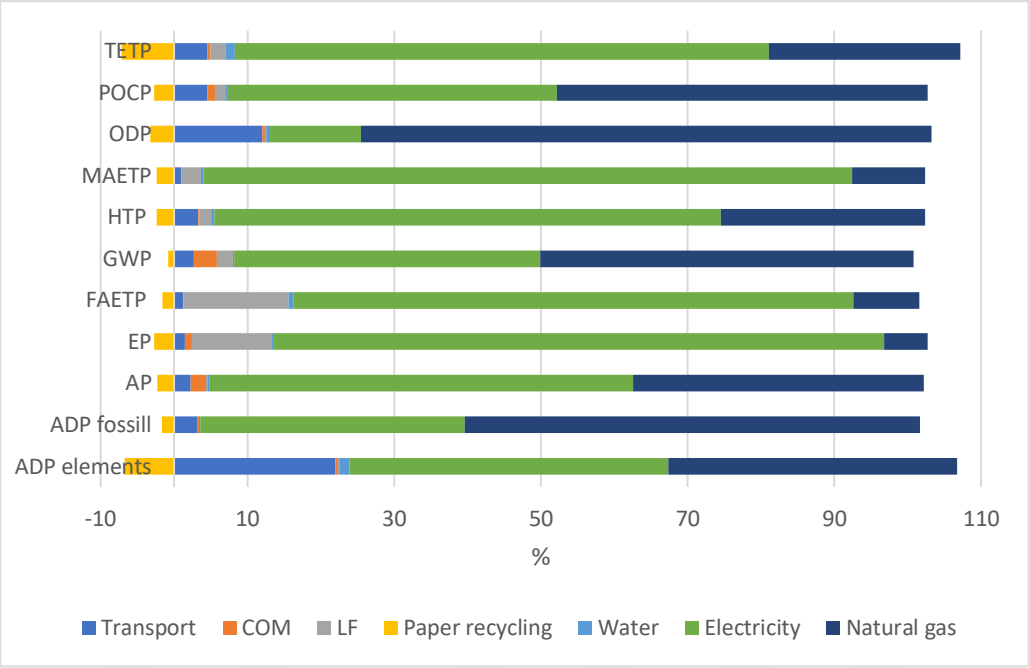


**Figure 5. 51:** Contribution of factors on overall environmental impact potentials of Scenario 4 (%).

While reducted water-related environmental impacts were range between 0%-2%, composting-related environmental impacts were ranged between 0%-3%. Paper recycling showed negative results for all environmental impact potentials. This means that paper recycling had environmental benefits in this scenario.

**Table 5. 10:** Changings on overall results when electricity was supplied from wind power and solar power in Scenario 4(%).

| | S4 | S4 (wind) | S4 (solar) |
|---|---|---|---|
| **ADP Elements** | 100 | -3% | 373% |
| **ADP Fossil** | 100 | -35% | -31% |
| **AP** | 100 | -57% | -48% |
| **EP** | 100 | -82% | -74% |
| **FAETP** | 100 | -61% | -41% |
| **GWP** | 100 | -41% | -36% |
| **HTP** | 100 | -60% | -35% |
| **MAETP** | 100 | -85% | -67% |
| **ODP** | 100 | -11% | 11% |
| **POCP** | 100 | -43% | -33% |
| **TETP** | 100 | -41% | -46% |

Table 5.10 shows changes in the overall results when electricity was supplied from wind power and solar power. According to the table, decrease for all impact potentials except ADP Element and ODP for solar power was observed like previous scenarios.

# 6. CONCLUSIONS AND RECOMMENDATIONS

Following conclusion and recommendations are derived from the calculated environmental impact potentials of waste management and energy consumption for a restaurant via life cycle assessment(LCA) approach. Results are represented for 1000 services.

In the base scenario (Scenario 0), all of the wastes are sent to landfill, no water and energy saving are applied.

Results show that ADP Elements of the restaurant is 6.78E-04 kg Sb-Equiv. Electricity and natural gas are the highest contributors to ADP Elements in this case, 39.81% and 21.54%, respectively. The contribution of electricity is mainly caused by transmission network(35%) and photovoltaic electricity production(32%).

ADP Fossil result is 1.43E+04 MJ. Results show that the highest contributors were natural gas(60%) and electricity(34.93%). The contribution of electricity is mainly caused by hard coal, lignite, and natural gas amount in Turkey's electricity mix.

AP result is 5.44 kg $SO_2$-Equiv. In this case, the highest contributors are defined as electricity(56.73%) and natural gas(38.87%) consumptions. Results show that the highest contribution to electricity is caused by $SO_x$ and $NO_x$ emissions to air from “electricity production, hard coal” and “electricity production, lignite” processes.

EP result is 3.35 kg Phosphate-Equiv in this study. Electricity and landfill application are the highest contributors, 57.66% and 36.49%, respectively. Electricity consumption-related EP is mainly caused by phosphate emissions to freshwater from “electricity production, hard coal” and “electricity production, lignite” processes. Landfill application-related EP is mainly caused by emissions to freshwater from treatment of municipal solid waste process.

FAETP result of the restaurant is 7.08E+02 kg DCB-Equiv. Electricity and landfill application are the highest contributors, 48.74% and 43.95%, respectively. Electricity

consumption related FAETP is mainly caused by copper, cobalt, beryllium emissions to freshwater from “electricity production, lignite” (70%) and “electricity production, hard coal”(18%) and transmission network (6%) processes. Landfill application-related FAETP is mainly caused by emissions to freshwater from treatment of municipal solid waste process.

GWP result of the restaurant is 1.26E+03 kg $CO_2$-Equiv. Main contributors to GWP are natural gas consumption(47.57%), electricity consumption(39.01%) and landfill application(9.71%) in this study. Inorganic emissions to air, specially carbon dioxide(92%), via electricity production from hard coal, electricity production from lignite and electricity production from natural gas have the biggest contributions of electricity-related GWP. Landfill application-related FAETP is mainly caused by emissions to freshwater from treatment of municipal solid waste process.

HTP result of the restaurant is 4.32E+02 kg DCB-Equiv. Electricity has the highest impact on the environment in this case(65.23%). Electricity contribution is mainly caused by heavy metal emissions to air such as arsenic, chromium, nickel from “electricity production, lignite”(59%) and “electricity production, hard coal”.(29%)

MAETP result of the restaurant is 1.35E+06 kg DCB-Equiv. Electricity has the highest impact on the environment in this case(78.50%). 60% of the impact of the electricity comes from “electricity production, lignite” and 35% comes from “electricity production, hard coal”.

ODP result of the restaurant is 4.88E-05 kg R11-Equiv. The main contributor of ODP is natural gas(71.42%) in this study. This result is caused by high amount of refrigerant usage in natural gas pipelines.

POCP result of the restaurant is 3.80E-01 kg Ethene-Equiv. The main contributors of POCP are natural gas(45.91%) and electricity(40.96%) in this study. The electricity-related impact is caused by inorganic emissions to air such as $SO_2$ and $NO_x$ via “electricity production, lignite”(51.4%) and “electricity production, hard coal” (30.8%) processes.

TETP result of the restaurant is 2.74 kg DCB-Equiv. Electricity consumption(62.79%) and natural gas consumption(22.48%) are the main contributors in this category. Electricity contribution to TETP is mainly caused by heavy metals to air and heavy metals to industrial soil in this study. Results show that 34.5% of the electricity-related

TETP comes from “transmission network”, 22.9% comes from “electricity production, lignite” and 21.1% comes from “electricity production, hard coal”.

In scenario 1, water reduction is applied and returnable products are sent back to the seller. The remaining waste is sent to a landfill. Results are gathered with electricity mix usage in the restaurant. A small amount of decrease, 1%-2%, is observed for all environmental impact potentials except EP and FAETP. 7% decrease for EP and 9% decrease of FAETP are observed. These decreases are caused by sending the lower amount of waste to landfill. Replacing electricity mix with wind power or solar power decrease all impact potentials except ADP Element(347% rise) and ODP(10% rise) for solar power. This is caused by a high amount of non-renewable element consumption in renewable energy sources and halogenated organic emissions to air caused by production of solar cells, respectively.

In Scenario 2, water reduction is applied and returnable products are sent back to the seller. Paper waste is recycled and the remaining waste is sent to a landfill. Results are gathered with electricity mix usage in the restaurant. Lower results than Scenario 0 and Scenario 1 are caused by sending a smaller amount of waste to landfill and adding a recycling process to the scenario. The biggest decreases(comparison with Scenario 0) are observed in EP(13%) and FAETP(15%) caused by reducing the amount of wastes to be sent to landfill. Replacing electricity mix with wind power or solar power decrease all impact potentials except ADP Element(371% rise) and ODP(11% rise) for solar power. The reason of it was explained above in Scenario 1.

In Scenario 3, water reduction is applied and returnable products are sent back to the seller. Paper waste is recycled, organic waste is sent to anaerobic digestion and the remaining waste is sent to a landfill. Results are gathered with electricity mix usage in the restaurant. Lower results than Scenario 0, Scenario 1 and Scenario 2 are caused by sending the smaller amount of waste to landfill, adding a recycling process to the scenario and sending organic waste (it was sent to landfill in previous scenarios) to anaerobic digestion. Biggest decreases (comparison with Scenario 0) are observed in EP(31%), FAETP(36%), MAETP(11%) and TETP(14%). EP, FAETP, MAETP reductions are mainly caused by sending the lower amount of waste to landfill. TETP reduction is caused by recycling and sending a lower amount of waste to landfill. Replacing electricity mix with wind power or solar power decrease all impact

potentials except ADP Element(374% rise) and ODP(11% rise) for solar power. The reason of it was explained above.

In Scenario 4, water reduction is applied and returnable products are sent back to the seller. Paper waste is recycled, organic waste is sent to composting and the remaining waste is sent to landfill. Results are gathered with electricity mix usage in the restaurant. The biggest decreases (comparison with Scenario 0) are observed in EP, FAETP, MAETP and TETP. EP, FAETP, MAETP reductions are mainly caused by sending lower amount of waste to landfill(94.26%, 96.48% and 79.90%, respectively.). TETP reduction is caused by recycling(44.79%) and sending lower amount of waste to landfill(49.67%). Replacing electricity mix with wind power or solar power decrease all impact potentials except ADP Element(373% rise) and ODP(11% rise) for solar power. The reason of it was explained above.

According to the overall results, it can be concluded that energy consumption of the restaurant is the critical point in this study(Atilgan & Azapagic, 2015). This is mainly caused by "electricity production, lignite" and "electricity production, hard coal" processes(Atilgan & Azapagic, 2015). Energy consumption-related environmental impacts are followed by landfill application-related environmental impacts. Sending lower amount of waste to landfill mainly contributes to reducing EP and FAETP. Transportation-related environmental impacts are considerably low as a result of close distance transportation. Switching electricity consumption from grid mix with solar or wind power decreases the environmental impacts related to electricity consumption. On the other hand, solar power could increase ADP Elements and ODP. Adding anaerobic digester or composting to scenarios does not make considerable increasing but those processes mostly tend to increase AP and GWP as a result of inorganic emissions to air from treatment of biowaste processes in anaerobic digestion and composting.

According to the results, it can be concluded that Scenario 3 gave the lowest environmental impacts in this study as a result of sending a lower amount of waste to landfill, adding recycling and anaerobic digester processes to the scenario. As a result, implementation of Scenario 3 can be recommended. In order to reduce energy consumption-related environmental impacts, replacement of electricity-consuming devices with energy-efficient models, reduction on excessive energy consumption can be recommended to be implemented on the restaurant basis.

On the other hand, switching electricity mix usage with wind or solar power can lead to the highest reduction of environmental impact potentials. This can be provided by the municipality. Also, separation of wastes can be provided by the shopping mall and treating them according to their characterization can be provided by the municipality.

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**CURRICULUM VITAE**

**Name Surname** **:** Meryem BAHADIROĞLU

**EDUCATION** **:**

- **B.Sc.** **:** 2017, Sakarya University, Faculty of Engineering, Environmental Engineering