WASTE INVENTORY FOR A REFRIGERATOR MANUFACTURING PLANT

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ABSTRACT

WASTE INVENTORY FOR A REFRIGERATOR MANUFACTURING PLANT

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Household appliances production, especially refrigerators, has an important share in the economy of many countries in the world and Turkey. Yet, waste production during production constitutes a problem that should be managed. For that purpose, it is important to identify the wastes from production and evaluate the environmental performance based on these wastes. In this thesis, production processes in a refrigerator manufacturing facility in Turkey are examined. Hazardous, non-hazardous and packaging wastes arising from these processes are identified to make a waste inventory for a refrigerator manufacturing company. According to the inventory study based on field study and data covering a production period of 5 years, it was calculated that 75.3% of the total waste produced was non-hazardous wastes. 23.9% of the total waste amount was packaging waste and remaining 0.8% was hazardous waste. The mass balance study carried out for the production area revealed that 0.0445 kg of waste was generated for 1 kg of materials entering into the system for refrigerator production. Additionally, it was determined that the main sources of scrap cost, which mainly constituted of non-hazardous wastes, were assembly lines, mechanical processes and dyeing processes. Environmental performance of the refrigerator production facility, including waste recycling rate and waste generation intensity, was evaluated through comparison to the figures declared by other leading household appliances manufacturers. Best

Available Techniques (BATs) alternatives were proposed which could be applied in the facility to improve environmental performance. As this study was conducted in a refrigerator plant which used typical refrigerator production processes and relevant process waste streams, results of this study can be used by other refrigerator manufacturers as well.

Keywords: Household Appliances Production, Refrigerator Manufacturing, Waste Management, Environmental Performance Evaluation, Best Available Techniques (BATs)

ÖZ

BİR BUZDOLABI ÜRETİM TESİSİ İÇİN ATIK ENVANTERİ

Dönmezoğlu, Cansu
Yüksek Lisans, Çevre Mühendisliği
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Dünyadaki birçok ülkede ve Türkiye'de ev aletleri üretimi, özellikle buzdolapları üretimi, ekonomide önemli bir paya sahiptir. Ancak, üretim sırasında oluşan atıklar, yönetilmesi gereken bir sorun oluşturmaktadır. Bu sebeple, üretimden kaynaklanan atıkların belirlenmesi ve bu atıklar bazlı çevresel performanslarının değerlendirilmesi önem taşımaktadır. Bu tezde, Türkiye'deki bir buzdolabı üretim tesisinin üretim süreçleri incelenmiştir. Bu süreçlerden kaynaklanan tehlikeli, tehlikesiz ve ambalaj atıkları, bir buzdolabı üretim tesisi için atık envanteri yapmak üzere belirlenmiştir. Saha çalışmaları ve 5 yıllık üretimi kapsayan verilere dayanan envanter çalışmasına göre, toplam atık miktarının %75,3'ünün tehlikesiz atık olduğu hesaplanmıştır. Toplam atık miktarının %23,9'u ambalaj atığı ve geri kalan %0,8'i tehlikeli atıktır. Buzdolabı üretim alanı için yapılan kütle denge çalışması, buzdolabı üretimi için sisteme giren 1 kg malzeme/yarı mamul için 0,0445 kg atık oluştuğunu ortaya çıkarmıştır. Ek olarak, tehlikesiz atıkların önemli bir kısmını oluşturan hurdaların ana kaynaklarının, sırasıyla montaj hatları, mekanik prosesleri ve boyahane proseslerinden kaynaklandığı belirlenmiştir. Buzdolabı üretim tesisinin atık geri dönüşüm oranı ve atık oluşum yoğunluğunu kapsayan çevresel performansı, sektörün önde gelen diğer beyaz eşya üreticilerinin beyan ettiği değerler ile karşılaştırılarak değerlendirilmiştir. Tesiste çevresel performansı arttırabilecek Mevcut En İyi Tekniklerin (MET) alternatifleri önerilmiştir. Bu çalışma, üretim süreçleri ve proses atık akımları bakımından genel buzdolabı üretimini temsil eden bir buzdolabı tesisinde yürütüldüğünden, çalışmanın sonuçları diğer buzdolabı üreticileri tarafından da kullanılabilir.

Anahtar Kelimeler: Beyaz Eşya Üretimi, Buzdolabı Üretimi, Atık Yönetimi, Çevresel Performans Değerlendirme, Mevcut En İyi Teknikler (MET),

To my beloved family

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ABBREVIATIONS

APPLIA: Home Appliance Europe

BAT: Best available techniques

BREF: Best available techniques reference documents

CECED: European Committee of Domestic Equipment Manufacturers

CFCs: Chlorofluorocarbons

CFC-11: Trichlorofluoromethane

CFC-12: Dichlorodifluoromethane

ERP: Enterprise resource planning

EPIs: Environmental performance indicators

GDP: Gross domestic production

GM: General Motors

GWP: Global warming potential

HC: Hydrocarbon

HCFCs: Hydrochlorofluorocarbons

HW: Hazardous waste

ISO: International Organization for Standardization

IT: Information technology

JEMA: The Association of Electrical Manufacturers of Japan

LCA: Life cycle assessment

MEUP: Ministry of Environment and Urbanization

NHW: Non-hazardous waste

ODP: Ozone depletion potential

PCB: Printed circuit board

P&G: Procter & Gamble

PW: Packaging waste

R11: Trichloromonofluoromethane

R12: Dichlorodifluoromethane

R134a: Tetrafluoroethene

R600a: Isobutane

SAP: System applications products

TUIK: Turkish Statistical Institute

TUBITAK: Scientific and Technological Research Council of Turkey

TURKBESD: Association of Household Appliances Manufacturers of Turkey

USA: United States of America

WEEE: Waste electrical and electronic equipment

CHAPTER 1

INTRODUCTION

Industrial waste can be classified in two main categories as hazardous and non-hazardous waste. Hazardous industrial wastes are dangerous to environment and to human health due to their properties such as corrosivity, toxicity, ignitability, reactivity, etc. If hazardous industrial wastes are not managed properly, they may lead to contamination of groundwater, surface water, soil and even air. Remediation cost is very high. In addition to high cost of remediation, emission of toxic gases, explosion risks, loss of lives and deterioration in ecosystem are other concerns (Gidarakos & Aivalioti, 2012). Therefore, industrial waste management has a vital importance worldwide. The amount of industrial waste produced each year has been increasing. According to the data provided by Turkish Statistical Institute, totally 16,267,000 tons of industrial waste was produced in 2016 (Turkish Statistical Institute, 2019).Industrial waste production increased by 30% in total between 2008 and 2016.

Management of industrial waste is a legal obligation in most of countries. Manufacturers should handle their waste by themselves or they can use licensed companies for collection and disposal (Koolivand et al., 2017). Manufacturers in Turkey are obliged to manage their waste as specified in the Waste Management Regulation that was amendment on March 23, 2017 (Republic of Turkey Ministry of Environment and Urbanization, 2017).

Manufacturing industry ranked the second in Gross Domestic Production (GDP) with a share of 16.6% and service sector ranked the first in GDP with a share of 21.2% in 2016 in Turkey (Ministry of Customs and Trade of the Republic of Turkey, 2018). Although, manufacturing industry has a large contribution to Turkish economy, waste originating from the industry should be examined in detail due to the relatively higher size of the sector. Turkey is the second ranking household appliances manufacturer in the world, and the leader manufacturer in Europe (Vakıf Yatırım Menkul Değerler A.Ş., 2018). The sector is important for the national economy. Yet, the sector contributes to industrial waste production as well.

Ismail and Hanafiah (2019) reviewed 61 Life Cycle Assessment (LCA) studies related with Waste Electrical and Electronic Equipment (WEEE) published since 2005 and only six of these studies were related with refrigerator and freezer. Foelster et al. (2016) and Xiao et al. (2016) focused on LCA studies on refrigerator recycling, while Baxter (2019) focused on recycling and reuse scenarios for refrigerators. Xiao et al. (2015) evaluated production, transportation, usage, and disposal within the system boundary of LCA. This study included solid waste generation during production, but only waste steel, epoxy resin, high impact polystyrene and polyurethane were evaluated within the scope of solid waste. In the studies in literature, there are gaps in the examination of waste produced in production of refrigerators. To fill these gaps, first an inventory of the wastes originating from refrigerator and freezer production should be made which is lacking in literature.

In this thesis, a refrigerator and a freezer manufacturing plant in Turkey was examined with respect to inventory of wastes originating from production. 5-year waste data was classified and its relationship to waste production was analyzed. The focus was on the production stages of refrigerators. All hazardous, non-hazardous and packaging wastes arising from production were identified and evaluated. The Company's environmental performance was evaluated in terms of waste intensity and waste recycling rate and compared to other household appliance manufacturers. When reports published by companies in the household appliances sector were examined, it was seen that increasing waste recycling rates, not sending the waste to a landfill, reducing hazardous wastes, reducing waste intensities were the main objectives to improve environmental performance on waste management (Electrolux, 2018; Whirlpool Corporation, 2018; Philips, 2018; LG Electronics, 2019; Samsung

Electronics, 2019; Miele, 2019; Bosch, 2018). Processes/departments of refrigerator production plant that contributed the most to scrap waste generation were determined. Relevant best available techniques (BATs) and literature studies were examined to make suggestions to reduce waste generation in processes. The contribution of this thesis to the literature is to provide a comprehensive qualitative and quantitative inventory of waste generation in refrigerator production and make suggestions for waste reduction.

CHAPTER 2

LITERATURE SURVEY

2.1. Household Appliances Sector

Furniture, household appliances and home care services are classified as a group in household consumption expenditures. The share of the group is 6.3% in 2017 and 6.8% in 2018 according to the distribution of household consumption expenditures statistics provided by TUIK (Turkish Statistical Institute, 2019). There is a strong relationship between the consumption-based household appliances sector and the performance of the national economy. When the data of the last 10 years is examined, there is a 0.7x correlation between the growth in the sales of household appliances and the GDP on a 5-year average (Vakıf Yatırım Menkul Değerler A.Ş., 2018). China has become the world leader in the household appliances sector by producing half of the household appliances produced in the world. Turkey is following China, ranking the second in household appliances sector worldwide. Turkey is the largest household appliances manufacturer in Europe (Vakıf Yatırım Menkul Değerler A.Ş., 2018). Turkey is followed by Brazil, United States of America (USA) and Poland in the sectoral rankings. England, France, Germany and Italy are other important producers in household appliances sector. While worldwide household appliances market grew at an average annual growth rate of 1.5% between 2012 and 2017, household appliances market in Turkey grew by 6% annually during this period (Vakıf Yatırım Menkul Değerler A.Ş., 2018). According to the data given by the Association of Household Appliances Manufacturers of Turkey (TURKBESD), the number of household appliances produced in Turkey in 2018 was 28,538,758 and this production number increased by 26% since 2014 (TURKBESD, 2019). TURKBESD represents nearly 90% of the household appliances production sector in Turkey. Refrigerators, freezers, dishwashers, dryers, washing machines and ovens are the main product groups of the household appliances. 30.2% of the total household appliances production in 2018 was for refrigerators and freezer production (TURKBESD, 2019)

2.2. Explanation of Refrigeration Cycle and Refrigeration

Some of the basic terms and the overall system of a refrigeration cycle must be explained to understand why some components and processes are used in refrigerator manufacturing. Refrigeration is the process of removing heat from substances to decrease their temperatures below ambient temperature (Danfoss, 2007). It has been used to conserve food for longer periods of time since older times. Chinese people discovered beverages can survive for longer time if their temperatures were kept lower than the surrounding ambient. They used ice, water and air as refrigerants (Danfoss, 2007). Since chemical and biological reaction rates are decreased, the loss of the nutrition of foods becomes less under low temperatures. Generally, temperatures should be around 0°C to 4°C (Cengel, 2011). Also, the growth of microorganism decreases under low temperatures. Due to less bioactivity in cooled foods, the shelf-life of produce becomes longer. Figure 2.1 shows how the growth-rate of bacteria is affected by low temperatures (Danfoss, 2007).

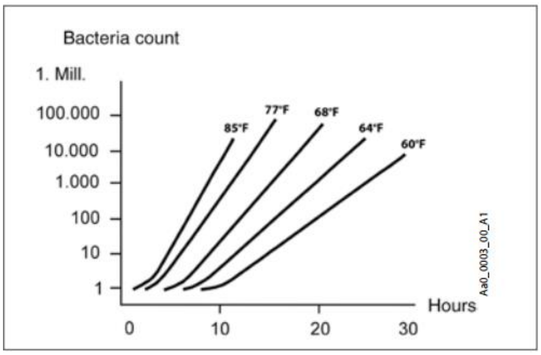

Figure 2.1.Time-based bacteria growth in different temperatures (Danfoss, 2007)

In modern days, refrigerators are being used for cooling work. Figure 2.2 shows the principle of the vapor compressed refrigeration cycle. The refrigerator takes heat from the cold space inside of the refrigerator and through a refrigeration cycle ejects the heat to outer surrounding (Cengel & Boles, 2015).

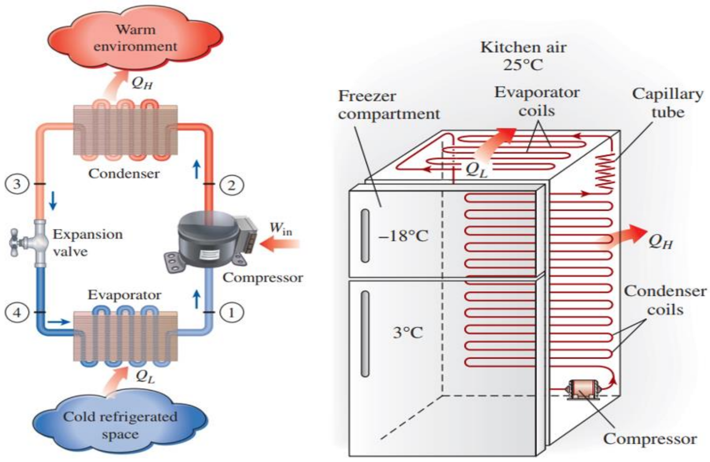

Figure 2.2. The basic refrigeration cycle in schematic, and basic refrigerator schema (Cengel & Boles, 2015)

The refrigeration cycle consists of following works (Cengel & Boles, 2015);

- The refrigerant fluid is pressurized by a compressor. During this process the fluid heats up to a temperature higher than the surrounding,
- In the condenser, heated and pressurized refrigerant gives heat to surrounding and condenses,
- The refrigerant in the condenser enters a receiver. The receiver collects the condensed liquid refrigerant. At this stage, the liquid refrigerant has a higher pressure than the pressure inside of the evaporator.
- Condensed liquid enters a capillary tube or an expansion valve during this process. The temperature and pressure of the refrigerant decrease

just below the boiling point. The capillary tube has a smaller diameter than the diameter of the condenser.

- The fluid inside the entrance of the evaporator is at a stage in which a small amount of heat changes the state of the refrigerant into vapor. While the refrigerant changes its state, it takes the heat from surrounding of the evaporator tube. Thus, the materials inside the refrigerator cool down. The refrigerant at the exit of the evaporator becomes vapor.
- The vapor enters the compressor and cycle finishes.

The following figure (figure 2.3) shows both system and pressure-enthalpy changes during the process (Danfoss, 2007). In Figure 2.3, the dark shaded areas show the liquid phases of the refrigerant, lighter areas show the gaseous phases of refrigerant. The figure sums up the process of the refrigeration cycle previously explained. The condenser and evaporator temperatures are “tc” and “t0” respectively (tc>t0). The pressure inside of the condenser and the evaporator are PC and P0 respectively. And the h’s in the table shows the enthalpy change of the refrigerant.

The letters from A to E are the stages of the refrigeration cycle. They are given below;

- E-A: Condenser;
- A1: Pressure exit of the condenser;
- B: Exit of the expansion valve;
- C: Evaporator;
- C1: Pressure exit of the evaporator;
- D: Pressure entrance of the condenser;

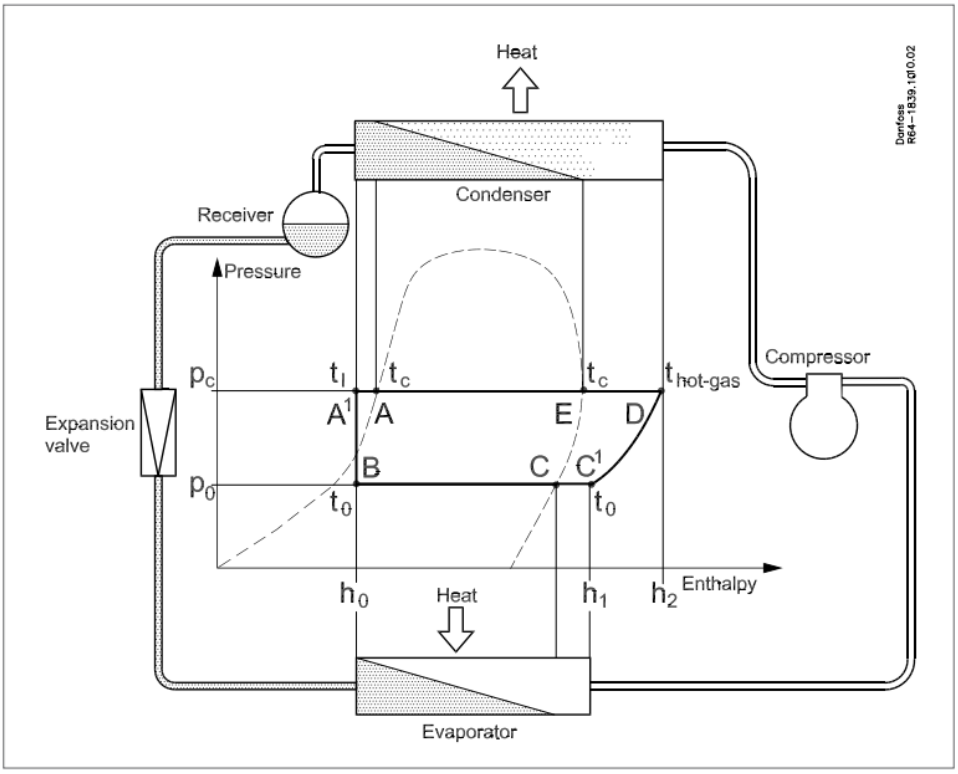

Figure 2.3. Temperature-enthalpy graph over refrigeration system schema (Danfoss, 2007)

2.3. Components and Manufacturing Processes of the Refrigerator

2.3.1. Compressor

Compressor is used to create pressure differences inside the refrigeration system with the help of a capillary tube. The compressor sucks the refrigerant from the evaporator side and pressures the refrigerant to a condenser. With this way, the refrigerant changes its stages at required temperatures. For household applications, the compressor must be hermetically sealed to keep the refrigerant gas inside the system. Mostly the piston type compressor is used in the industry (Danfoss, 2007). This type of compressors uses the technique called scotch-yoke or slider crank mechanism. The scotch-yoke mechanism translates the rotational movement on the crankshaft that is created by an electrical motor to translational movement of the compressor piston

(Rasmussen, 1997). Thus, it has moving components which needs to be lubricated. Therefore, oil is used on the bearing of these components (Danfoss, 2007).

The compressor is one of the heaviest parts of the refrigerators. The compressor contains iron, cast alloy and copper materials. Nearly %15 percent of the compressors are made of cast iron (Proklima, 2018). The iron is the most used material in a compressor. The main parts like crankshaft, crankcase, stator, rotor, as well as the outer shell that seals the compressor from outer surrounding are made of iron. The motor (rotor + stator) generally consists of steel plate and the copper wires (in some applications for a cheaper solution aluminum wires may be seen). Also the outer shell of the compressors is made of thick steel plates (Rasmussen, 1997). Figure 2.4 shows the schema of the hermetically sealed compressor which is generally used for home applications.

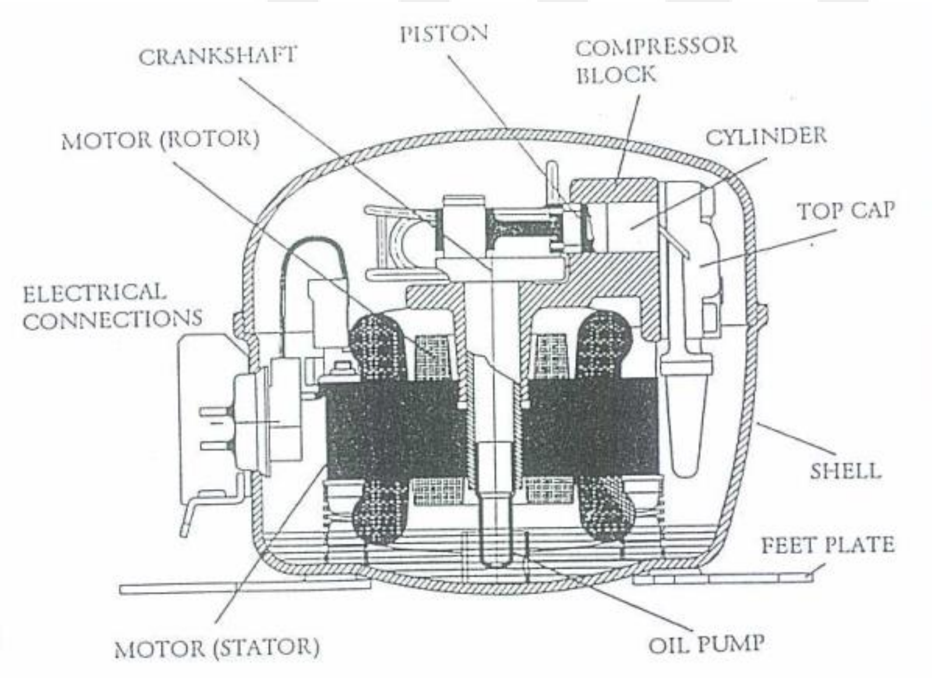

Figure 2.4. The components of a general compressor (Rasmussen, 1997)

2.3.2. Condenser

The object of a condenser is to reject the heat from the heated refrigerant to external domain. During this operation, pressurized refrigerant gas losses heat and condenses to a liquid form. There are two general types of condensers in refrigeration appliances. These are statically cooled and fan cooled condensers. For larger refrigerators, the fan cooled condensers are necessary to keep the condenser size at normal limits. The forced condensers will increase the heat transfer compared to static condenser type (Secop, 2016). The static cooled condensers usually consist of metal wires while the fan cooled (forced convection type) condensers usually consist of fins to improve the heat transfer (Secop, 2016). The basic drawings of the condenser types can be found in the Figure 2.5. The fins on condenser units are usually made of steel or aluminum. The condenser tubes are also generally made from steel (Secop, 2016). But in some cases the condenser tubes can be made from copper to improve heat transfer performance (Indian Institute of Technology Kharagpur, 2008).

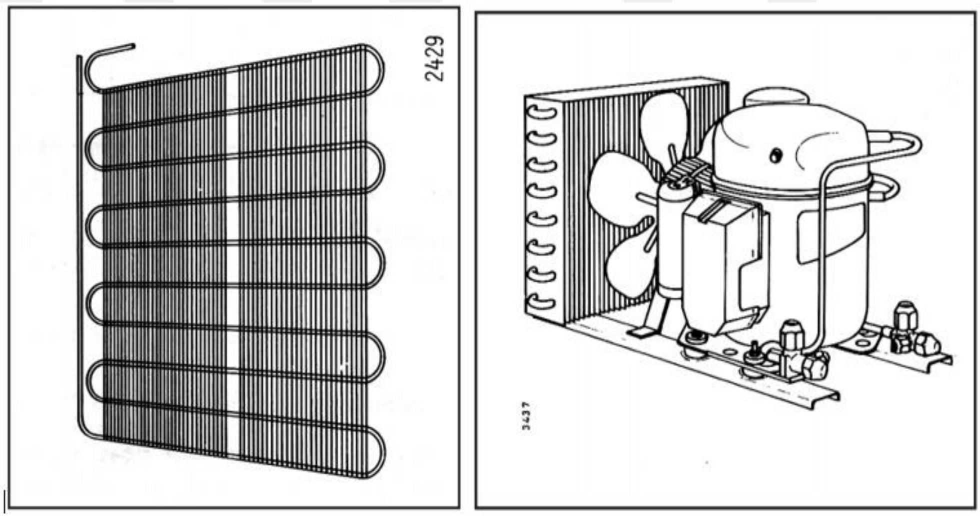

Figure 2.5. (a) Static type condenser on wire; (b) Fan cooled condenser unit with fins (Secop, 2016)

2.3.3. Evaporator

The evaporator has a similar design with a condenser. Both have mostly steel and serpentine shape tubes. From the capillary tube or expansion chambers, the low pressured saturated liquid enters the evaporator. The main purpose of the evaporator is to take heat from the substances inside the domain by evaporating the liquid refrigerant. The tubes can be brazed to aluminum sheets with internal channels. Also, to improve the performance of the evaporator, both fins and fans are also used by the refrigerant manufacturers. The fins can be aluminum or steel (Mascheroni & Salvadori, 2005).

2.3.4. The capillary tube and expansion chambers

The pressure difference between high and low-pressure sides is usually created by capillary tubes or expansion valves. The capillary tube is a simple tube with smaller inner diameter. The capillary tube is enough component for simple refrigerators. For more energy efficient refrigerators, the evaporator and condenser pressures need to be controlled. Capillary tubes are not sufficient to control a pressure difference, therefore, in more energy efficient applications, expansion valves are used (Mascheroni & Salvadori, 2005).

2.3.5. Refrigerant

The refrigerant provides the heat transfer in a refrigeration cycle. The refrigerant gives heat at high temperature, high pressure and collects heat at low temperature and low pressure. Phase of refrigerants changes during cycles. A refrigerant is mainly preferred for its low condensing pressures due to construction limits of a refrigerator structure. The higher condensing refrigerants can result in use of more construction material to build a robust system (Wang, 2001).

During the historical development, many hydrochlorofluorocarbons (HCFC) and chlorofluorocarbons (CFC) were tested and used as refrigerants in different fields of refrigeration industry. In time order, trichloromonofluoromethane (R-11) and dichlorodifluoromethane (R-12) were the industry dominants which were replaced with tetrafluoroethene (R134a) due to their high ozone depletion potential (ODP). The R134a is not very efficient at low evaporating temperatures compared to R12 and it needs synthetic compressor oil for lubrication. In addition to its efficiency problems, R134a also has a high Global Warming Potential (GWP) with 1300 CO2eq/kg. In Europe, especially Northern Europe and developing countries, R134a has been replaced widely with a hydrocarbon (HC) refrigerant called as isobutane (R600a). R600a has better energy efficiency but it is flammable. In addition to its efficiency, it has 0 ODP and a GWP lower than 20. Also it needs less refrigerant charge in grams for a refrigeration system compared to R134a (Mascheroni & Salvadori, 2005; IPCC, 2014; Hastak & Kshirsagar, 2018; Wang, 2001).

2.3.6. Insulation

There is an inevitable heat gain caused by temperature difference between outer surrounding and refrigerator inner cabin. Insulation is necessary for domestic refrigerators to reduce thermal losses. The main thermal insulation for a refrigeration system is a polymer called as the polyurethane. In addition to the insulation property of polyurethane foam, it gives the structural rigidity for refrigerator cabinets. Polyurethane is produced by reaction of di-isocyanate or polyisocynate and polyol (Dutta, 2018; Tantisattayakul et al., 2018). To form foam, polyurethane polymer is blown by blowing agents (European Plastics Industry, 2005; Singh, 2002).

Usage of the blowing agent started with CFCs such as trichlorofluoromethane (CFC-11) and di-chlorodifluoromethane (CFC-12) (Singh, 2002). CFC-11 was frequently used by polyurethane industry. CFC usage is banned in developed countries by the Montreal Protocol because of their ozone depleting properties (United States Department of State, 2019). CFC-11 has an ODP of 1 and a GWP of 4,750 CO2eq/kg. CFC-12 has an ODP of 1 and a GWP of 10,900 CO2eq/kg (WHO, 2015; UNEP, 2019). Cyclopentane started to be used in polyurethane production for blowing process with near similar thermal conductivity and low toxicity. Cyclopentane has zero ODP and low GWP with 11 CO2eq/kg (Helling & Parenti, 2013). Cyclopentane has good performance and environmental advantages but it has flammability in air (Mascheroni & Salvadori, 2005;R. S. Agarwal & S. Roy, 2002).

2.4. Refrigeration Production Wastes

Yılmaz et al. (2017) studied hazardous wastes production in household appliances sector and proposed a sectoral waste management guidance document. Yet, the focus was only on hazardous wastes which are classified as process-specific and non-process wastes in the guideline. Wastes that match the process specific wastes in the list obtained from Yılmaz et al. (2017) are waste chemicals occurred in polyurethane formation and waste hydraulic oil. Wastes that match to non-process wastes in Table 2.1 is provided by Yılmaz et al. (2017).

Table 2.1. Non-process wastes (Yılmaz et al., 2017)

Waste Code	**Description**
15 01 10	packaging contaminated with hazardous materials
15 01 11	empty pressure containers
15 02 02	contaminated waste
16 02 13	discarded components/equipment which contains hazardous material
16 02 15	hazardous components removed from discarded equipment
16 06 01	lead batteries
18 01 03	medical wastes
20 01 21	fluorescent tubes and other mercury-containing waste

Studies related to non-hazardous waste and packaging wastes originating from refrigerator manufacturing are lacking in the literature. Therefore, a complete inventory of all wastes originating from production does not exist, which may be required for waste management in total quality approach. This thesis, therefore will contribute to literature by identifying all types of wastes.

Moreover, this study focuses on the production of refrigerators instead of whole household appliances sector.

Non-hazardous wastes originating from the refrigerator manufacturing process are mostly expected to be derived from discarded components and materials. Packaging wastes mostly arise from protective packaging of materials from sub-industry or suppliers. Hazardous wastes of refrigerator manufacturing process originate from waste oil, packaging contaminated with hazardous materials, discarded components/equipment which contains hazardous material, hazardous components removed from discarded equipment, contaminated waste, waste chemicals occurred in polyurethane formation, and sludge.

2.5. Material Composition of Refrigerators

Eschborn, (2018) states that steel material, compressor, plastic material and polyurethane material contributes most to the weight of refrigerators in Europe with a total of 92% of the total material composition. 91.64% of refrigerators are made of steel (including stainless steel), plastic, polyurethane foam, and glass as provided by the European Committee of Domestic Equipment Manufacturers (CECED) which represents domestic appliances industry in Europe (Magalini et al., 2018). Baxter (2019) indicates that 94.1% of the weight of a refrigerator originates from steel, plastic, polyurethane foam, and glass. According to the Japanese Electrical Manufacturers Association (JEMA) (2014), 79.1% of the weight of originates from steel and plastic materials. Table 2.2 shows the percentage of the materials used in refrigerator production in four studies. As can be seen in Table 2.2, plastic and steel have large percentages in material composition of refrigerators.

Table 2.2. Average material composition of refrigerators

Material Types	Magalini et. al (2018)	JEMAI et. al (2014)	Baxter (2019)*	Eschborn (2018)
	%	%	%	%
Aluminum	2.18	0.90	2.20	-
Copper	2.23	1.70	3.60	-
Non-ferrous material	-	-	-	5.00
Electronics	1.02	-	-	-
Glass	7.97	-	10.10	-
Plastics	23.39	39.70	19.70	16.00
Polyurethane Foam	12.39	-	14.70	10.00
Stainless steel	1.04	-	-	-
Steel	46.85	39.40	49.60	43.00
Electronic Circuit Board	-	0.50	-	-
Compressor	-	-	-	23.00
Others	2.93	17.90	0.10	3.00

*Material composition data are given for one kilogram in Baxter (2019). The data is converted to percentages for comparison with other studies

The material composition of the refrigerators has changed and will continue to change depending on supply and demand, production cost, research and development studies. Examples of this change on polyurethane foam, electronic component, plastic material and steel material are given by CECED. The polyurethane foam used in refrigerator panels rose from 10% to 12% to increase energy efficiency of refrigerators by improving heat transfer losses. Electronic components used in refrigerators rose from 0.2% to 1.0% with developing technology. Plastic material usage increased from 6.8% to 23.4%. The reasons of increasing plastic material usage and replacement of steel with plastic in production are to improve production flexibility and reduce refrigerator production costs (Magalini et al., 2018). CECED indicates that 2.8 megatons steel, 1.14 megatons plastics, 0.35 megatons copper, 0.33 megatons stainless steel, 0.24 megatons aluminum, 0.28 megatons glass were used in household appliances sector in 2016 (Magalini et al., 2018). Considering the worldwide use of materials in European Union household appliances sector, the shares of steel usage, plastic usage, copper usage, aluminum usage are 0.2, 0.5, 1.2 and 0.5, respectively, as shown in Figure 2.6.

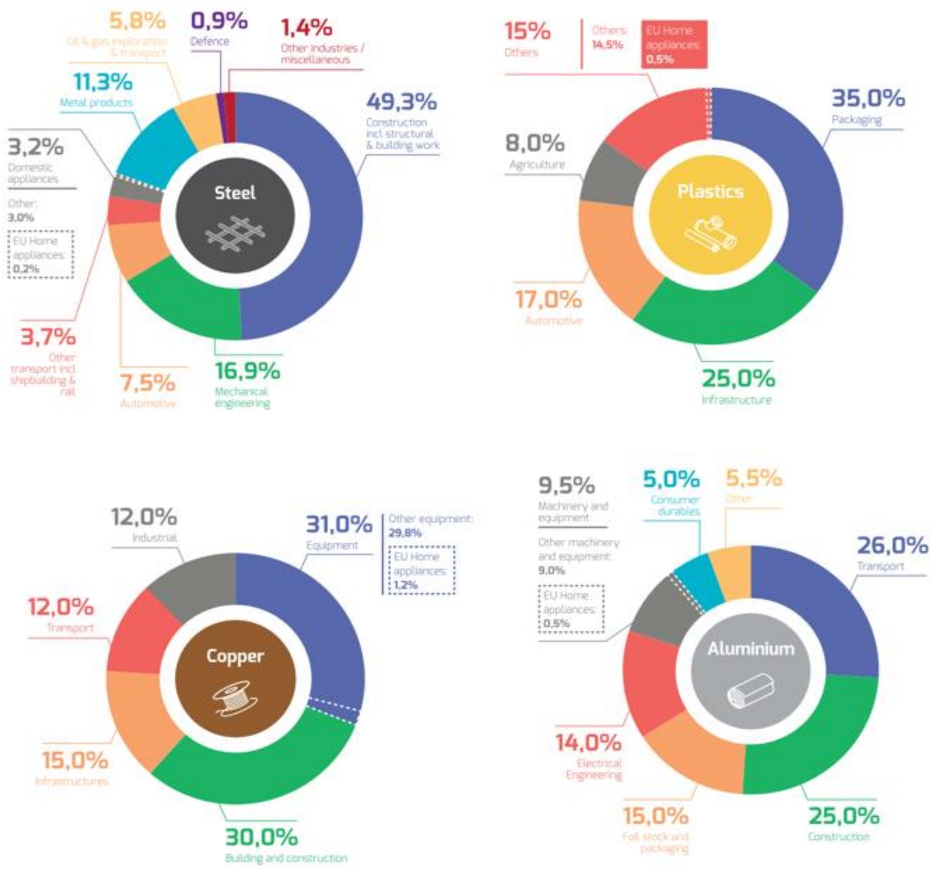

Figure 2.6. Worldwide use of materials in European Union (Magalini et. al, 2018)

2.6. Industry based waste management approaches

In the following sub-sections, industrial waste management examples are given. It can be noticed that every company listed below has an approach to manage its waste within the context of circular economy, zero waste etc. The common purpose is to reduce the waste related to a process. Some companies use approaches directly related to production, while some adopt the waste reduction approach to include all activities. Some companies are focusing on total waste whether non-hazardous or hazardous, while others are only interested in non-hazardous wastes. Although below examples are not related to refrigerator manufacturing, they provide information on the benefits of industrial waste management and circular economy. Studies relevant to refrigerator manufacturing do not exist in literature. Most of the studies for the sector consider waste management for refrigerator disposal following usage (Ismail & Hanafiah, 2019 ; Proklima, 2018; Kim et. al., 2014; Foelster et al., 2016; Lee et al., 2017; Xiao et al., 2016; Li et al., 2019; Deng et al., 2008; Nicol & Thompson, 2007; Baxter, 2019; Menikpura et al., 2014; Wath et al., 2011; Ruan et al., 2017; Chung et al., 2011). Below examples constitutes of brief highlights of what have been done to achieve waste management goals.

2.6.1. Coca-Cola

According to Song et al.. (2015) packaging is a step possessing a good potential for waste minimization and management. Companies are producing new packaging with less material through new technologies to provide similar protection. Thus, they are producing less waste. The Coca Cola Company had made some improvements on packaging of their products (Song et al., 2015);

- 600 ml plastic bottle is trimmed by 25%,
- The weight of the 33 cl coca cola Al can is reduced to 70%,
- The weight of the 25 cl glass bottle is reduced 50%

Coca Cola reports that from all the improvements on packaging, they made a total savings of 180 million dollars in 2011 and 2012 (Song et al., 2015).

2.6.2. Subaru

Subaru claims that in their manufacturing site in Indiana/USA, 96% of the waste produced was recycled or reused. They recycled or reused around 25,000 tons of scrap metal, roughly 1500 tons of cardboard and paper and 75 tons of wood in 2010 (Subaru, 2010). According to Song et al. (2015), Subaru obtained these achievements from following practices;

- They are shipping the copper slug from welding operations for recycling in Spain,
- The styrofoam that covers critical engine parts are sent back to Japan to reuse in next shipments,
- Every plastic part is collected and melted to reuse.

2.6.3. DuPont

DuPont figured out new approaches to recycle the materials from the Corian Site in 2012. Some of the significant ones are listed in Table 2.3.

Table 2.3. Example of recycled materials in DuPont (Song et al., 2015)

Material	**Recycled form/or Method**
Carrier films	Glue manufacturing
Bandings	Melted to same
Pallets	Repaired
Scrap wood	Animal bedding
Paper & cardboard	Recycled to same

2.6.4. Toyota

Toyota started its zero-waste policy in 1990s. Two of the Toyota factories in North America became zero waste factories in 2003. As Toyota stated, they have adopted the principle of “doing more with less” (Toyota, 2018). Accordingly, 98% of the waste originating from operations was recycled in 2018 and 560.24 thousand m^3 of water was recycled or reused. In their environmental report they are explaining some of their practices to manage the waste at 98% recycle rate.

The practices followed by the Toyota are listed below (Toyota, 2018);

- In the Indiana factory of Toyota, for one of the models being produced, they managed to save around 11,000 kg material from the underbody water preventive spray operations. This was done just by detailed investigation of which parts should be sprayed to provide protection.

- Toyota uses scrap clothing parts from industrial post processes which are made of cotton or synthetic fiber as silencer or insulation in various parts of their vehicles.
- In four of their models, they are using bio-based plastics for seats.
- The reusable containers that they used for shipment of associated models are recycled in one of the Toyota's Supplier in Canada when the model was decommissioned. This way, the old containers were not sent to landfills.
- Toyota recycles the windshields damaged in processing in a recycling facility in North America,
- Toyota was wasting 689 kg of sealer, which was hazardous, in their Mexico Plant. However, they managed to save the sealers by putting a pump at the bottom of the sealer container.
- Toyota has plans for future to track all returnable containers by placing chips on containers. Toyota plans to reduce containers that are lost in transportation.
- Toyota Japan plans to use new magnets with materials that are not produced from rare materials. They are planning to produce new magnets for their high-performance electric motors vy lanthanum and cerium instead of using rare material neodymium.

2.6.5. General Motors

As of February 2018, General Motors (GM) increased the number of facilities implementing "zero waste to landfill " policy in 142 plants (General Motors, 2018) According to sustainability report of GM, they aim to increase this number to 150 by 2020 (General Motors, 2019). In addition to this, GM processed 84% of the waste from production using composting, reuse and recycling methods. When GM started to apply zero waste to landfill policy, they invested roughly 10 dollars to reduce 1 ton of waste (General Motors, 2018).

Following practices were used (General Motors, 2018);

- GM used recycled cardboards to create acoustic noise insulators inside the vehicle cabins.
- GM used the oil that spilled in Gulf of Mexico to make some of the plastic parts in one of their models,
- GM recycled pallets to make the wood beams which can be used in building constructions.
- GM collected plastic bottles from some of the GM's locations to turn the plastic bottles into acoustic insulators for engine compartments.
- GM used the recycled plastics from consumer products to make the air deflectors used in GM's vehicles.
- GM started to design parts with lightweight concept which made their production more efficient and reduced the waste amount per product.
- GM took the battery covers in their electric models to make shelters for birds.

2.6.6. Unilever

As Unilever conveys, they have achieved zero waste at least in 600 sites globally. These sites are not just factories. They also adopt their vision in zero waste in their offices and centers. Unilever focused on non-hazardous wastes. They adopt the approach of 4Rs (reuse, recycle, recover, reduce). They plan to have zero waste in all their supply chain to meet the circular economy model as EU describes. Unilever also conveys that these efforts have saved 200 million euros so far (Unilever, 2016). The goal of doing more and better with less is also adopted by Unilever. This approach not only decreased the waste but also increased the business efficiency. According to Unilever, they have produced %37 less waste in 2018 than 2008 (Unilever, 2019). Practices applied by Unilever are listed below;

- As other companies applied, they also used reusable pallets and containers so that they are producing less waste for transportation (Unilever, 2019).

- Unilever changed their plastic containers with reusable steel ones so that they decreased the amount of plastic waste produced in a factory in Italy (Unilever, 2019).
- To ensure damaged products are not shipped, Unilever used machines for separation of damaged products. This way Unilever can recycle them in a factory in Russia (Unilever, 2019).
- Unilever gave away their used cardboard boxes for reuse for other purposes like house moving. This way Unilever reduced 10% of their waste related to cardboard boxes (Unilever, 2019).
- Unilever gave away their soaps that did not meet their quality standards to companies which use them for car washing (Unilever, 2019).
- Unilever uses the used drums and waste pallets to make garden furniture (Unilever, 2019).
- Unilever sent some of their waste to a cement factory as an alternative fuel in kilns(Unilever, 2019).
- In an factory in Italy, they switched from card boxes to reusable bags to transport the raw material used in making of ice creams (Unilever, 2019).
- Unilever returns waste soil from vegetables to farmers for usage in fields that grows the same vegetable (Unilever, 2019).
- Unilever Turkey plans to reduce packaging waste by one third till 2020 (Unilever, 2012)
- Unilever Turkey switched from 2-layer cover design to 1-layer cover design for their packaging of the shampoos and hair conditioners. The factory saved 55 tons of material by this practice (Unilever, 2012).
- Unilever TR saved a total of 577 tons of packaging material in 2012 with improved packaging solutions (Unilever, 2012).

2.6.7. Procter & Gamble (P&G)

P&G names their waste management approach as "Zero Manufacturing Waste to Landfill". P&G plans to produce less than 0.5% of waste from the processes by 2020 (Procter & Gamble, 2019). For future, P&G plans to have zero waste both from manufacturing and post-consumer usage. P&G conveys that the company plans to create robust guidelines for every process to have a sustainable zero waste approach (Procter & Gamble, 2019). According to The Guardian, 45 of the P&G factories are zero waste factories. The waste materials produced from processes are reused, recycled or transferred into energy by a ratio of 99% (Sadhbh Walshe, 2013). P&G plans to achieve the zero waste by making their products either recyclable or reusable. For that mission they are producing innovative solutions from packaging to material selection. According to P&G, 86% of their product packaging is recyclable. Their challenge is to have 96% of the packaging recyclable by 2020 (P&G, 2019).

The practices followed by P&D are listed below;

- By switching to biodegradable materials in their razor packaging, plastic usage is decreased by 57% (Sadhbh Walshe, 2013).
- After recycling process of scrap paper, P&G is producing surplus fiber in one of their factories in Latin America. These surplus material are turned into cheap roof tiles (Sadhbh Walshe, 2013).
- P&G uses the surplus materials resulted from shampoo production as fertilizer (Sadhbh Walshe, 2013).
- P&G produces the packaging of toilet papers from fully recyclable materials (P&G, 2019).
- In addition to making their packaging of the shampoo recyclable, they are using plastics recycled from beaches by 25% (P&G, 2019).
- P&G recycles the waste sanitary pads into absorbing cat litter (P&G, 2019).

CHAPTER 3

METHODOLOGY

The Company where the study was conducted at is one of the important refrigerator manufacturers in Europe. In the study, data relevant to produced wastes in the factory was taken from the Company. Then, refrigerator production processes, wastes originating from these processes, materials/semi products used in refrigerator productions, and refrigerators produced were examined on-site. Field observations and waste data obtained from the Company were compared in data screening. After data screening, necessary corrections were made on the information received from the Company, such that inaccurate data recording were corrected. Wastes were then classified as hazardous, non-hazardous and packaging wastes. Subclassification of these three waste groups was made as process waste and non-process waste. Waste classification and waste data were combined to create a waste inventory. In addition to creation of waste inventory, mass balance study was conducted. Observation from field study and screened data were combined to do a mass balance for the production area of the Company. Results of mass balance study were used in environmental performance evaluation. Besides mass balance results, results of waste inventory calculations were used to evaluate environmental performance. Scrap cost calculation was another step of the study. Scrap cost was calculated independent of the mass balance study and environmental performance evaluation. Data related with scrap was used to do this calculation. The aim of scrap cost calculation was to see the production processes that contributed the most to scrap production. Finally, BATs were investigated to improve environmental performance of the Company, which could be useful for other household appliance companies as well. The schematic of the methodology used in the study can be seen in the Figure 3.1

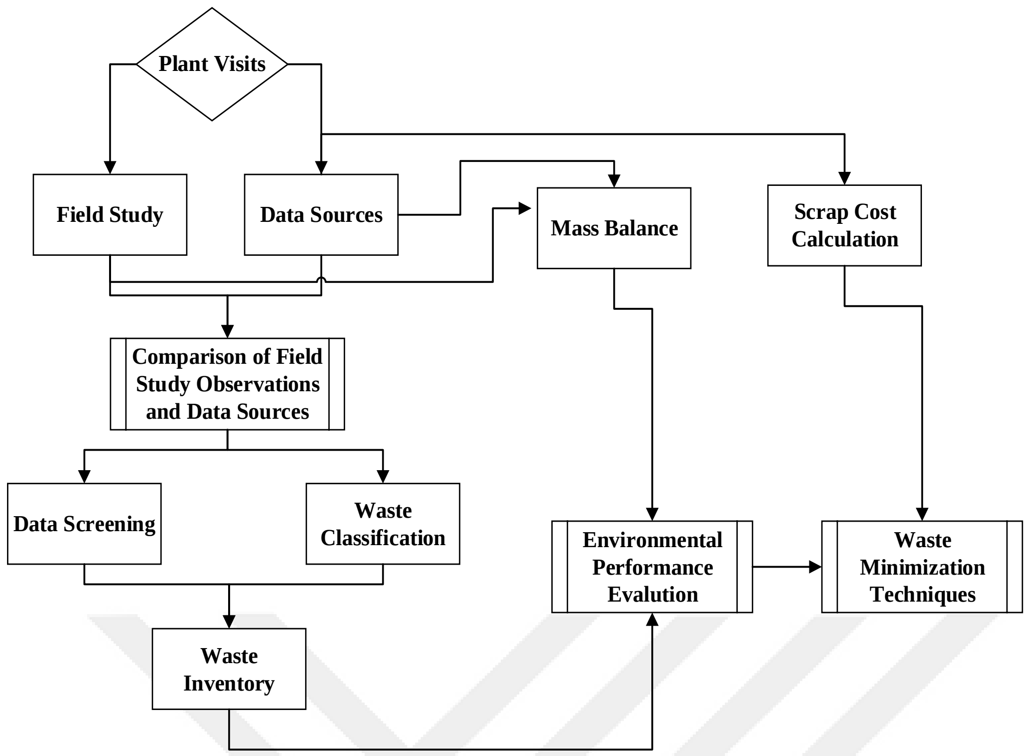

Figure 3.1. The schematic diagram of the methodology

3.1. Data sources

Waste declarations to MEUP have been made by the company within the scope of Waste Management Regulation (Çevre ve Şehircilik Bakanlığı, 2015). Declaration is consisted of waste code, waste name, waste oil category if there is a waste oil, quantity generated (kg/year), waste recovery and disposal code, name of the waste processing plant/municipality that received medical waste/exporter. Hazardous waste (including vegetable oil and waste oil), non-hazardous waste, packaging waste and medical waste were in the declarations made. Waste data in the records of refrigerator and freezer production plant was obtained from the company that showed the figures for the period between 2015 and 2018. The waste records included waste sending date (day-month-year), waste code, waste name, quantity generated (kg), recovery and disposal code, financial gain and expenditure (in TL), name of the licensed waste processing plant. Only for 2014, financial gains and expenditures were missing for hazardous waste in 2014. As a result, for this parameter, only 4 years of data is available spanning the period between 2015 and 2018. Figure 3.2, shows the general system inputs and outputs. Materials that are used for refrigerator production are the inputs and outputs are the waste generated by production and final product put in the market.

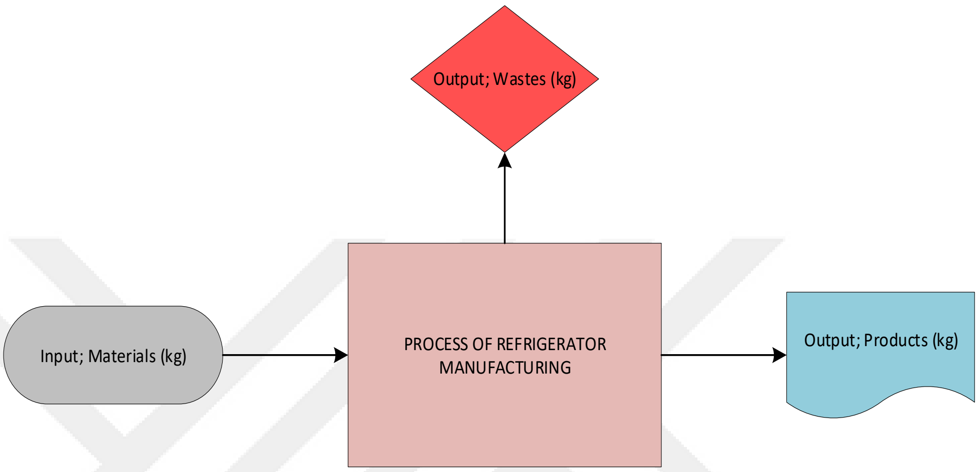

Figure 3.2. Mass balance of refrigerator production

Data of production units wastes and materials for 4 years including 2015, 2016, 2017, and 2018 were obtained. The number of productions of each model, weights of used materials, weights of refrigerators for each model were obtained through the System Applications Products (SAP)- Enterprise Resource Planning (ERP) program. The ERP is a business management software which controls business processes in real time. The ERP system keeps the records of the raw material amounts, production numbers, material information etc. It is a continuously updated system.

3.2. Field Study

The company mentioned in the thesis is one of the biggest home appliance manufacturers in Europe. It has sales both in Europe and overseas market (South Africa, Far East, America etc.). The company produces vast variety of products in home appliance market ranging from small gadgets like vacuum cleaners to washing machines. In this study the refrigerator plant of the company was taken under inspection. The refrigerator production line of the company was examined to investigate the wastes at its sources and extract the information to do the inventory of the waste produced. The inventory of waste was used to find out the gaps existing in waste management of the company and suggest improvements.

There were several types of production methods used in the factory (like thermoforming, polyurethane foaming, etc.). The following steps were followed;

- Each production type was visited at production sites.
- For each production site, meetings were conducted with the responsible personnel.
- Processes were inspected, input materials and outputs (product, waste) were determined.
- For every operational step in each manufacturing process, process flow diagrams were generated including workflows and waste sources.
- Information gathered was used to separate wastes in process related and non-process related wastes and data screening was performed. A mass balance was conducted to quantify the amount of wastes produced.

In this thesis, information that will eliminate the anonymity of the company name, company-specific projects/processes and waste amount per unit product of the Company are not provided due to confidentiality.

3.3. Data Screening

The waste inspected (as mentioned in Section 3.1) and the list of waste codes taken from the company were compared with the waste codes specified in regulations. Screening was applied as some of the waste data misleading and hard to interpret as given in following cases;

- During examination of the data it was realized that the chemical wastes from polyurethane foaming process were recorded under different waste codes as 07 02 14 and 08 05 01 in different years. This variation in waste codes was corrected to have a better statistical analysis and mass balance calculation. Thus, the waste amount of 07 02 14 and 08 05 01 coded wastes were combined for 5 years of the data.
- The accumulator and battery wastes were recorded under different waste codes year by year. These codes were also combined in one code for each waste type.
- Some wastes were formerly classified as hazardous waste was analyzed by the Scientific and Technological Research Council of Turkey (TUBITAK) according to Annex-3/B of the Waste Management Regulation and the results showed the waste were non-hazardous. This resulted in disorder of the classification data for the wastes. In this study, data of mentioned waste was interpreted according to the current classification for all 5 years.
- Some of the waste produced by the company was not related to refrigerator manufacturing process. Thus, the data belonging to these wastes originating from other facilities of the company were excluded from the study.

Following data screening, waste classification was performed.

3.4. Waste Classification

Waste classification is done according to the list in Annex IV of the Waste Management Regulation that complies with the Commission Decision 2014/955/EU (European Parliament and Council, 2008). Waste codes are given as six digits codes in the list. The list of waste data obtained from the company was inspected at stations where it was produced. The mistakes were noticed in the list of data due to miss matching of the waste code and waste. The list of waste data was rearranged in accordance with the mentioned regulation.

As shown in the following Figure 3.3, wastes were inspected and grouped according to types of waste and process/non-process waste and waste related activity. The process wastes were defined as the wastes that were produced directly from the production process or the remainder of the materials used in the production process. For instance, chemical wastes produced during the polyurethane blowing operation were classified as the process waste. The powder paint waste generated from the powder paint operation was classified as process waste. The packaging waste of the hazardous materials, on the other hand, was classified as non-process waste. Waste codes used in classification of a waste as hazardous, non- hazardous, and packaging, and their explanations can be seen in the Table 3.1, Table 3.2 and, Table 3.3 respectively.

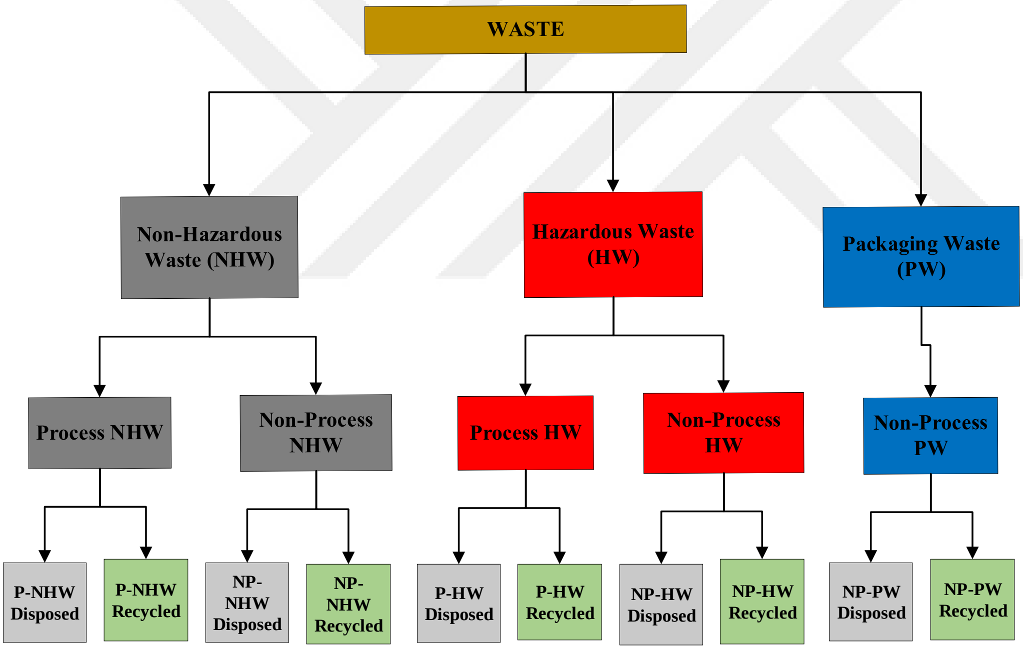

Figure 3.3. Waste classification tree

Table 3.1. Waste codes used for hazardous waste (European Parliament and Council, 2008)

Waste code	**Explanation of waste code**
07 02 14	wastes from additives containing hazardous substances
08 04 09	waste adhesives and sealants containing organic solvents or other hazardous substances
08 05 01	Waste isocyanates
13 01 13	other hydraulic oils
13 03 10	other insulating and heat transmission oils
13 07 01	fuel oil and diesel
13 07 03	other fuels (including mixtures)
15 01 10	packaging containing residues of or contaminated by hazardous substances
15 01 11	metallic packaging containing a hazardous solid porous matrix (for example asbestos), including empty pressure containers
15 02 02	absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances
16 02 13	discarded equipment containing hazardous components other than those mentioned in 16 02 09 to 16 02 12
16 02 15	hazardous components removed from discarded equipment
16 06 01	lead batteries
16 06 05	other batteries and accumulators
18 01 03	wastes whose collection and disposal is subject to special requirements to prevent infection
19 08 13	sludges containing hazardous substances from other treatment of industrial waste water
20 01 21	fluorescent tubes and other mercury-containing waste
20 01 26	oil and fat other than those mentioned in 20 01 25

Table 3.2. Waste codes used for non-hazardous waste (European Parliament and Council, 2008)

Waste code	Explanation of waste code
08 01 12	waste paint and varnish other than those mentioned in 08 01 11
12 01 01	ferrous metal filings and turnings
12 01 03	non-ferrous metal filings and turnings
12 01 04	non-ferrous metal dust and particles
12 01 05	plastics shavings and turnings
16 02 16	components removed from discarded equipment other than those mentioned in 16 02 15
17 04 01	copper, bronze, brass
17 04 07	mixed metals
17 04 11	cables other than those mentioned in 17 04 10
19 10 01	iron and steel waste
19 12 04	plastic and rubber

Table 3.3. Waste codes used for packaging waste (European Parliament and Council, 2008)

Waste code	Explanation of waste code
15 01 01	paper and cardboard packaging
15 01 02	plastic packaging
15 01 03	wooden packaging
15 01 04	metallic packaging
15 01 05	composite packaging
15 01 06	mixed packaging
20 01 01	paper and cardboard

3.5. Waste Inventory and Classifications

During the literature survey, no information was found about the waste inventory of the refrigerator manufacturing process. As a result, processes were examined one by one and wastes produced were identified to be able to suggest improvements in waste management. Following the retrieval of data from field studies, wastes were grouped under three main groups as hazardous, non-hazardous and packaging wastes. Total amounts of these wastes were calculated. Percentages of each waste type were calculated with respect to the total waste amount or the total weight in a given waste category. As a result, distributions of waste types were determined. Moreover, percentages or distributions of different waste types on a 5-year average basis were calculated for hazardous, non-hazardous and packaging wastes with respect to the total waste amount. The percentages of hazardous wastes with different waste codes with respect to the total hazardous waste amount in a given year were determined. This was conducted for non-hazardous and packaging wastes as well.

The frequency of waste generation recurrence within five years was calculated to determine whether the waste is a one-time waste or a continuous waste. Some wastes do not continuously occur due to following reasons; a closed facility, outdated materials or a waste that recently been taken into a recycling program. These types of wastes could mislead the numbers considered for waste management. Due to that, they should be excluded from calculations for waste management suggestions. In following sections of the thesis, the frequencies of waste occurrence will be used to decide on which wastes should be focused on to make waste reduction suggestions. The wastes that have the higher frequencies and amounts will be given priority in waste management suggestions.

Frequencies of wastes were calculated as given below.

$$F_W = N_r / N_{ty} \quad (1)$$

Where;

F_W = Frequency of waste (1/year)

N_r = Number of recurrences of waste within years

N_{ty} = Number of total years of given data (year)

Temporal variation in the percentages of waste sent to a landfill and waste recycle are determined as well using Equations 2 and 3, respectively.

$$P_l = (W_l / W_t) * 100 \qquad (2)$$

Where;

P_l =waste amount sent to landfill (%)

W_l = weight of waste sent to landfill (kg)

W_t = weight of total waste (kg)

$$P_r = (W_r / W_t) * 100 \qquad (3)$$

Where;

P_r = waste amount sent to recycle (%)

W_r = weight of waste sent to recycle (kg)

W_t = weight of total waste (kg)

3.6. Mass Balance Calculations

Mass balance can provide more in depth understanding of how wastes are distributed. For one kg of input material the amounts waste and products produced can be seen. Therefore, mass balance provides quantitative information and major materials used in the production of a refrigerator. In mass balance analysis, materials used in refrigerators were grouped as main materials/semi-products and other materials/semi-products. The main materials/semi products are the ones that have an overall share of 98.55% in the total weight of materials used. Materials/semi products with a share of 1.45% in the total weight of materials used were classified as other materials/semi-products. Weights of steel, plastic, aluminum, copper, glass, polyurethane foam were evaluated as main materials and compressor main semi product in inputs. Powder paint, other insulating materials, refrigerants, printed circuit boards (PCB), cables, screws, brazing wires were considered as other materials in inputs. Dryers were considered as other semi-product. Calculations of these materials were made in two ways.

Compressors which constitute a major component in refrigerator manufacturing have 139 different stock numbers. Production units of compressors were withdrawn from SAP and the unit weights of these compressors were obtained using Teamcenter® software. Teamcenter is a software developed by Siemens. Software is utilized in various processes in the organization. It helps teams to work collaboratively and effectively even if the groups work in different locations. The software controls the business processes, records information (like product weights etc.) under a single platform which is connected to company's servers (Siemens, 2017). Total weights of compressors produced in 2015, 2016, 2017 and 2018 for each stock number were calculated. An example calculation is given as follows:

$$W_{ct} = N_{pc} * W_c \tag{4}$$

Where;

W_{ct} = Weight of compressor a in total production (kg)

N_{pc} = numbers of unit production for compressor a (unit)

W_c = weight of compressor a (kg/unit)

In the other materials group, some refrigerator components are given directly in kg, while some are given in m^2 and number. Components given in m^2 and number were multiplied by unit weights to determine their weights. In this study, approximately 2800 models of refrigerators with different stock numbers and unit weights were examined as output products. Weights of refrigerators produced in 2015, 2016, 2017 and 2018 for each stock number was calculated. An example calculation is as follows:

$$W_{rt} = N_{pr} * W_r \qquad (5)$$

Where;

W_{rt} = Weight of refrigerator a in total production (kg)

N_{pr} = numbers of unit production for refrigerator a (units)

W_r = weight of refrigerator a (kg/unit)

Wastes produced are another output in the mass balance. Waste amounts as hazardous and non-hazardous wastes were considered. Packing material was not included in the system boundary used for the mass balance. Therefore, weights of refrigerators represent unpackaged weights. With the mass balance material usage and waste production amounts were calculated for unit refrigerator production.

The produced waste amount per product will not be given for confidentiality reasons. However, the range for kg waste/unit refrigerator will be calculated using the results of the mass balance calculations and the average refrigerator weights which is provided in Table 4.7. Lower and upper limits for kg waste/unit refrigerator were calculated as given below.

$$L_l = \frac{0.0445 \text{ kg of waste}}{0.9688 \text{ kg of product}} * \frac{79.49\ kg}{unit\ product} \quad (6)$$

$$L_u = \frac{0.0445 \text{ kg of waste}}{0.9688 \text{ kg of product}} * \frac{99.42\ kg}{unit\ product} \quad (7)$$

Where;

L_l = Lower limit (kg/unit refrigerator)

L_u = Upper limit (kg/unit refrigerator)

3.7. Scrap Cost Calculation

The Company has no data on exactly how many kilograms of hazardous and packaging waste are generated from specific processes or machines. However, the Company has cost data in TL for scrap materials originated from different processes. Scrap costs for each process were calculated using a cost dataset between 2014 and 2018 obtained from the company. Non-hazardous waste consists of scrap materials and polyurethane waste. As most of the scraps were related to metal scrap, the costs of scrap material were assumed to represent the scrap amount. The scrap cost data shows the source of the most scrap producing process. Findings were then used to focus on areas that may be prioritized for waste management and reduction projects.

Scrap cost is calculated as given below.

$$C_s = P_b - P_s \quad (8)$$

Where;

C_s = Scrap Cost (TL)

P_b = Purchase price of materials (TL)

P_s= Sale price of scraps (TL)

CHAPTER 4

RESULTS AND DISCUSSION

Main production processes and waste outputs are investigated in detail in this section. The results of the calculations mentioned in the methodology section are also shown in this section and the evaluations are presented.

4.1. Refrigerator Production Process & Waste Production

As can be seen in Figure 4.1, general refrigeration production process consists of six main processes. These are; sheet metal forming, painting, plastic injection and extrusion, polyurethane injection, thermoforming and assembly. The refrigerator production starts with sheet metal cutting and processing. The processed sheets are painted in dye house. Painted sheet metal parts are then sent to assembly lines. Some of the plastic parts of refrigerators are produced in the plastic factory. The production of the refrigerator starts with the formation of the inner body called as thermoforming. Polyurethane injection is a critical process, giving the refrigerator its strength and insulation properties. The final process is assembly where produced parts are assembled. Refrigerator production in the plant follows these steps as well.

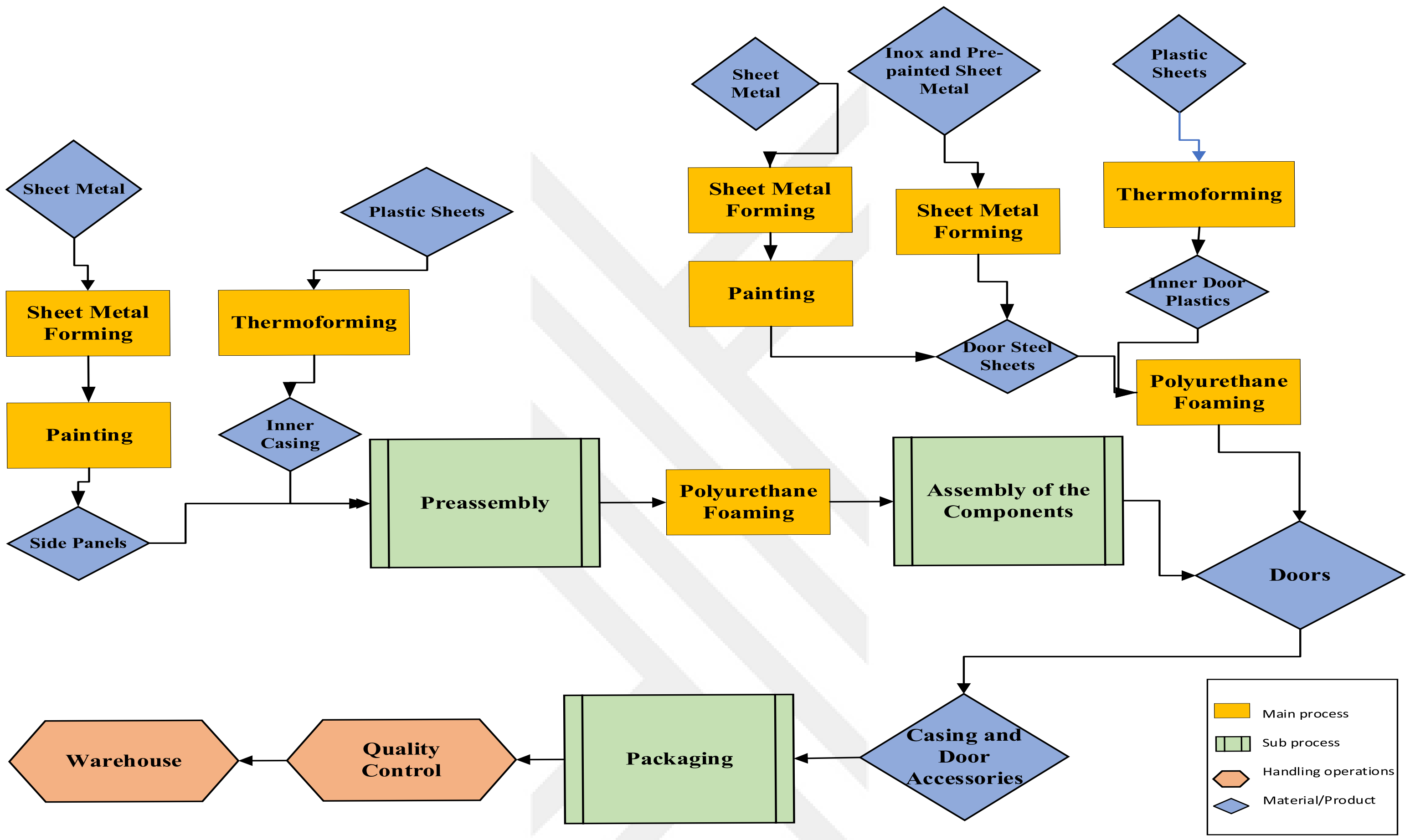

Figure 4.1. Diagram of refrigerator manufacturing processes in the Company

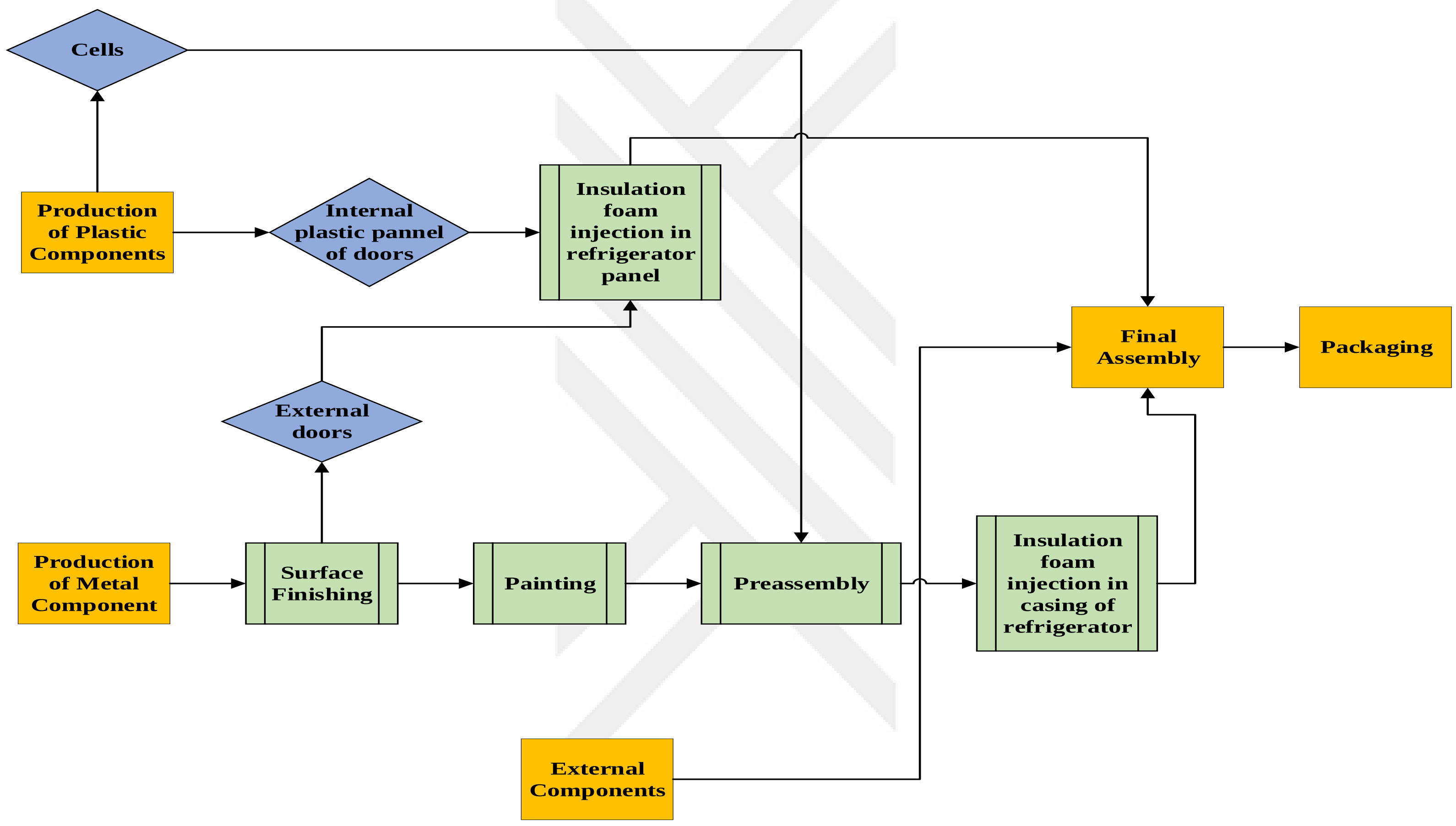

Figure 4.2. Diagram of refrigerator manufacturing processes (Braglia, 2014)

4.2. Process and Non-Process Wastes

Hazardous wastes can be classified under two main classes as process-specific and non-process specific wastes in sectoral waste guide for household appliances (Yılmaz et al., 2017) . In this thesis, in addition to hazardous, non-hazardous and packaging waste grouping, process and non-process grouping was also made. This classification can be seen in Table 4.1,Table 4.2 and Table 4.3.

Table 4.1. Process and non-process hazardous wastes

Process Waste	07 02 14 08 05 01
	13 01 13
Non-Process Waste	08 04 09
	13 03 10
	13 07 01
	13 07 03
	15 01 10
	15 01 11
	15 02 02
	16 02 13
	16 02 15
	16 06 01
	16 06 05
	18 01 03
	19 08 13
	20 01 21
	20 01 26

07 02 14, 08 05 01 and 13 01 13 coded wastes are evaluated as process-specific wastes in hazardous wastes. 07 02 14 and 08 05 01 coded wastes are wastes from additives containing hazardous substances originating from chemicals used in polyurethane foam mixture used to provide insulation and give strength

in refrigerator panels. Wastes with 13 01 13 code refers to other hydraulic oils. It is originated from hydraulic oils used in machines in production.

The other wastes in hazardous wastes are considered as non-process specific wastes. Sealant material was used in the modification of the roof of the company. Surplus sealant was sent to a licensed company for one time with the code 08 04 09. 13 03 10, 13 07 01, 13 07 03 coded wastes were originated from cogeneration plant of the company. 13 03 10 waste occurs due to insulation and heat conduction oils. 13 07 01 and 13 07 03 coded waste was due to liquid fuels. Cogeneration plant was closed. Therefore, these wastes will not occur again. Waste with 15 01 10 code is derived from packaging of oils and other chemicals. After using oil and chemicals, empty barrels, IBC tanks, plastic drums are sent to a licensed company. 15 01 11 is empty pressure vessels wastes. 15 02 02 means materials contaminated with hazardous substances such as absorbent pads, filter media, cleaning cloths and protective clothing. 16 02 four-digit code refers to electrical and electronic equipment wastes. 16 02 13 coded waste means waste which contains hazardous substances except 16 02 09 to 16 02 12. Electronic cards, waste from the information technologies department and human resources are sources of this type of waste in Company. 16 02 15 coded waste refers to hazardous parts removed from discarded equipment. Waste capacitors originating from the reassessment center are evaluated within this waste code. 16 06 four-digit codes refer to batteries and accumulators. 16 01 01 means batteries and accumulators containing lead, and 16 06 05 means other batteries and accumulators. 18 01 03 refers to medical waste. Company has an infirmary. This coded waste originates from infirmary. 19 08 13 coded waste is generated during Company's Wastewater Treatment Plant operations. 20 01 21 coded waste means fluorescent tubes and other mercury-containing waste. This coded waste occurs during the replacement of fluorescent lamps throughout the factory. 20 01 26 refers to fat and oil other than mentioned in 20 01 05 which means edible oils and fats.

Table 4.2. Process and non-process non-hazardous wastes of Company

Process Waste	08 01 12
	12 01 01
	12 01 03
	12 01 04
	12 01 05
Non-Process Waste	16 02 16
	17 04 01
	17 04 07
	17 04 11
	19 10 01
	19 12 04

Non-hazardous wastes with 08 01 12, 12 01 01, 12 01 03, 12 01 04, 12 01 05 codes are evaluated in process-specific wastes. 08 01 12 coded waste is welded from the painting process. They are the paints that cannot be attached to the panels during spray painting of the panels. 12 01 01 coded waste mostly refers to scrap metal sheets which originate from returns due to quality reasons and filings and turnings of metal sheets which result from mechanical production. 12 01 03 coded waste means aluminum scraps. 12 01 05 coded waste refers to plastic scraps. It is mostly originated from plastic production.

16 02 16, 17 04 01, 17 04 07, 17 04 11, 19 10 01, 19 12 04 wastes are evaluated as non-process specific wastes in non-hazardous wastes. These wastes are not related directly to production.16 02 four-digit code refers to electrical and electronic equipment wastes. 16 02 16 coded waste refers to parts removed from discarded equipment. 17 04 four-digit code means metal waste. Waste with 17 04 01 code refers to copper, bronze, brass metal waste. 17 04 07 refers to mixed metal waste. Company’s factory debris and machine apparatus piece are processed under this code. 17 04 11 coded waste means cables except than cables containing oil, tar and other dangerous substances. Waste with 19 10 01 code is iron and steel waste from decomposition of metal-containing process.19 12 04 coded waste means plastic and rubber waste. It is originated from reassessment center of Company.

Table 4.3. Non-process packaging wastes of Company

Non-Process Waste	15 01 01
	15 01 02
	15 01 03
	15 01 04
	15 01 06
	20 01 01

15 01 01, 15 02 02, 15 01 03, 15 01 04, 15 01 06 and 20 01 01 coded waste are not related directly to production. These wastes are originating from unpacking of the supplied material for use in production. Therefore, these wastes are evaluated in the non-specific process waste category. Process and non-process wastes are evaluated as percentage by weight in hazardous and non-hazardous wastes in Table 4.4 and Table 4.5, respectively.

Table 4.4. Percent by weight distribution of process and non-process hazardous wastes

	2014	**2015**	**2016**	**2017**	**2018**
Waste Classification	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
Non-Process Waste	77.1	74.4	92.7	86.7	72.7
Process Waste	22.9	25.6	7.3	13.3	27.3

Table 4.5. Percent by weight distribution of process and non-process non-hazardous wastes excluding municipal solid wastes in years

	2014	2015	2016	2017	2018
Waste Classification	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
Process Waste	55.2	63.5	66.4	63.6	61.3
Non-Process Waste	44.8	36.5	33.6	36.4	38.7

4.3. Wastes Originating from Specific Processes

Following the field studies and meetings with related personnel, following process flow diagrams were developed. Moreover, wastes arising at each step of the production were identified and shown on the process flow diagram. These are as follows:

4.3.1. Sheet Metal Forming

Sheet metal forming varies according to the type of sheet metal. In the company, there are two separate streams as shown in the Figure 4.3, sheet metal and inox/pre-painted sheet metal.

Sheet metal rolls enter the sliding process to set the width at first and then length is adjusted in length cutting process. Width and length of sheet metal vary according to the refrigerator model. As can be seen in Figure 4.3, sheet metal rolls are packaged with metal, plastic, carton, plastic or metal tape to prevent scratches, moisture and chemical affects and are shipped by the supplier. Therefore, wastes with the 15 01 01, 15 01 02, 15 01 03, 15 01 04 codes are generated during unpacking of a roll. After width and length arrangement, sheet metal proceeds to mechanical line for puncturing and bending operations. Processed metal sheets such as top panel, side panel and doors are sent to stocking area before delivery to dye house.

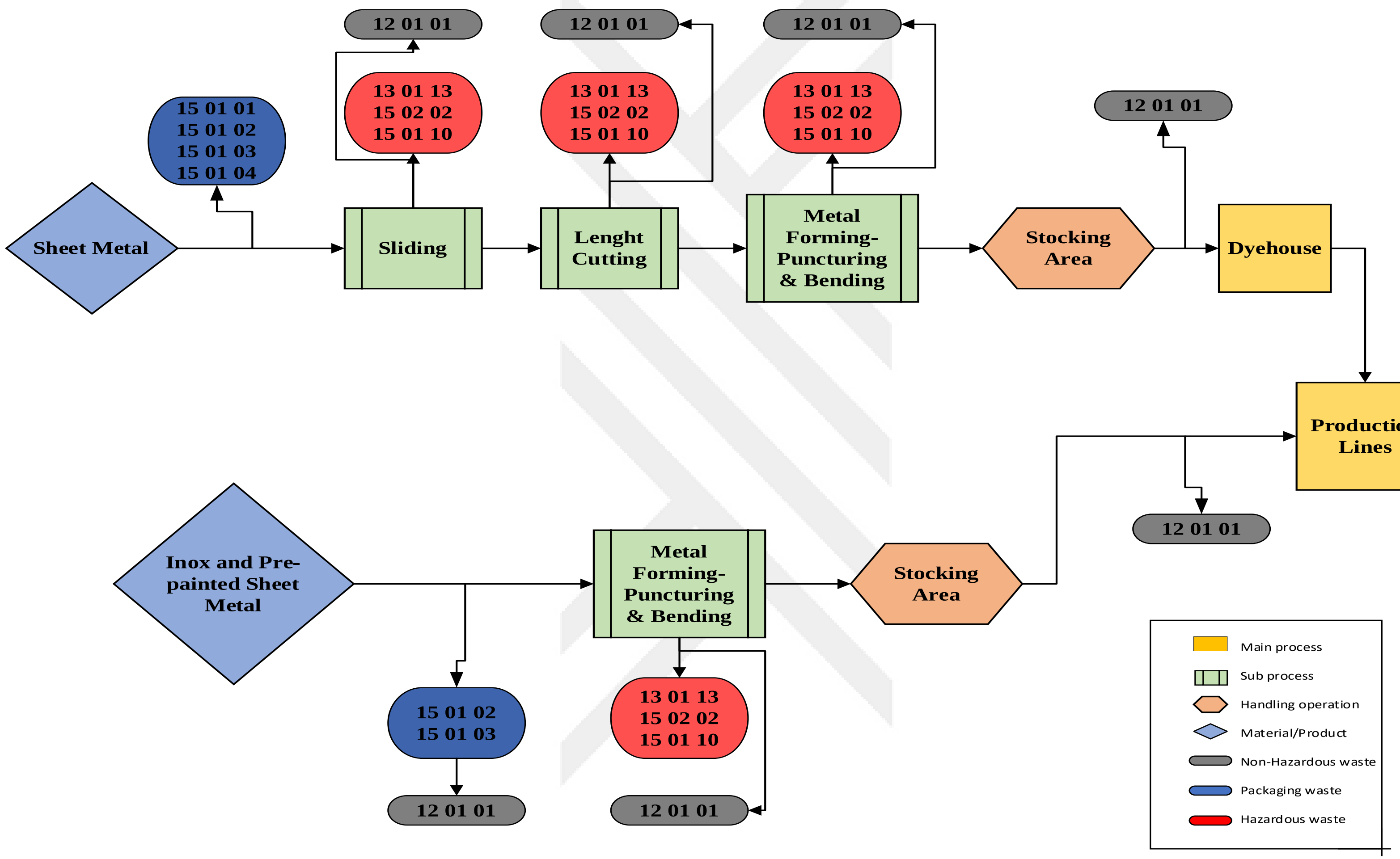

Figure 4.3. Sheet metal forming process and wastes produced

Figure 4.4. Packaged sheet metal rolls (Tat Metal, 2019)

Inox and pre-painted metal sheets are shipped as packed with wooden pallet, plastic tapes and plastic. Therefore, wastes with the 15 01 02, 15 01 03 codes are generated during the unpacking process. This type of sheet metals does not enter the sliding and length cutting process and are taken directly on mechanical line to do puncturing and bending operations. After that these operations, Inox and pre-painted sheet metals are sent to stocking area before delivery to production lines. Wastes with the 15 02 02 code may occur in whole process during the routine machine cleaning and removal of excess oil. Hydraulic oil is used for maintenance of machines and hydraulic oil system of machines. Waste hydraulic oil with 13 01 13 code is originated from maintenance and hydraulic oil system of machines. Waste with 15 01 10 code refers to contaminated packaging (European Parliament and Council, 2008). Empty oil packaging is evaluated within this waste scope. 12 01 01 waste code refers to ferrous metal filings and turnings (European Parliament and Council, 2008). If a faulty is detected in whole sheet metal forming process during visual checks and measurements, it will be reevaluated depending on the type and the size of the faulty. It can be usable for operations requiring smaller metal sheet in the scope of waste reduction approach. However, if it cannot be used, it will be scrap with 12 01 01 waste code. Furthermore, sliding, length cutting, puncturing and bending operations cause small size metal scraps. In addition to this, if there are any faulty originated from metal sheet suppliers, metal sheets return to the supplier.

4.3.2. Painting

Shaped metal sheets which are to be painted are loaded to hangers at the beginning of the painting process line as shown in Figure 4.5. Hanged metal sheets are moved along the line during whole operation. Before painting process, metal parts are prepared for painting by surface treatment. Typical surface treatment includes degreasing, rinsing and coating processes. Sheet metal producers use oil to prevent rust and oxidation of iron-based metals. To do effective surface treatment, oil should be removed from the surface in the first step. After degreasing process, rinsing step is applied to get smooth metal surface (Menta et al., 2012). Coating is essential to prevent corrosion, modify physical properties of sheet metal, and bring visuality (Taylor, 2004). If any faulty is observed during hanging, surface treatment, coating and drying processes, sheet metal arises as scrap with 12 01 01 waste code due to quality concerns. Waste hydraulic oil with 13 01 13 code is originated from degreasing bath in surface treatment process. Wastes with 15 02 02 code may occur during cleaning in whole painting process. After surface treatment and coating processes, drying is applied to get rid of moisture (Glick, 2019). Powder paints are received in boxes wrapped with nylon on the wooden pallet. Therefore, wastes with the 15 01 02, 15 01 03 codes are generated during opening of the powder paint boxes. Waste powder paint with 08 01 12 code is also generated in dyeing process. After dyeing process, painted products in various colors move to a curing operation to remove any moisture. Painted products are picked from hangers as a final process in painting. If any faulty is observed while picking products from hangers, it is evaluated and can be regarded as scrap with 12 01 01 waste code due to quality concerns. After these operations, painted sheet metals are sent to stocking area before delivery to production lines.

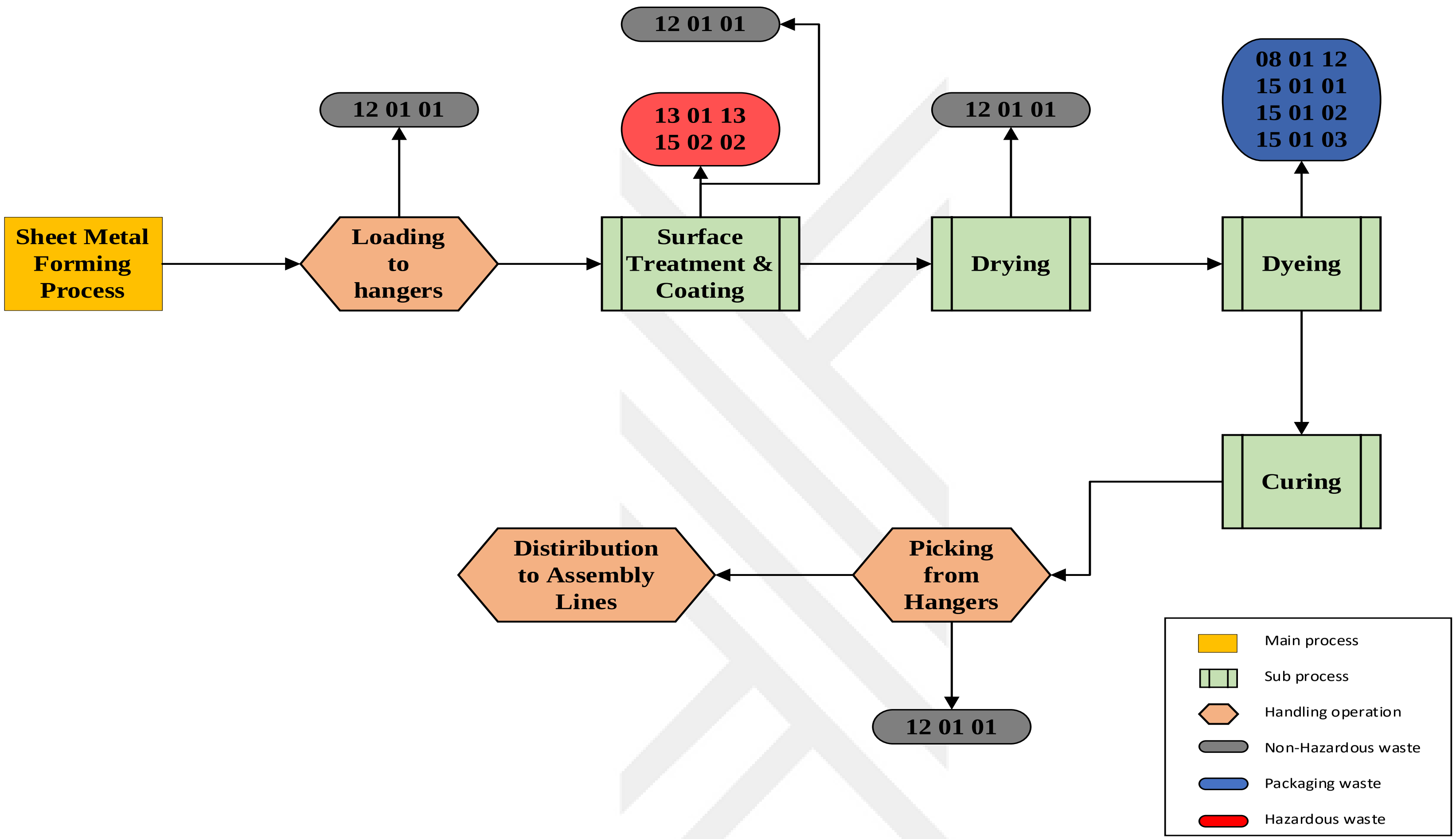

Figure 4.5. Painting process flow diagram and produced wastes

4.3.3. Plastic Production

Extrusion, injection molding, thermoforming and blow molding are the main processes in plastic manufacturing. Extrusion and injection processes are applied in the production of plastic parts used in refrigerators. Plastic raw material enters the stock silo before the extrusion process. The arrival of raw plastic material is made with bags, big bags and containers. Therefore, wastes with 15 01 01, 15 01 02, 15 01 03 codes are generated during material unloading in stock silo. Raw plastic materials that are poured out during the unloading of raw materials into the silo are scraps with the code 12 01 05. As shown in the Figure 4.6, plastic pellet contained in a closed chamber is melted and forced to flow through mold cavity by applying pressure. During this process, material is shaped according to the mold cavity.

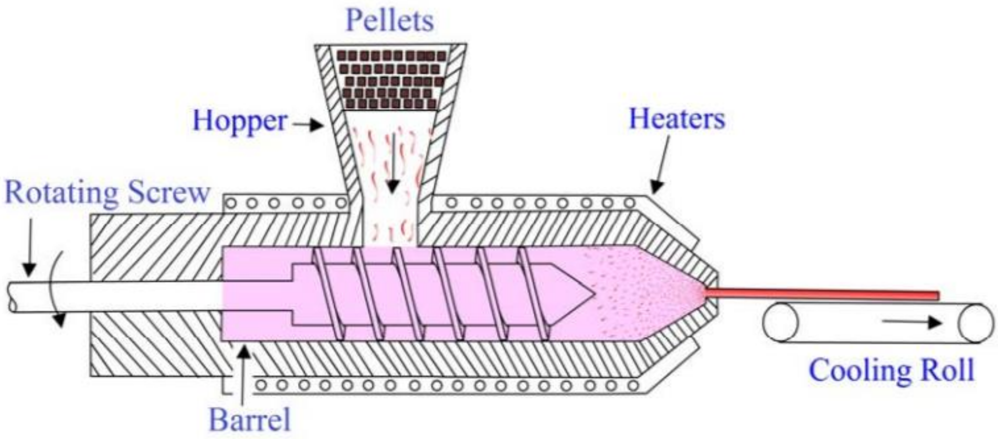

Figure 4.6. Plastic extrusion (National Programme on Technology Enhanced Learning, 2018)

Plastic sheets and plastic sheet rolls are produced by extrusion process. Details of the process are in Figure 4.7. Wastes with the 15 02 02 code may occur in whole process during the routine machine cleaning and removal of excess oil. Hydraulic oil is used for maintenance of machines and hydraulic oil system of machines. Waste hydraulic oil with 13 01 13 code originates from maintenance and hydraulic oil system of machines. Empty oil packaging is evaluated within 15 01 10 waste code. Width is adjusted in the sliding process and length is adjusted in length cutting process. If a faulty is detected in product after extruder, sliding and length cutting processes, it is reevaluated in plastic crushing with the condition of being non-greasy and non-burned. In the same way, small plastic parts from the sliding and length cutting processes and faulty products returned from the thermoform process are reevaluated in plastic crushing. Plastic crushing machine is one of the equipment used for plastic recycling. Grinding, melting and crushing methods are applied on plastic material for conversion into granules. These granules can be used in new products (Orhorhoro et al., 2018). After crushing, plastic granules are sent to the crushed plastic silo and it is mixed with raw plastics coming from the stock silo before the extruder. During transfer to crushed plastic silo, spilled plastic granules can become scrap with the code 12 01 05.

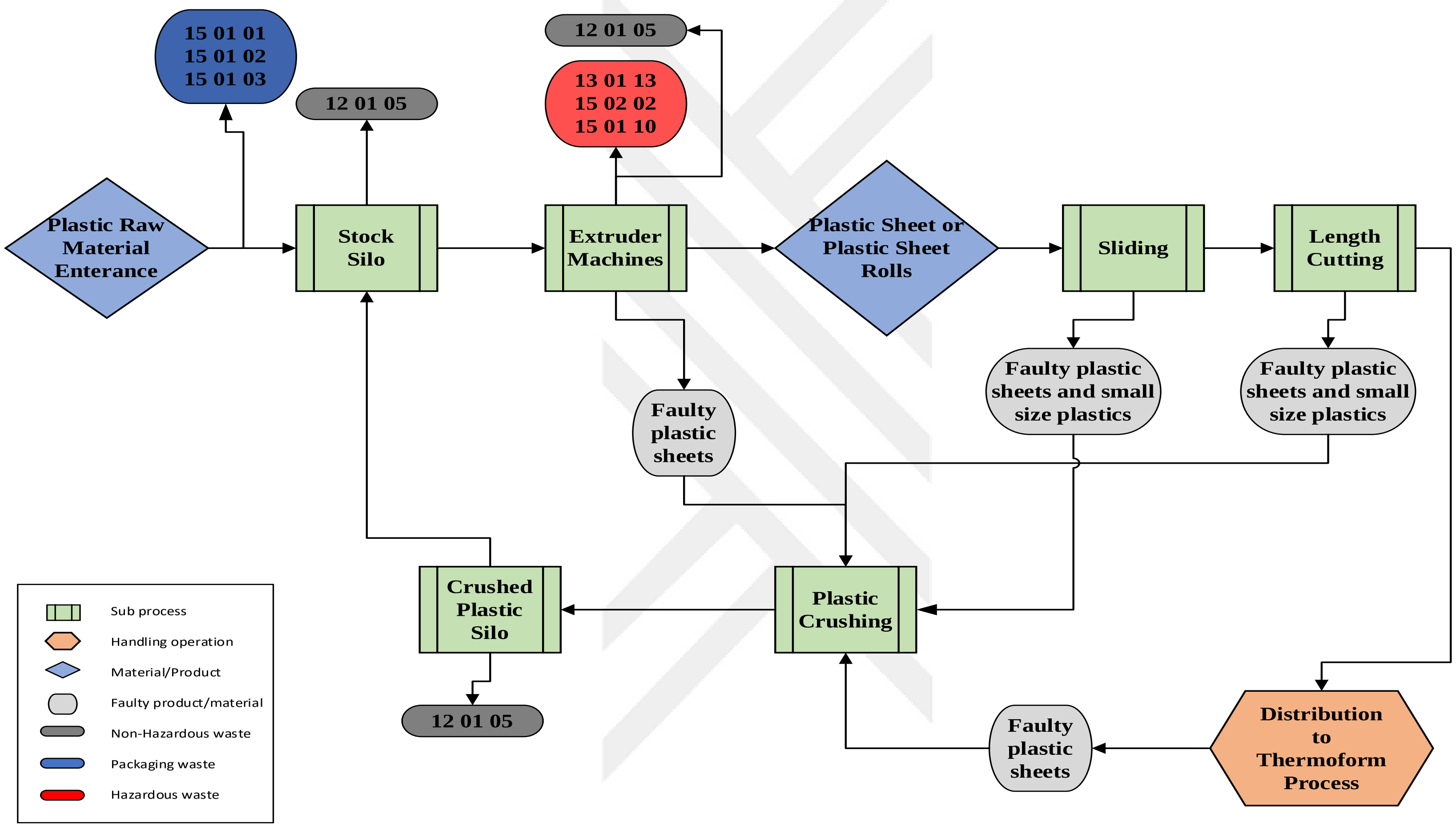

Figure 4.7. Plastic extrusion process flow diagram and produced wastes

As can be seen in Figure 4.8, plastic raw material enters the stock silo before the injection process. Raw plastic material is brought with bags, big bags and containers. Therefore, wastes with 15 01 01, 15 01 02, 15 01 03 codes are generated during material unloading in stock silo. Raw plastic materials that are poured out during the unloading of raw materials into the silo are scraped with the code 12 01 05. Complex plastic parts is made through injection molding process (Kazmer, 2017) . Plastic raw material is melted by heating in the first step of injection. After heating, it is injected to mold. When cooling process is complete, it is removed from the mold. Wastes with the 15 02 02 code may occur in whole process during the routine machine cleaning and the removal of excess oil. Hydraulic oil is used for maintenance of machines and hydraulic oil system of machines. Waste hydraulic oil with 13 01 13 code is originated from maintenance and hydraulic oil system of machines. Empty oil packaging is evaluated within 15 01 10 waste code. Faulty plastic parts originated from injection and returned from assembly lines are recycled using a plastic crushing machine. Crushed plastics are sent to crushed plastic silo and then mixed with raw plastic materials from the stock silo. During unloading to crushed plastic silo, spilled plastic granules are scraped with the code 12 01 05.

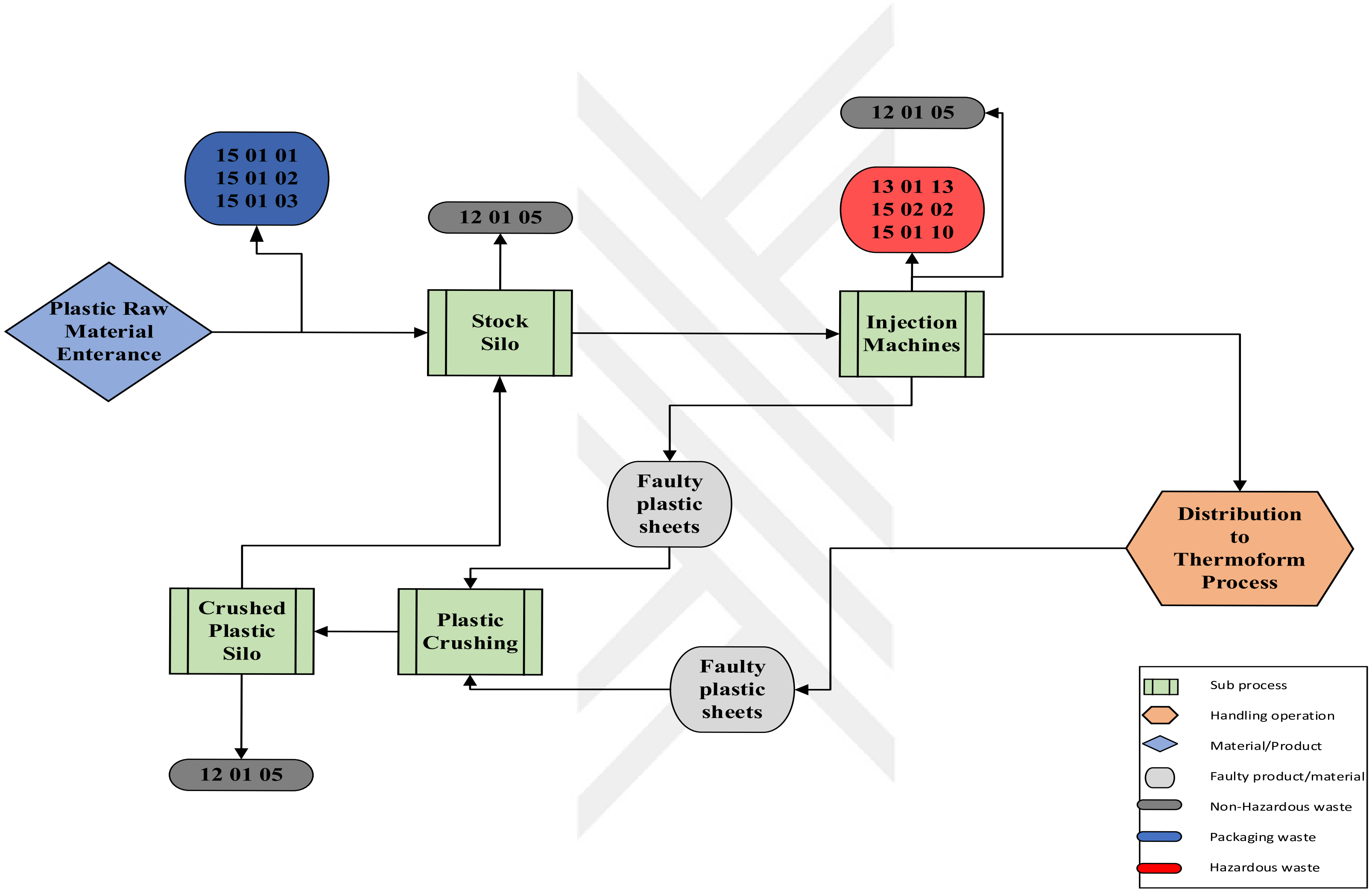

Figure 4.8. Plastic injection process flow diagram and produced wastes

4.3.4. Thermoforming Process of Inner Casing and Door

In thermoforming, plastic sheets are heated and put into a form using a mold (Throne & Throne, 2012). Types of thermoforming vary according to the method used. Vacuum, pressure, plug assist application are examples of these methods. (Kazmer, 2017). Vacuum thermoforming process is visualized by Figure 4.9.

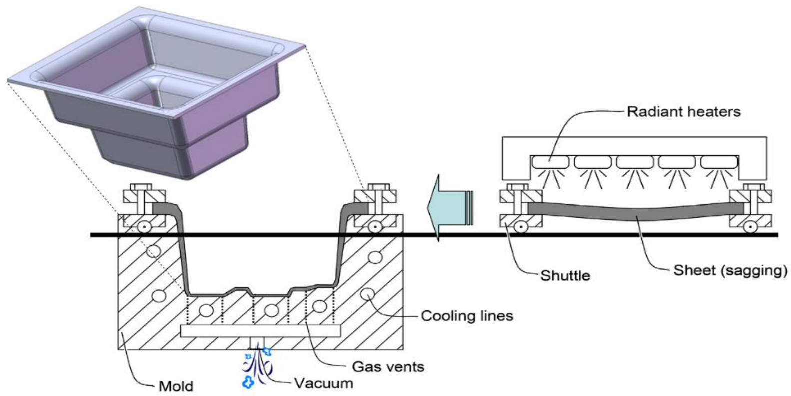

Figure 4.9. Vacuum thermoforming process (Kazmer, 2017)

Plastic sheets coming from plastic production station are put into a thermoforming machine. In the beginning of the process, plastic sheets are heated. After heating, plastic sheets are shaped using a mold. Faulty products originating from thermoforming process are returned to plastic crushing. Following thermoforming, shaped plastic undergoes cooling, puncturing and bending processes. Small plastics originating from puncturing are scraped with 12 01 05 waste code. If small plastics coming from bending are not greasy or burnt, they are sent to plastic crushing. Wastes with the 15 02 02 code may occur in whole process during the routine machine cleaning and removal of excess oil. Waste hydraulic oil with 13 01 13 code is originated from maintenance and hydraulic oil system of machines. As shown in Figure 4.10 and, Figure 4.11 inner door and inner casing are formed with the same method.

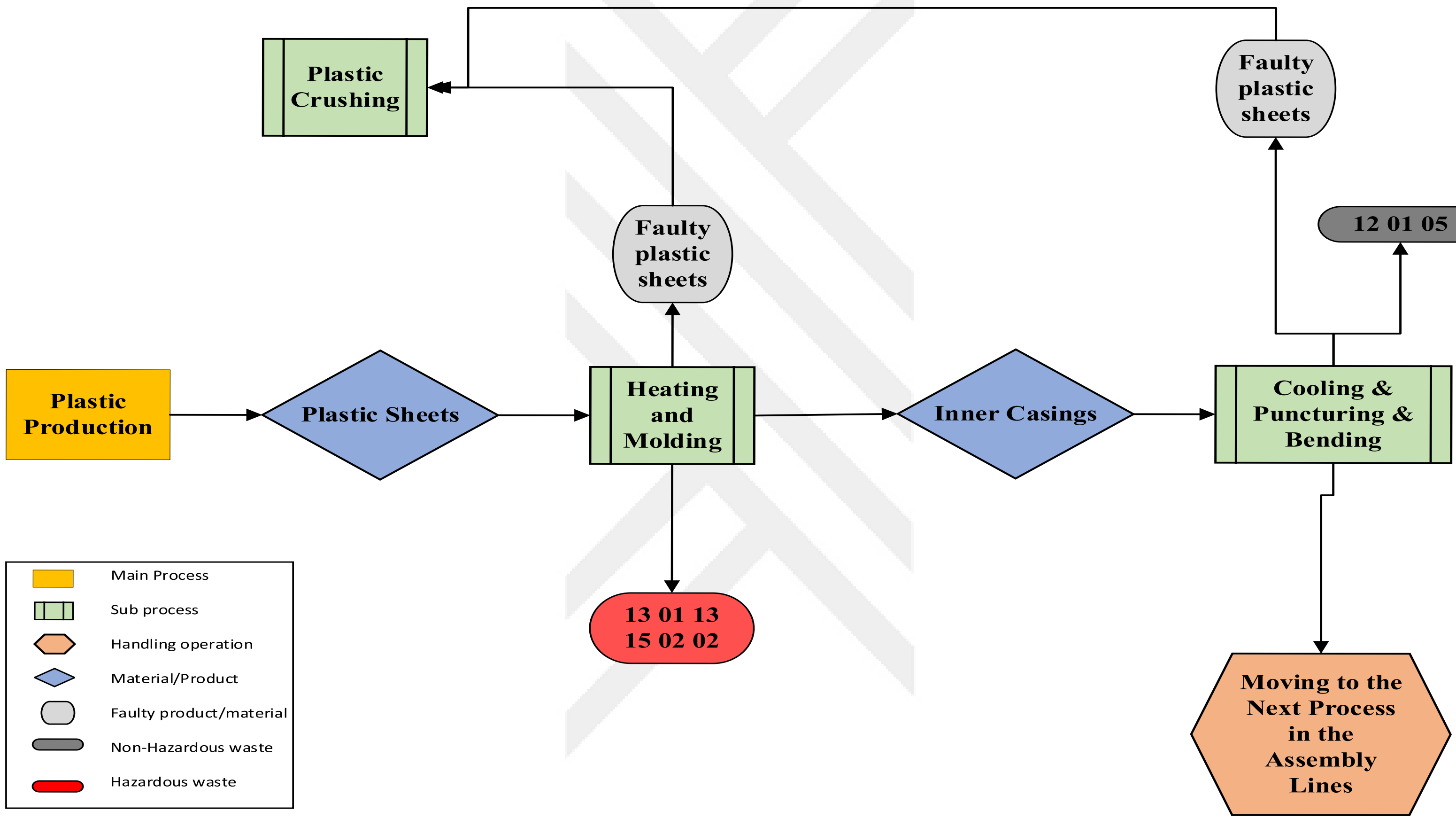

Figure 4.10. Thermoforming process for production of inner casing

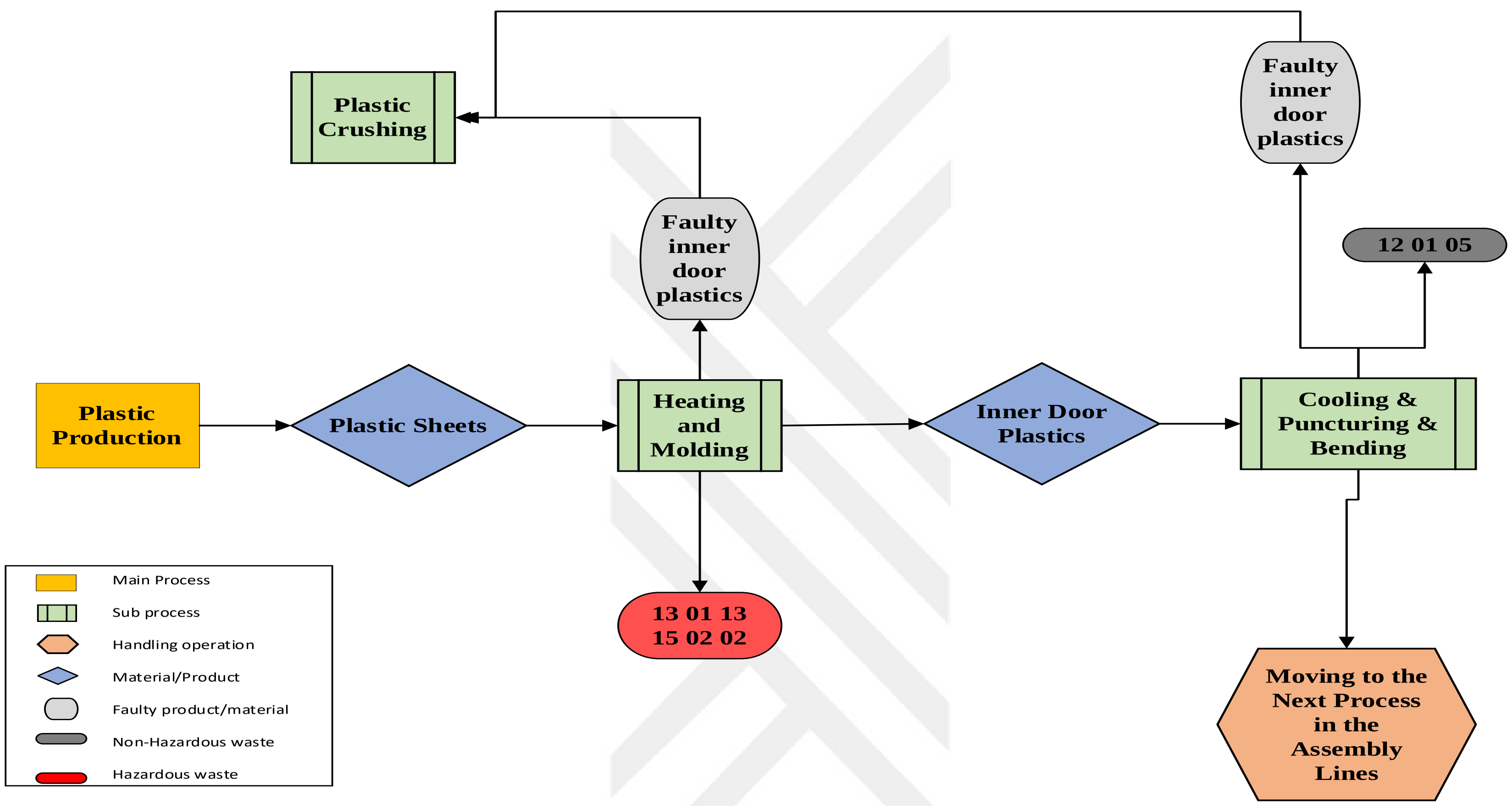

Figure 4.11. Thermoforming process for production of inner door

4.3.5. Polyurethane Foaming

Polyurethane is ranked the 6th among commonly used polymers in the world (Stančin et al., 2019). 7.7% of produced polyurethane is used for automotive manufacturing, insulation of building and refrigerator insulation foam (Calderón et al., 2018). Because of good insulating properties of polyurethane, it is commonly used to insulate the refrigerator (Stančin et al., 2019). 10% of the weight of a refrigerator is polyurethane (Kang et al., 2016; Eschborn, 2018) Polyurethane is formed by the polymerization reaction of diisocyanate or polyisocynate and polyol and adding at least one blowing agent (Tantisattayakul et al., 2018; Zhang, et al., 2017)

Inner casing from thermoforming process and side panels from sheet metal forming and optional painting process are put together, and polyurethane is injected between them. During polyurethane foaming process, waste with 07 02 14 code (additives including hazardous substances) emerges while adjusting the appropriate ratio. Waste with 16 02 16 code grows out of casting head of polyurethane. Waste hydraulic oil with 13 01 13 code originates from maintenance and hydraulic oil system of machines. Wastes with the 15 02 02 code may occur in whole process during the routine machine cleaning and cleaning of chemicals spilled during the process.

Inner door plastics from thermoforming process and door steel sheets from sheet metal forming and optional painting process are combined before the polyurethane injection. As seen in Figure 4.12 and Figure 4.13, the same waste occurs in door foaming and casing foaming process. After the polyurethane process is completed, foamed casing and door moves to the next process in the assembly lines.

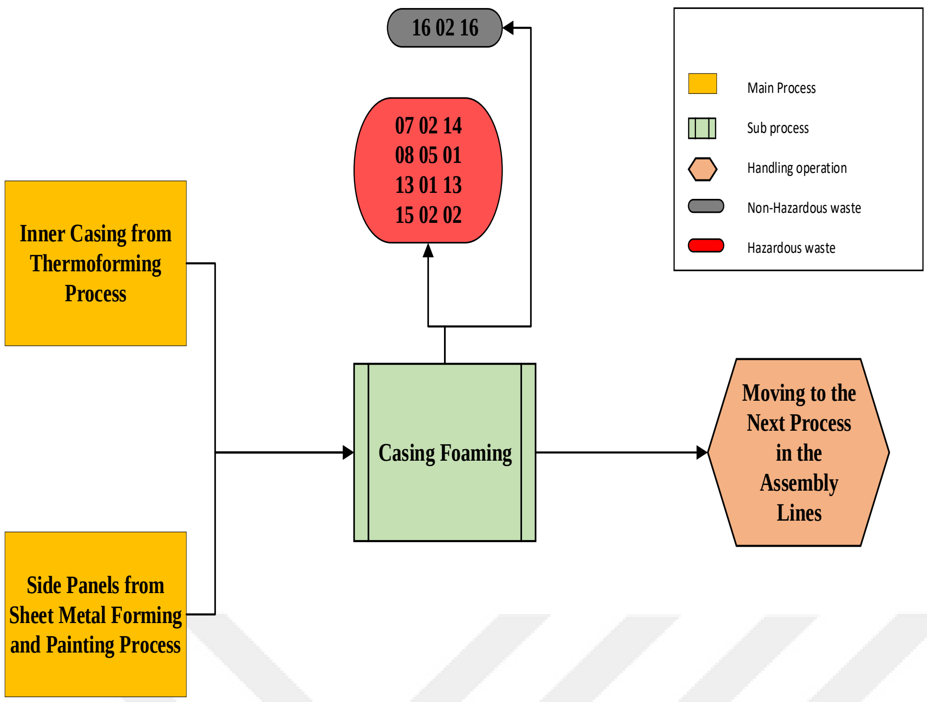

Figure 4.12. Casing foaming process flow

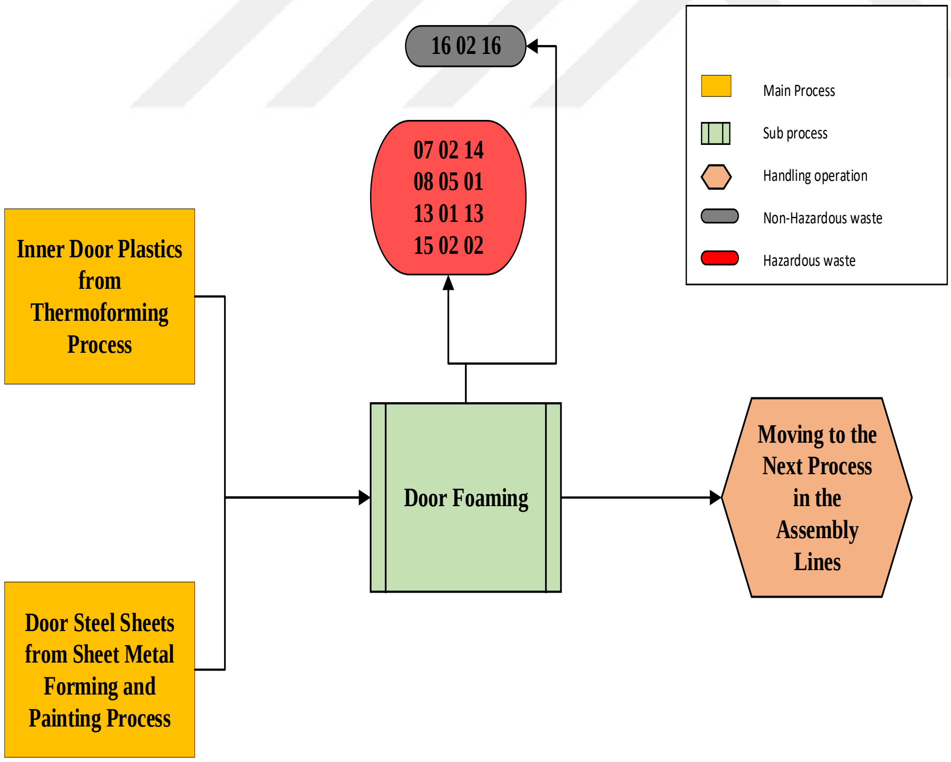

Figure 4.13. Door foaming process flow

4.3.6. Assembly

The refrigerator assembly of the company is similar to the general assembly lines shown in Figure 4.2 and Figure 4.14. Therefore, it can be said that a typical assembly process is applied at the plant. Inner casing produced during thermoforming process proceeds through the line to assemble the coolant components and back wall, etc. Inner casing and side panels that underwent sheet metal forming and painting are assembled. Polyurethane injection occurs between inner casing and side panels. Assembly of compressor and condenser parts is done. Door production process includes thermoforming for preparation of inner door plastic and sheet metal forming and painting for preparation for door steel sheet. Polyurethane injection is made between inner door plastic and door steel sheet. Door assembly is also completed, and accessories assembly is done. After quality check, the product is packaged to send to the warehouse. Sheet metal forming process, painting process, thermoforming process and polyurethane foaming wastes are mentioned in other sections. In assembly process, wastes are commonly sourced from the packages of products for assembly. Wastes with 15 01 01, 15 01 02 and 20 01 01 codes originate from unpacking of coolant components. Wastes with 15 01 01, 15 01 02, 15 01 03 and 20 01 01 codes are derived from unpacking of the compressor and condenser parts. During assembly of casing and door accessories, wastes with 15 01 01, 15 01 02 and 20 01 01 codes occurs because of the unpacking of these accessories. Waste having 13 01 13 code can be originated from maintenance and hydraulic oil system of machines. Empty oil packaging is evaluated within 15 01 10 waste code. Wastes with the 15 02 02 code may occur during cleaning performed in whole assembly process.

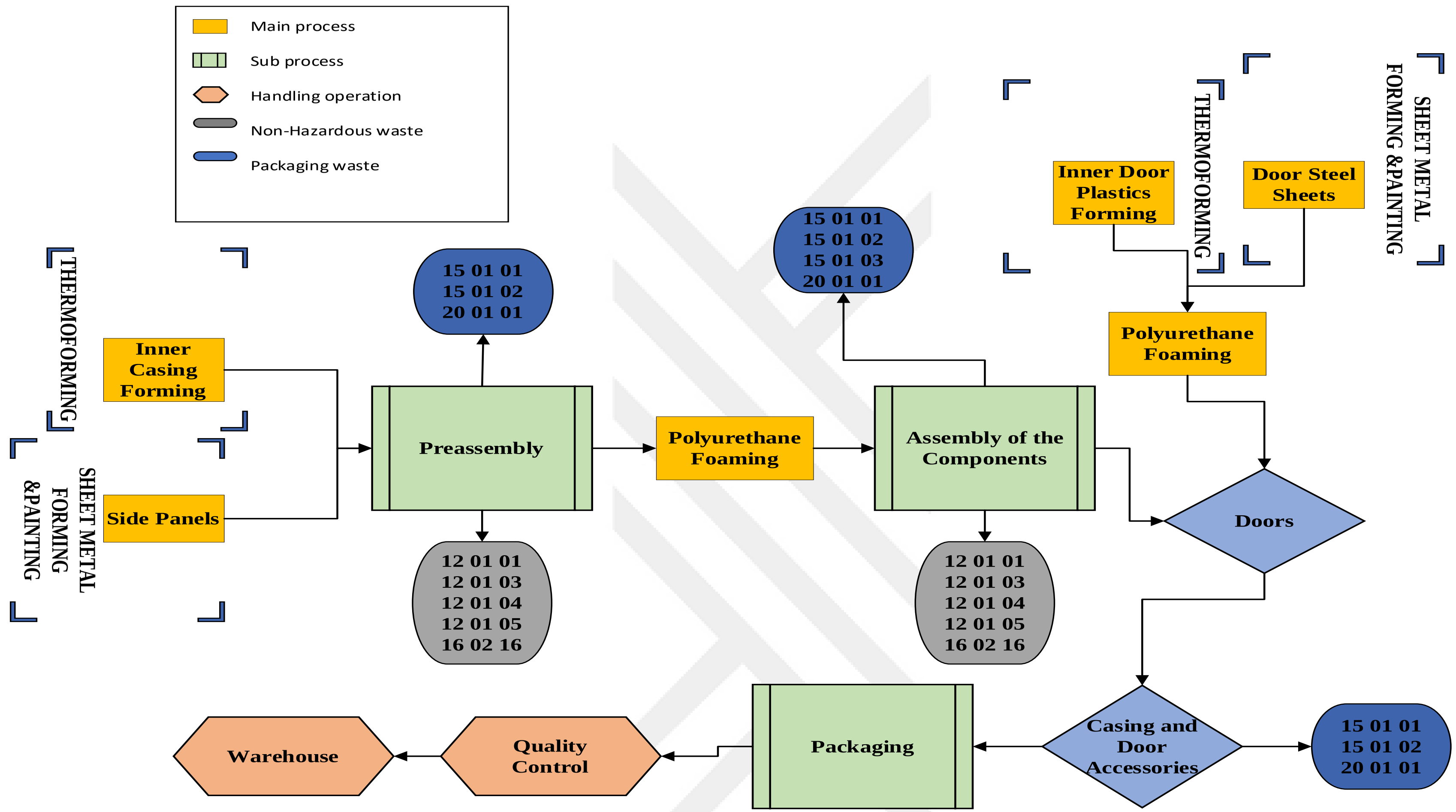

Figure 4.14. Assembly line process flow diagram and produced wastes

4.4. Distribution of HW, NHW and PW in Relative Years

Amounts of total HW, NHW and PW produced during production that follows above steps are calculated separately for 5 years. Figures can be seen in Table 4.6. The total percentages of three types of waste is completed to one hundred in every year.

Table 4.6. Distribution of the waste in years

	2014	**2015**	**2016**	**2017**	**2018**
Waste Description	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
Non-Hazardous Waste	88.00	79.87	71.69	67.30	67.83
Packaging Waste	11.41	19.53	27.31	31.47	31.48
Hazardous Waste	0.59	0.61	1.00	1.24	0.70

*Amounts are given as percent by weight (municipal solid waste is excluded)

Table 4.6 shows the change in the distribution of waste type in years. Non-hazardous wastes have the highest share compared to other types of wastes in 2014 to 2018. Packaging wastes ranks the second. Hazardous wastes have the least share in the total waste amount in five years. While the percentage of packaging wastes in total increased over the years, the percentage of non-hazardous wastes decreased. To clearly understand these increases and decreases, the graphs related to quantity and production are given below.

It may be useful to know the weight of a refrigerator because the amount of waste can be evaluated based on the weight of a product. Weight and internal storage volume of refrigerators vary depending on their models. However, a classical model was chosen to make an evaluation in general. Top freezer type having a width of 70 cm to 75 cm refrigerators are considered as the classic model of refrigerators. Therefore, 14 top freezer refrigerators with a width of 70 cm to 75 cm produced by different companies that are members of the Home Appliance Europe (APPLIA) are examined in terms their internal storage volumes and weights (Table 4.7). Among the examined refrigerators, the maximum weight of a refrigerator is 99.42 kg in an internal storage volume of 507 liters in Model 11. The minimum, on the other hand, is 79.49 kg in an internal storage volume of 507 liters in Model 1.

Table 4.7. Weights and internal storage volumes of different freezers and refrigerators

Model	**Weight, kg**	**Internal storage Volume, liter**	**Reference**
Model 1	79.49	507	(Bosch, 2019)
Model 2	86.37	507	(Bosch, 2019)
Model 3	85.27	507	(Bosch, 2019)
Model 4	81.29	578	(Bosch, 2019)
Model 5	84.67	514	(Bosch, 2019)
Model 6	82.00	516	(Samsung, 2019)
Model 7	83.00	543	(Samsung, 2019)
Model 8	80.50	543	(Samsung, 2019)
Model 9	86.18	507	(Siemens, 2019b)
Model 10	84.29	507	(Siemens, 2019b)
Model 11	99.42	507	(Siemens, 2019b)
Model 12	85.48	507	(Siemens, 2019b)
Model 13	81.69	507	(Siemens, 2019b)
Model 14	80.29	507	(Siemens, 2019b)

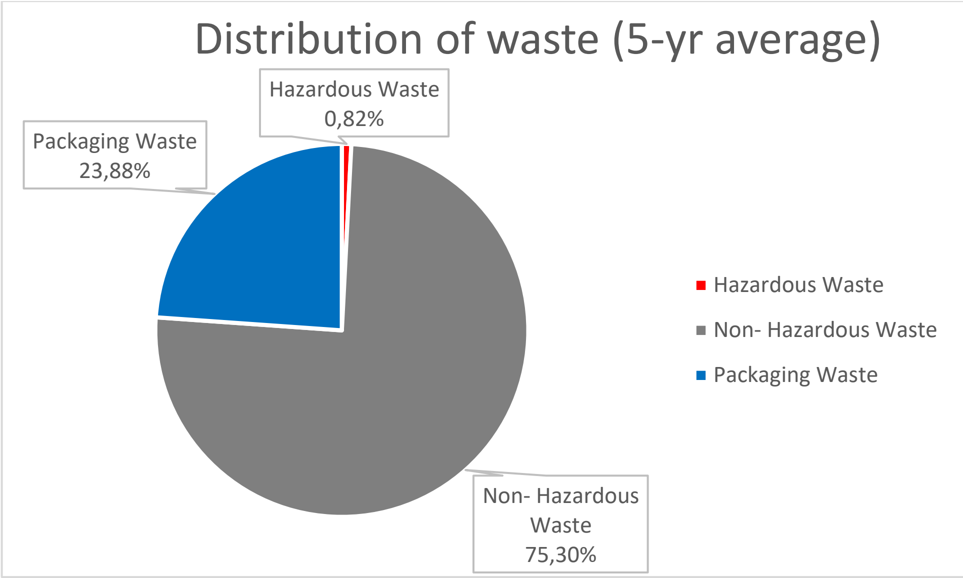

Figure 4.15. Waste distribution for 5 years average

Figure 4.15 shows the waste type distribution as averaged over 5 years between 2014 and 2018. The share belongs to NHW in pie chart. Among different waste types under NHW group, wastes with codes 12 01 01 and 12 01 03 prevail.

4.5. Non-Hazardous Waste

As can be seen from Figure 4.16, NHW amount decreased in years until 2017. Nevertheless, the production numbers did not change drastically. The main reason for the observed decrease in NHW amount and the seemingly mismatches between the production and the NHW produced is the increasing scrap reduction projects conducted in the operations for production. As an exception to this situation is for 2018. The amount of waste increased while the amount of production decreased in this year.

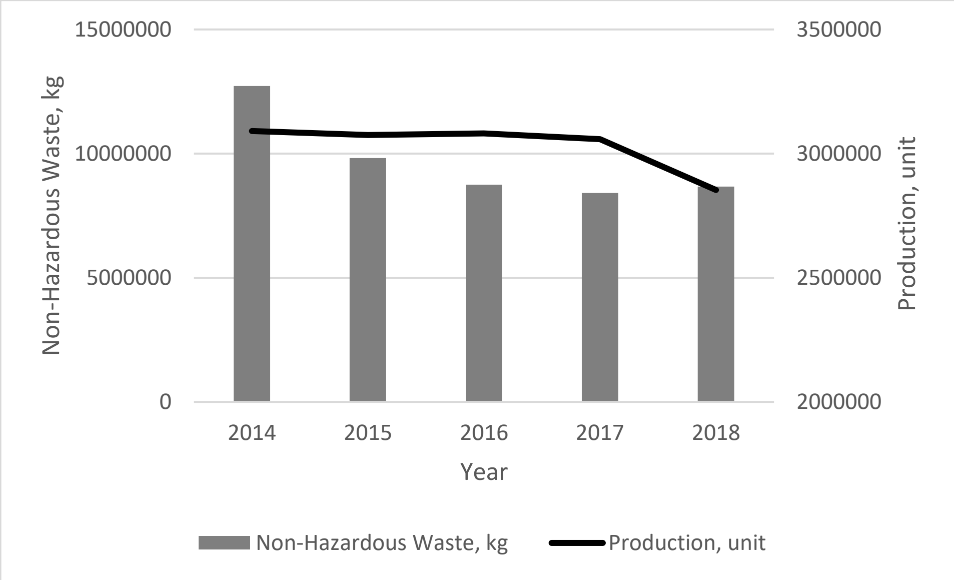

Figure 4.16. Changes in NHW amounts (kg) and production (unit) in years

4.6. Packaging Waste

On contrary to NHW, it can be seen from the following Figure 4.17, that the PW amount increased year by year. Yet the production numbers did not follow PW production either. The increase trend in PW can be attributed to operation cut downs in the production process. The reasons for operation cuts downs are the outsource projects. The operation outsources are resulting in increasing semi products, for instance the semi product packaging. For example, increasing plastic semi products are resulting as protective packaging increase.

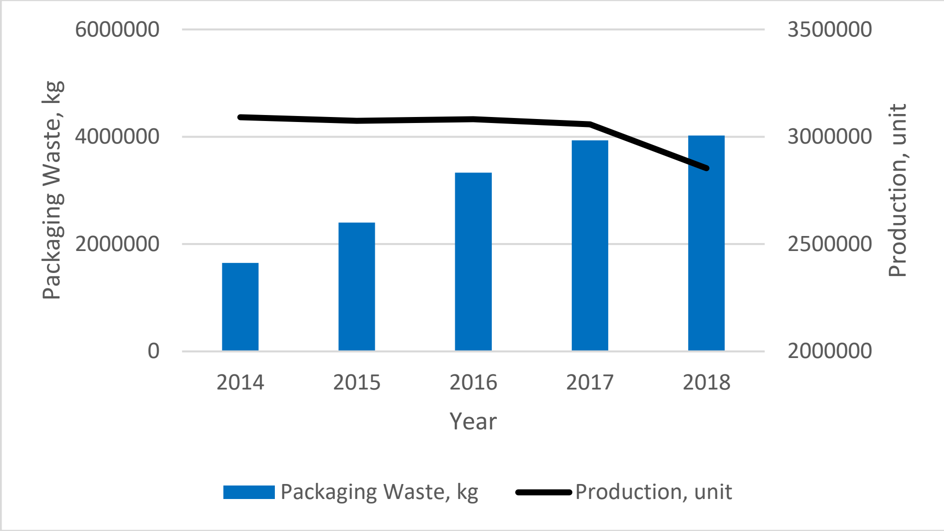

Figure 4.17. Changes in PW amounts (kg) and production (unit) in years

4.7. Hazardous Waste

For HW there is a similar behavior as observed for NHW and PW when it comes to the correlation with the production amounts. Correlation cannot be interpreted easily from Figure 4.18.

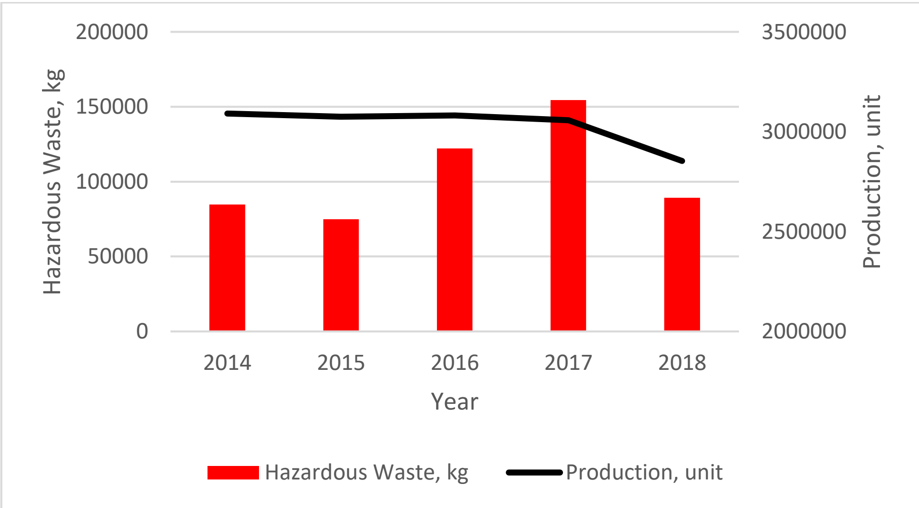

Figure 4.18. Changes in HW amounts (kg) and production (unit) in years

The changes in waste codes might have played a role in the non-correlating. Therefore, Main waste groups are examined as well according to their sub-classification with waste codes.

4.8. Sub- Classification of Main Waste Groups

Hazardous, non- hazardous and packaging wastes were evaluated in terms of waste codes contributing to a given group using waste codes in Table 4.8, Table 4.10 and, Table 4.11 respectively. This evaluation showed which waste codes are more important in terms of weight-based amounts and should be examined to reduce total waste amounts. Wastes with codes that have more than five percent share for a given year over 5 years are determined.

Table 4.8. Percent weight-based distribution of hazardous wastes in years

	2014	**2015**	**2016**	**2017**	**2018**
Hazardous Waste Codes	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
15 02 02	23.85	27.05	14.19	17.37	20.45
15 01 10	21.96	12.34	5.21	35.35	14.03
16 02 13	18.41	16.75	10.19	7.83	14.35
07 02 14 08 05 01	6.77	12.16	3.13	9.95	25.08
19 08 13	10.02	8.82	9.21	5.98	13.30
16 02 15	0.00	2.70	26.72	7.12	5.78
13 01 13	16.11	13.42	4.21	3.39	2.19
16 06 01	2.36	3.34	2.51	5.42	1.61
13 07 01	0.00	0.00	12.99	0.00	0.00
20 01 26	0.00	2.55	1.78	1.10	2.30
08 04 09	0.00	0.00	0.00	6.08	0.00
13 03 10	0.00	0.00	6.03	0.00	0.00
13 07 03	0.00	0.00	2.65	0.00	0.00
20 01 21	0.40	0.29	0.51	0.18	0.76
15 01 11	0.12	0.27	0.36	0.10	0.00
18 01 03	0.00	0.31	0.12	0.11	0.14
16 06 05	0.00	0.00	0.19	0.01	0.00

Table 4.9. Frequency of hazardous waste

Frequently generated wastes	Frequency in five years	Trend
07 02 14 08 05 01	1	increasing
13 01 13	1	consistent decreasing
15 01 10	1	fluctuating
15 02 02	1	fluctuating
16 02 13	1	increasing
16 06 01	1	fluctuating
19 08 13	1	fluctuating
20 01 21	1	fluctuating
15 01 11	0.8	fluctuating
16 02 15	0.8	decreasing
18 01 03	0.8	fluctuating
20 01 26	0.8	fluctuating
16 06 05	0.6	decreasing
08 04 09	0.2	ceased
13 03 10	0.2	ceased
13 07 01	0.2	ceased
13 07 03	0.2	ceased

Wastes with 15 01 10, 15 02 02, 16 02 13, 19 08 13 codes have more than five percent contribution in relevant years for five years and their frequencies are 1.0 for all. 15 01 10 coded waste is packaging contaminated with hazardous materials. This type of waste is mainly caused by empty packaging of substances such as chemicals and oils in the plant. 15 02 02 coded waste can occur in whole processes during the routine machine cleaning and removal of excess oil. Discarded equipment which contains hazardous material is recorded with 16 02 13 code. Electronic cards waste from the information technologies department and human resources are the sources of this type of waste in the plant. 19 08 13 coded waste is generated from wastewater treatment plant operations.

07 02 14 is a waste from additives containing dangerous substances. Wastes of polyurethane forming chemicals are included in this waste code. This waste was generated every year within 5 years, so that it has a frequency of 1. Although the reason for the decrease in the amount in 2016 is unknown, the reason for the sharp increase in 2018 is the increase in trial productions and calibration control of the polyurethane chemical ratio.

13 01 13 is waste hydraulic oil and generated every year, so that it has a frequency of 1. Company reduced its usage of hydraulic oil in 2016 and consequently reduced waste oil generation in 2016 and beyond. 13 03 10, 13 07 01 and 13 07 03 coded wastes are originated from the cogeneration plant which was closed. Therefore, these wastes are excluded. As can be seen in

Table *4.9*, it has a frequency of 0.2. 08 04 09 coded waste is out of use insulation material and one-off waste. Frequency of this waste is low with a value of 0.2 as expected. 16 06 01 coded waste is lead batteries. This waste is generated every year within 5 years, so that it has a frequency of 1. Replacing required batteries is the reason for the increase in 2017. 16 02 15 coded waste is hazardous parts removed from scrap equipment. Waste capacitors originated from reassessment center are evaluated within this waste code.

Table 4.10. Percent by weight distribution of non-hazardous wastes excluding municipal solid wastes in years

	2014	**2015**	**2016**	**2017**	**2018**
Non-Hazardous Waste Codes	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
12 01 01	50.93	58.90	59.81	58.22	56.24
16 02 16	35.17	29.85	27.58	30.60	31.20
12 01 05	3.72	3.82	5.72	4.49	4.45
17 04 07	4.72	3.03	2.85	2.22	3.40
19 12 04	2.70	2.30	2.02	2.47	3.02
19 10 01	1.76	0.98	0.63	0.60	0.62

Table 4.10. Percent by weight distribution of non-hazardous wastes excluding municipal solid wastes in years (continued)

	2014	2015	2016	2017	2018
Non-Hazardous Waste Codes	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
08 01 12	0.35	0.48	0.52	0.57	0.39
17 04 01	0.27	0.31	0.30	0.33	0.30
17 04 11	0.13	0.07	0.27	0.22	0.14
12 01 03	0.15	0.22	0.08	0.10	0.07
12 01 04	0.09	0.03	0.22	0.18	0.16

12 01 01 coded waste refers to filings and turnings of ferrous metal. As previously mentioned in Refrigerator Production Process & Waste Production section, main sources of this type of waste are sheet metal forming and painting processes. 12 01 01 is the waste that has the highest share in the non-hazardous waste group with over 50% for 5 years. As shown in Figure 4.16, the amount of non-hazardous waste decreased within five years.

As the total amount of non-hazardous waste is reduced, the percentage of wastes with 12 01 01 code in total non-hazardous waste has increased. In fact, the main reason for the reduction of non-hazardous waste is the reduction of waste with 12 01 01 code. As previously mentioned, scrap reduction projects and increase of automation projects in the plant are the reasons for the decrease in waste amount.

16 02 16 coded waste refers to parts removed from discarded equipment other than 16 02 15. Main sources of this waste are reassessment center. Refrigerators which return from production and field due to any fault is examined to find the cause of fault in reassessment center. Refrigerator parts which arise as waste out of this examination and evaluation are named with 16 02 16 code. All non-hazardous waste has a frequency of 1. Therefore, the most consistent waste type in terms of the frequency of production in a given year is the non-hazardous waste.

As previously mentioned in Section “2.5. Material Composition of Refrigerators”, percentages of materials used in production will be changing. This will also affect waste distribution of Company. It is predicted that while wastes due to electronic components, and plastic-based wastes will increase, steel-based wastes will decrease.

Table 4.11. Percent by weight distribution of packaging wastes in years

	2014	**2015**	**2016**	**2017**	**2018**
Packaging Waste Codes	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**	**Amount (%)**
15 01 03	53.49	36.14	32.22	27.83	37.27
15 01 01	31.79	39.67	32.65	30.85	30.53
15 01 02	14.73	24.19	22.07	19.17	18.06
15 01 04	0.00	0.00	0.00	7.86	6.83
15 01 06	0.00	0.00	13.05	13.78	7.08
20 01 01	0.00	0.00	0.00	0.51	0.22

Table 4.12. Frequency of packaging waste production in a given year

Frequently generated wastes	**Frequency in five years**	**Trend**
15 01 01	1	consistent increasing
15 01 02	1	fluctuating
15 01 03	1	consistent increasing
15 01 06	0.6	decreasing
15 01 04	0.4	decreasing
20 01 01	0.4	decreasing

The total amount of packaging waste increased as shown in Figure 4.17. Wastes with 15 01 01, 15 01 02, 15 03 01 codes have more than five percent contribution to the total weight in relevant years over five years. These wastes are originating from paper and cardboard packaging, plastic packaging, wooden packaging, respectively. Especially, 15 01 01 and 15 01 03 coded wastes have the largest share in the total amount of packaging waste. As can be shown in Table 4.12, their frequency of waste generation is 1.

Separate collection of PW provides higher quality recyclables compared to the unsorted PW (Oliveira et al., 2018). For this reason, wastes with 15 01 04 and 20 01 01 codes have been collected separately from other wastes since 2017. 15 01 06 coded waste has been collected separately from other packaging wastes since 2016.

15 01 04 coded waste refers to metallic packaging waste. This waste originated form unpacking of sheet metal rolls. Frequency of this coded waste is 0.4. The percentage of 15 01 04 coded waste in total packaging waste in 2017 and 2018 are higher than 5%. 15 01 06 refers to mixed packaging waste. It has a frequency of 0.6. The percentage of waste with 15 01 04 code in total non-hazardous waste in the last 3 years are higher than 5%. 20 01 01 coded wastes mean waxed paper waste. This type of waste originates from unpacking of the compressor, condenser parts and accessories.

4.9. Recycled and Disposed Waste of the Company

The percentage of waste sent to a landfill with respect to total amount of waste is calculated as described in methodology section. Results of these calculation can be seen in Table 4.13 and Table 4.14

Table 4.13. Recycled and disposed waste % for hazardous waste

Waste Management	2014	2015	2016	2017	2018
Recycled	99.88	99.69	99.88	99.89	99.86
Disposed	0.12	0.31	0.12	0.11	0.14

Infirmary of the Company generates medical wastes which are sent to the landfill. As can be seen in Table 4.8, the amount of this waste is very small in the total amount of waste. Empty pressure vessels wastes were only sent to landfill in 2014. This type of waste was sent to intermediate storage in other years. Other hazardous wastes of the plant were sent to licensed companies for recycling over 5 years. Company sent up to 0.31% of its waste to a landfill within 5 years.

Table 4.14. Recycled and disposed waste % for non- hazardous waste

Waste Management	2014	2015	2016	2017	2018
Recycled	98.62	98.16	98.05	97.97	98.68
Disposed	1.38	1.84	1.95	2.03	1.32

* Municipal solid waste was excluded.

Rigid polyurethane foam was sent to the landfill for 5 years. All non-hazardous waste except polyurethane waste was sent to licensed facilities for recycling. The Company sent up to 2.03 % of its non-hazardous waste to the landfill within 5 years. The ratio of the amount of non-hazardous waste sent to a landfill with respect to the total amount of non-hazardous waste changed between 1.32 and 2.03 within 5 years.

All packaging waste was sent to licensed facilities for recycling within 5 years. Therefore, it was not shown in table form. Company sent 100% of collected packaging waste to recycle in 5 years.

The total waste recycling rate, including hazardous waste, non-hazardous waste and packaging waste, was calculated as 98.7% over a 5-year average. In addition to the 5-year average waste recycling rate, the Company's waste recycling rate in 2018 was calculated as 99.1%. This value will be used for comparison to waste recycling rates of other household appliance companies in 2018.

4.10. Mass Balance for the Refrigerator Plant

The system boundary of this study is provided in Figure 4.19. In setting up the mass balance, materials used for refrigerator production, manufacturing of refrigerators, and waste generated by production and the final product are considered.

The materials used in refrigerators are considered as main materials and others. Main materials are steel, plastics, aluminum, copper, glass, polyurethane foam. Compressor is the most important semi-product used in refrigerator manufacturing and main semi-product used in refrigerator. Other materials are powder paint, other insulating material, refrigerants, PCB, cable, screw, brazing wire. Dryer is other semi-product. Other category in Figure 4.19 consist of dryer and other materials. While the share of main inputs in the total weight of materials/semi product used is 98.55%, the share of others in the total weight of materials/semi product used is 1.45% Process of refrigerator manufacturing includes six main process as mentioned before such as sheet metal forming, painting, plastic injection and extrusion, polyurethane, thermoforming and assembly. Waste generated due to production includes hazardous wastes and non-hazardous wastes. Final products mean unpackaged refrigerators. The mass balance of a refrigerator plant is shown in detail in the Figure 4.19. The material data are given as values with one-kilogram increment in this study. When the inputs and outputs are compared, 1 kg of material enters the manufacturing processes, the outputs out of the system boundary are 0.0445 kg of waste and 0.9688 kg of product. There is a 1.33% difference between input and output mass. The main reason for this difference is that some materials are not included as inputs due to the difficulty in accessing the data, and that these non-added materials do not affect the weight as much as the main materials and other material groups.

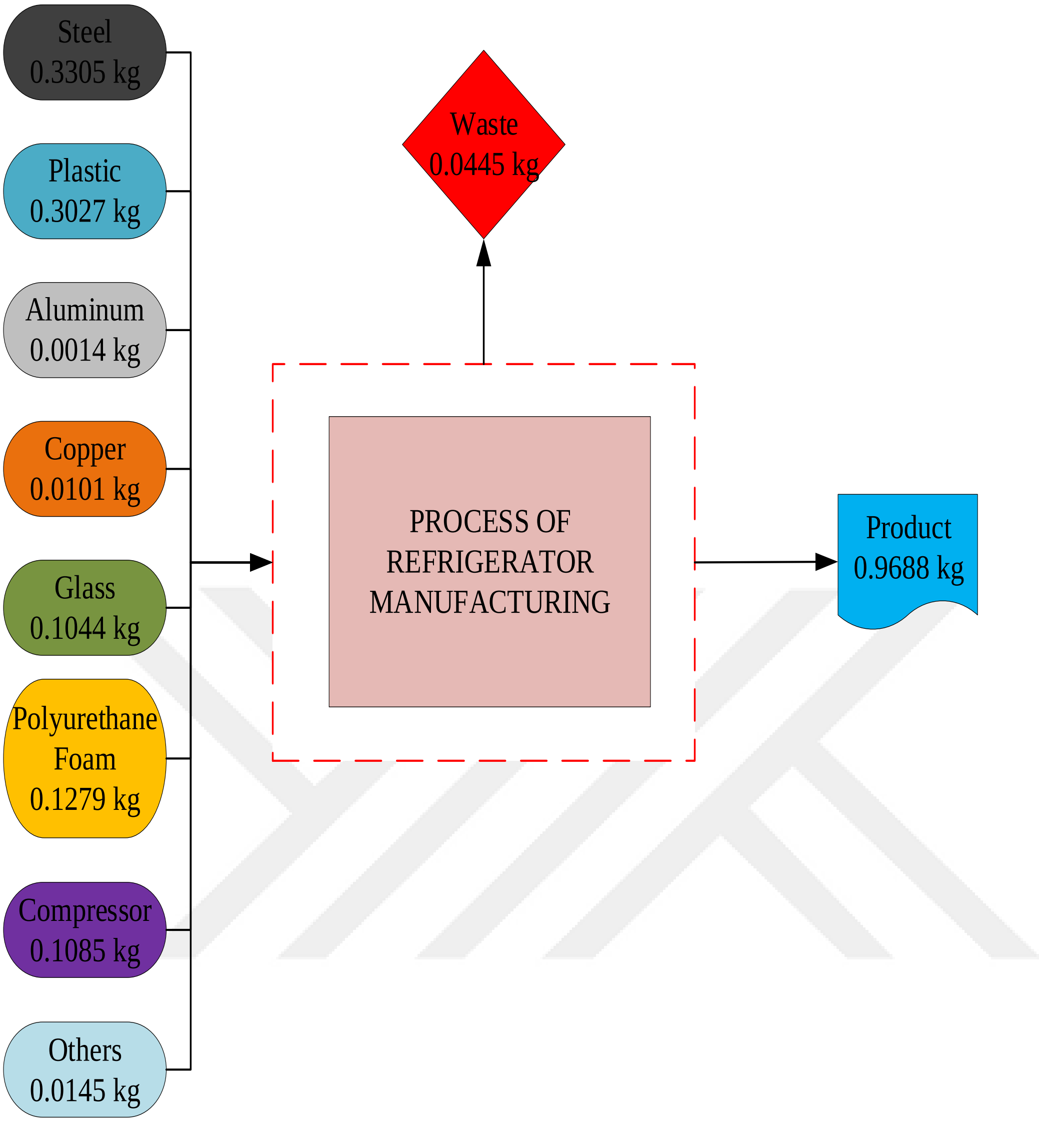

Figure 4.19. Mass balance within the system boundary

4.11. Source of Manufacturing Scraps

Manufacturing metal and plastic scraps were evaluated in the non-hazardous waste category in this study. Purchase price of metal and other materials are always higher than sale price of scrap materials. In Figure 4.20, scrap costs percentages and their sources calculated based on 5-year average scrap costs are shown.

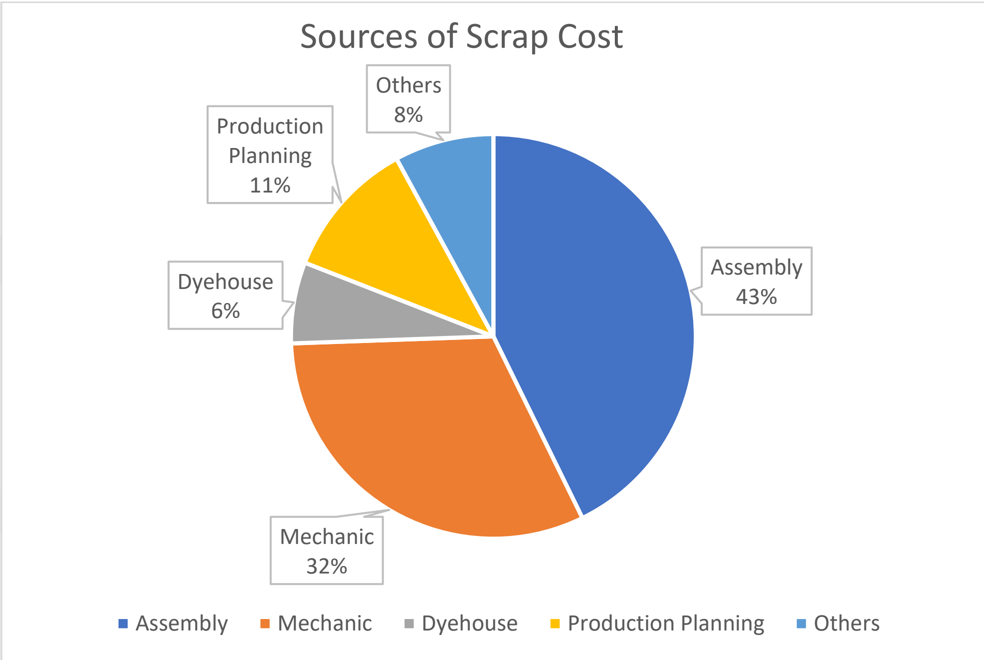

Figure 4.20. Distribution of scrap costs

The aim of drawing scrap costs source distribution graph is to find the process that most affect manufacturing scraps in the non-hazardous waste.

4.12. Environmental Performance of the Company

In this thesis, the Company's environmental performance is evaluated based on waste generation factor and percentage of waste recycling. In evaluations, these values are compared to the ones declared by other companies as well. Miele (2019) stated that 0.151 kg of waste, which is directly welded from production, was obtained during production of 1-kg of product between 2017 and 2018.

Waste intensity of one of the leading household companies was 5.97 kg/product in 2015, 6.39 kg/product in 2016, 6.65 kg/product in 2017, and 6.55 kg/product in 2018 (Whirlpool Corporation, 2018).

Exact waste amount per unit product of the Company could not be given because of confidentiality issues. However, when 1 kg of material enters the manufacturing processes, 0.0445 kg of waste and 0.9688 kg of product are produced according to the mass balance conducted for the production area of the facility. Using this data, waste production amount in terms of kg per 1 kg of product is calculated as 0.0459. According to Table 4.7, weight of an average refrigerator is between 79.49 kg and 99.42 kg for a refrigerator of an internal storage volume of 507 liters. With this method, a general waste intensity range of the Company is calculated instead of an exact waste intensity. As can be seen in table 4.15., waste intensity range is between 3.65 kg/product and 4.57 kg/product.

Table 4.15. Range of waste intensity

Weight of a refrigerator, kg*	**Waste intensity, kg/product**
79.49	3.65
99.42	4.57

*Refrigerator weights do not belong to the Company. These values are taken from other refrigerator manufacturing companies.

Waste production values of the Company are compared with the two home appliances manufacturers. Waste generation per product of the Company or waste generation per 1-ton of product was lower than the waste generation values of the other two companies.

Sustainability reports of leading household appliances manufacturers were examined. Their waste recycling rates in 2018 are listed in Table 4.16. As previously mentioned in section 4.9., waste recycling rate of the Company was calculated 99.1% in 2018. When waste recycling rate of the Company was compared with the waste recycling rates of other companies, the environmental performance of the company in terms of waste recycling rate was quite good. It is worth noting that the waste recycles ratio and waste generation amount of the Company include the production of refrigerators only, whereas waste recycling ratios and waste generation amounts of other household appliances companies include not only the production of refrigerators, but also other household appliances as well.

Table 4.16. Waste recycling rates of other household appliances companies

Waste recycling rate, %	References
>96.0	(Whirlpool Corporation, 2018)
95.0	(Samsung Electronics, 2019)
84.0	(Philips, 2018)
83.5	Bosch, 2018
76.0	(LG Electronics, 2019)

Environmental performance of the Company is evaluated as good in terms of waste generation factor and percentage of waste recycling when compared to other companies in the sector. Nevertheless, improvements can still be possible to further improve the environmental performance of the Company. Waste minimization and BATs will be discussed in the next section. Suggested BATs can be applied to achieve further improvement in the environmental performance of the Company.

4.13. Waste Minimization and Best Available Techniques

The percentage of non-hazardous wastes in total waste is high with 75.3% on a 5-year average. To reduce the amount of waste produced, focusing on this group may be important. Moreover, in current business trends, the scrap costs are one of the focus areas to lower the costs and remain competitive (Nguyen, 2004). Because of these reasons, techniques for waste reduction have been evaluated only for non-hazardous wastes, even though management of hazardous waste cannot regard as insignificant just because the amounts are small. Yet, in this study, the focus was given to the waste group that has the highest contribution to the overall scrap amount. Also, for waste code 16 02 16, which is classified as non-hazardous waste, is currently being sent to disposal. For 16 02 16, better waste management alternatives can be used.

As mentioned before, there is no BREF document tailored towards refrigerator production. As a result, BAT alternatives in BREF documents that can be relevant are identified and evaluated considering their adaptability to the plant regarding environmental benefits, technical practicability and economic feasibility. Surface treatment of metal and plastic BREFs can be used for metal forming process and dyeing processes in the plant. However, information on waste minimization in refrigerator manufacturing processes is limited in these BREFs.

Waste reduction and waste management techniques which can be seen in Table 4.17 were compiled using the waste management approaches of different industries, sustainability reports of household appliances companies and literature search. Whether the techniques investigated exist in the company, their potential in applicability, reasons if not applicable are determined by talking to the responsible personnel one by one. In communications, it was concluded that some of the techniques had already been applied in this refrigerator manufacturing company, some are applied but not common, some are not applicable, and some are applicable and recommended for the company.

Table 4.17. Waste reduction and management techniques for process of refrigerator plant

Number	BAT	Target	Situation in the Company	Reference
1	Information Technology (IT) Systems	Waste Reduction, Effective Use of Raw Materials	+	(Siemens, 2019a) ("Information Technology for Manufacturing: A Research Agenda," 1995)
2	Inventory Management	Waste Reduction, Effective Use of Raw Materials	+	(Hunt, 1991)
3	Preventive Maintenance	Waste Reduction, Effective Use of Raw Materials	+	(Hunt, 1991)
4	Modifying Production Process	Waste Reduction, Effective Use of Raw Materials	+	(Hunt, 1991)
5	Air Knives Usage	Waste Reduction, Effective Use of Raw Materials	√	(Ministry for the Environment, 1997)
6	Laser Cutting	Waste Reduction, Effective Use of Raw Materials	~	(European Resource Efficiency Knowledge Center, 2019)
7	Prevention of the Metal from Corrosion	Waste Reduction, Effective Use of Raw Materials	+	(Integrated Pollution Prevention and Control, 2006)

Table 4.17. Waste reduction and management techniques for process of refrigerator plant (continued)

Number	BAT	Target	Situation in the Company	Reference
8	Optimization of Nesting	Waste Reduction, Effective Use of Raw Materials	+	(Juriani & Lahri, 2016)
9	Physical Recycling of Waste Polyurethane	Waste Volume Reduction, GHGs Reduction	√	(Yang et al., 2012)
10	Chemical Recycling of Waste Polyurethane	Waste Reduction Effective Use of Raw Materials	-	(Shin et al., 2019) (Kugler, 2004)
11	Zero Waste to Landfill Policy	Waste Reduction, Waste Recycle, Conservation of Resources	+	(Electrolux, 2018)(Whirlpool Corporation, 2018)(Philips, 2018)
12	Recycling Rate Target	Waste Recycle, Conservation of Resources	+	(LG Electronics, 2019)(Samsung Electronics, 2019)(Miele, 2019)(Philips, 2018)(Bosch, 2018)
13	ISO 14001:2015 Environmental Management System	Waste Management, Waste Reduction	+	(Electrolux, 2018)(Bosch, 2017)(Miele, 2017) (Whirlpool Corporation, 2018)(Samsung Electronics, 2019)(Bosch, 2018)

Table 4.17. Waste reduction and management techniques for process of refrigerator plant (continued)

Number	**BAT**	**Target**	**Situation in the Company**	**Reference**
14	Lean Manufacturing & Six Sigma Method	Waste Reduction, Effective Use of Raw Materials	+	(Mor et al., 2015) (Şen et al., 2019)
15	Crushed Plastic Usage	Waste Reduction, Effective Use of Raw Materials	+	(MacLean-Blevins, 2017)
16	Recycled Plastic Usage	Plastic Waste Reduction and Effective Use of Raw Materials	~	(Bosch, 2018)(Whirlpool Corporation, 2018) (Miele, 2019) (Philips, 2018) (General Motors, 2018)
17	Waste Paint Recovery and Usage System	Waste Paint and Cost of Paint Reduction	-	(Zorlu Holding, 2018)(AkzoNobel, 2019)
18	Screwless Design-Snap Design& Ultrasonic Welding	Waste Reduction	+	(Samsung Electronics, 2019) (Acer Corporate, 2007)
19	Packaging with Bio-Based Materials	Waste Reduction	√	(Samsung Electronics, 2019) (Sadhbh Walshe, 2013)
20	Wooden Pallet Repairing	Waste Reduction	√	(Song et al., 2015)
21	Wooden Pallet Recycling	Waste Reduction	-	(General Motors, 2018)

Table 4.17. Waste reduction and management techniques for process of refrigerator plant (continued)

Number	BAT	Target	Situation in the Company	Reference
22	Wooden Pallet Reuse	Waste Reduction	√	(Unilever, 2019)
23	Making Animal Bedding by Using Scrap Wood	Waste Reduction	√	(Song et al., 2015)
24	Reusable Containers& Pallets	Waste Reduction	~	(Toyota, 2018) (Unilever, 2019)
25	Container Tracking System	Effective Use of Raw Materials	√	(Toyota, 2018)
26	Reuse Cardboard Boxes	Waste Reduction	√	(Unilever, 2019)
27	Using Waste as Alternative Fuel	Waste Reduction	+	(Unilever, 2019)

+: already applied, ~: not common, -: not applicable, √: suggested

Information Technology (IT) Systems

Information technology (IT) systems can be used to control assembly line. These systems are applied in different industries such as household appliances, PCBs production, mechanical assembly, automotive suppliers, electronic devices. Some of the advantages of using IT system on assembly lines are to improve traceability of the production line and products to detect any defect quickly in production and to check the process during and before the operations (Siemens, 2019a). If there is a defect in the assembly line, it will be quickly corrected. Therefore, wastes especially scraps can be reduced ("Information Technology for Manufacturing: A Research Agenda," 1995).

Inventory Management

The inventory management is an important waste management method. Keeping a balance between production of final products, semi-products and supply of raw materials can keep the raw materials from being expired in the shelf. Also, if inventory management is not made properly, more materials will be stacked in warehouses. Thus, the storage space and maneuverability of transportation tools will reduce. This will increase the risk of accidents and the spills of residues during transportation of materials Overproduction can cause damaged final products. The overall cost of the mentioned problems not only add up to disposal cost but also the material used in the products would be wasted.

Implementing the methods like just in time manufacturing will tighten the supply chamber and the shipment of the finished product. Thus, the waste caused by expiration of raw material and improper inventory management may be reduced. Though the waste could be reduced by implementing the so-called methods, just in time manufacturing is hard to apply (Hunt, 1991).

Modifying Production Process

For each business model, the first step to reduce the waste and propose a better management is to examine the whole process from supplying the raw material to shipment of the finished product. Some suggestions for optimizing the production process can be (Hunt, 1991);

- Improvement of storage and transport of both raw materials and finished products to reduce the losses resulted by spills, leaks, damages, etc.,
- Planning the production to reduce cleaning work, for example painting with light colors, can be accomplished before painting with dark color. Because dark color covers light colors easily, and there is no need to clean paint booths.
- Tightening the internal quality controls to minimize faulty raw materials going into production.

- Collecting surplus material for reuse.
- Segregation of the waste to improve recycling efficiency.

Maintenance

The preventive maintenance actions can also help to reduce the waste related to equipment failures. This way, equipment loss and the loss of a semi-product can be reduced by proper management of preventive maintenance. Also, it is important to note that the equipment loses can cause large scale waste of scrap materials. Therefore, preventive maintenance should be handled properly. (Hunt, 1991).

Air Knives

The air knives are becoming more popular for heating and drying processes in industry. It is being used for drying products and surfaces. Air knives are more energy efficient rather than compressed air and heating elements. Air knives take less time to warm up than the conventional compressed air dryers. Also, air knives give more uniform drying than heating elements and compressed air dryers. Thus, it prevents the manufacturing of damaged, oxidized or out of tolerance products (Ministry for the Environment, 1997).

Air knives usage is suggested before drying process in dye house. This technique will remove the water remaining at the corner and thus reduce the amount of corrosion-induced scrap. In addition to waste reduction, responsible personnel can be informed that this will also eliminate the heat spent to remove remaining water in the drying process. Thus, natural gas will be saved, and greenhouse gas reduction will be achieved.

Laser Cutting

Generally, shaped parts are cut out from sheet metal and mechanical punches have been used. The mechanical systems use a punch and die in the cutting job. This kind of system works with approximately %25-%30 cutoff ratio. The laser cutting systems are more efficient and they can work with less cutoff ratios (European Resource Efficiency Knowledge Center, 2019). Therefore, less waste will be produced compared to mechanical punching systems. Laser cutting is applied in the Company, but it is not common. Responsible personnel stated that laser cutting method can slow down the system where production is intense and fast. Therefore, it is necessary to use many lasers cutting machines, which may be costly.

Prevention of the Metal from Corrosion

Recommendations to reduce scrap formation in the Reference Document in the BAT for Surface Treatment of Metals and Plastics (Integrated Pollution Prevention and Control, 2006) aim to protect metals from corrosion. The surface treatment and coating can be damaged by corrosion on metal surfaces. Thus, corroded parts will appear as scraps. To protect relevant parts from corrosion, the following methods should be used;

- Reducing the waiting time spent on storage
- Improvements on storage and transport operations
- Proper packaging
- Immersing into oil for protection from corrosion.

Optimization of Nesting for Sheet Metal Cutting

Sheet metal forming is an important process for manufacturing industry due to its impact on costs. Therefore, improvements are conducted on materials, new forming technologies are applied, and production equipment are used in sheet metal forming process (Tisza, 2013).

The optimization of metal plate cutting is an important method to reduce waste generation. Scrap metals from offcuts are the main waste arising from the cutting operation. The cutting layout design for optimum scrap metal generation would reduce the waste related to offcuts (Juriani & Lahri, 2016).

Polyurethane Waste Management

Polyurethane waste is hard to handle due to its high volume per kilogram. The waste covers large space in landfill and its incineration produces poisonous gasses which can be important for air pollution and control. Therefore, the waste of the polyurethane should be recycled. Approaches are listed below;

***Physical recycling*:**

There are several ways to recycle the polyurethane waste. The most used method is to crush the polyurethane foams. The polyurethane particles would be mixed with adhesives and molded again by compression. The method is cheap and simple. However, the performance of the recycled product is lower than the original. Therefore, recycled polyurethane can be used in cheaper products (Yang et al., 2012).

Waste polyurethane is sent to licensed facilities for disposal and frequency of this operation is high due to the volume of waste polyurethane. Physical recycling of waste polyurethane is suggested for the Company. By using this technique, high volume of waste polyurethane and the number of sending operations could be reduced. Thus, greenhouse gas generation could be reduced due to lower number of trips.

Chemical recycling;

- Characteristics of the rigid polyurethane foams vary due to recycled polyol produced by chemical reactions(Shin et al., 2019) .
- This method is used by a few polyurethane manufacturers. They use their polyurethane waste to regain the polyol and recycled polyol is refeed into the process (Kugler, 2004).
- The chemical recycling is yet to be efficient and the method is limited for certain types of polyurethane. But the process is promising for recycling of all waste polyurethane (Kugler, 2004).

Recycling of polyurethane is a preferable method compared to sending to disposal. However, installation and operation of a recycling facility will be costly. In addition to this, responsible personnel stated that quality problems because of recycled polyol usage are possible. Therefore, this technique will not be applied and not recommended to the Company.

Zero Waste to Landfill

Nowadays many companies in cosmetics, automotive, consumer packaged goods, alcoholic beverages, technology and household appliances sector are implementing zero waste policy. However, the scope of the zero-waste policy they apply varies from company to company. Some companies have defined their zero waste policy as not to send their wastes to a landfill (Philips, 2018; Whirlpool Corporation, 2018) while some companies have also regarded the waste they sent to incineration without energy recovery within zero waste policies (Electrolux, 2018). In brief, zero waste policies may provide means to waste reduction and waste material reuse in other sectors. Yet, research may be required for the latter.

Recycling Rate Target

When sustainability reports of household appliances companies were examined, it was seen that they have commitments on recycling of waste (LG Electronics, 2019; Samsung Electronics, 2019; Miele, 2019; Philips, 2018; Bosch, 2018). These commitments comply with their zero waste to landfill policies. Companies improve processes and waste management methods to increase this rate over the years. Therefore, adopting manufacturing technologies in combination with zero waste policies may help the Company to further improve its environmental performance.

ISO 14001:2015 Environmental Management Systems

International Organization for Standardization (ISO) 14001:2015 indicates the need for an environmental management system. Within the scope of the Company's environmental policy, this standard aims to improve environmental performance, to comply with legal requirement and to achieve environmental targets. Therefore, most of the household appliances company have ISO

14001:2015 certification (Electrolux, 2018; Bosch, 2017; Miele, 2017;Whirlpool Corporation, 2018; Samsung Electronics, 2019)

Waste Paint Recovery and Usage System

Some of the paint manufacturer and household appliances companies carried out recycled paint projects. Paint manufacturer used waste white paints which were undergone to sorting, filtering and refining process. The final paint was produced from 35% recycled white paint (AkzoNobel, 2019). A household appliances company has wet paint application systems with an average paint usage efficiency of 50%. The remaining 50% is collected and filtered (Zorlu Holding, 2018). Since the powder painting system is used in the Company, this wet paint recovery system is not suitable for the refrigerator Company.

Six Sigma

Six Sigma is a statistical analyzing and problem solving technique that aims to reduce faults caused by operations to 3.4 in million parts (Şen et al., 2019). Usage of such statistical analysis tools and data mining can illuminate the root causes of faults in processes and actions can be taken accordingly. Faults could be reduced through data analysis, which in turn, would reduce the waste related to faults.

Lean Manufacturing

Lean manufacturing principles basically focus on the reduction of non-value adding operations (NVA). One of the most known principle about the lean manufacturing is the Total Productive Maintenance (TPM). Some of the example methods are listed below (Mor et al., 2015).

- Reduction of handling operations prevents unnecessary movement in production. In this way, operators in production can focus only on few movements and the wastes caused by lack of attention can be reduced.
- As a part of TPM, operators can be educated to use the machines that they constantly work with. This way, the operator may do the

maintenance autonomously. Maintenance can reduce the faulty in operations.

- Within TPM, it is aimed to prevent all leakages such as oil and air. With leakage prevention, waste oil and contaminated waste can be reduced. In addition to waste reduction, air which is a high energy consuming operation to supply can be used efficiently.

Crushed Plastic Usage

Rather than sending the plastic waste resulting from thermoforming, injection and extrusion processes to a licensed recycling facility, plastic waste can be crushed to refeed into the process (MacLean-Blevins, 2019). Thus, raw material usage and plastic waste generation can be reduced.

Recycled Plastic Usage

To reduce the consumption of resources, recycled plastics are used in production along with the primary plastic raw material (Bosch, 2018). Expanding the usage of recycled plastics is desired by the industry. However, integration of recycled raw materials into existing processes is relatively complex and requires time to implement. Moreover, following the usage of recycled material, the product should meet the performance required for product functions and meet the quality standards of the company (Miele, 2019). The Company is using recycled plastics only for the production of few components. The usage can be increased for components which do not require high robustness to function.

Screwless Design

The screwless design methods can be used for assembling parts together. The screwless design will decrease the material used for fastening. Parts can be easily dismount and easier to recycle (Acer Corporate, 2007). According to the information taken from the responsible personnel of Research and Development Department, following methods can be used to assemble parts;

- Snap fit design can be used to connect parts together. This method does not require extra fasteners. Thus, the materials used for assembly can be decreased.
- Rather than using fasteners and sealing components, ultrasonic welding can be used to connect plastic parts that do not require leakage control. Downsides of this method are that it will be time consuming and expensive.

Packaging Waste Reduction Techniques

Different industries mentioned in Section 2.6. and household appliances manufacturers had focused on packaging waste reduction. These techniques and their applicability or current situation in the Company are discussed below.

Wooden pallets are usually broken after 10-12 times of usage as declared by the responsible personnel from the material planning department. As can be seen in Table 4.11 and Table 4.12, 15 01 03 coded wastes have an important share in the total amount of packaging waste and their generation trend consistently increases. Pallet repairing method and method of using pallets for other purposes such as making furniture or animal bedding can be applied in the Company to reduce wooden packaging wastes (Song et al., 2015; Unilever, 2019). General Motors (2018) recycled pallets to make wooden beams which can be used in building constructions. This technique cannot be applied in the Company because it may be hard to find a building construction firm located nearby to send the wastes.

As can be seen in Table 4.11 and Table 4.12, 15 01 02 coded wastes ranked the third in the total amount of packaging waste and their trend is fluctuating. Toyota (2018) used the reusable containers to reduce old containers which were sent to landfills. Unilever (2019) also used reusable pallets and containers to reduce the waste produced in transportation and changed their plastic containers with the reusable steel ones. As a result, they decreased the amount of plastic wastes produced in a factory in Italy. In addition to using reusable containers, Toyota (2018) has plans for future to track all returnable containers by placing chips on containers to monitor and reduce the number of containers lost in transportation. Reusable pallet usage is applied in the Company but is not common. Reusable container tracking system is suggested for the Company to reduce plastic packaging waste.

As can be seen in Table 4.11 and Table 4.12, 15 01 01 coded wastes have an important share in the total amount of packaging waste and their trend consistently increases. Unilever (2019) gave away their used cardboard boxes for reuse for other purposes like house moving. This way Unilever reduced 10% of their waste related to cardboard boxes. By applying this approach, the Company can reduce its paper and cardboard packaging wastes.

Companies improve their packaging vision by using recycled materials in their product packaging. For example, 86% of product packaging of P&G is recyclable (P&G, 2019). Samsung (2019) uses bio-based material in some packages. Use of bio-based material in product packaging can be suggested and applied in the Company. Product packages protect the product from external influences to prevent damage to the product during storage and/or transportation. Unsuitable packaging will result in products scraps. Therefore, tests such as compressing performance test, vibration test, shock test, temperature test, etc. should be done before changing packaging (Nefab, 2019).

Sending Waste to a Cement Factory

Unilever (2019) sent some of their waste to a cement factory as an alternative fuel in kilns. This technique is already applied in the Company. The Company sent its 07 02 14,15 02 02, 19 08 13, and 20 01 26 coded waste to a cement factory as an alternative fuel.

CHAPTER 5

CONCLUSION

The aim of this study is to fill gaps in the examination of waste produced during the production of refrigerators. All hazardous, non-hazardous and packaging wastes arising from production are evaluated in a process-based approach. Process specific and non-process specific wastes are determined. Current disposal methods of the company are evaluated in terms of waste sent to a landfill and recycle.

In this study, following results are obtained.

- The refrigerator assembly of the plant is similar to the general assembly lines presented in the literature.
- According to 5 years of data, non-hazardous wastes have by far the largest share in the total waste. Hazardous wastes have the lowest share.
- Wastes from additives containing hazardous substances (07 02 14), packaging waste containing residues or contaminated by hazardous substances (15 01 10), wastes contaminated by hazardous substances (15 02 02), discarded equipment containing hazardous components (16 02 13), sludges from treatment of industrial waste water (19 08 13) have the greatest impact on the total amount of hazardous waste produced in the plant.
- Metal scrap waste (12 01 01) and waste of non-hazardous components removed from discarded equipment (16 02 16) contribute the most to the amount of total non-hazardous waste in the plant.
- Paper and cardboard packaging (15 01 01), plastic packaging (15 01 02) and wooden packaging (15 01 03) wastes dominate the total amount of packaging waste.

- 100% of collected packaging wastes are diverted away from the landfill within 5 years. At least 99% of hazardous wastes are diverted away from the landfill. This figure is 97% to 98% for non-hazardous wastes. The total waste recycling rate, including hazardous waste, non-hazardous waste and packaging waste, is calculated as 98.7% over a 5-year average.
- The percentage difference between incoming material and resulting product and waste is very low at 1.33% according to mass balance study. This shows that good recording is performed, and input material and output product are consistent in terms of mass.
- Environmental performance of the Company in terms of waste generation factor and percentage of waste recycling is evaluated and compared to leading household appliances companies. Compared to other companies, waste recycling rate is higher and waste generation factor is lower. It is recommended that the BATs listed below be applied to further improve the Company's environmental performance.
  - ✓ Air knives usage
  - ✓ Physical recycling of waste polyurethane
  - ✓ Packaging with bio-based or reusable materials
  - ✓ Wooden pallet repairing and reuse
  - ✓ Use of scrap wood for different purposes
  - ✓ Use of a container tracking system
  - ✓ Reuse of cardboard boxes

As the refrigerator manufacturing processes and steps used in the Company is similar to a conventional production process scheme, results obtained in this study can be used at least for comparison purposes by other companies that manufacture refrigerators. Although environmental performance of the Company is good for the parameters considered in this study, there are still some actions that can be taken for further improvements. As the inventory of wastes and locations of waste production in the production scheme is now well documented, it may be easier to establish better waste management approaches and observe the impact of new measures on waste production. The study indicated that majority of the waste produced during production is of non-hazardous nature. As packaging waste reaches 23.9% of the total waste amount, focus can be given to obtain reduction in this category of waste as they are not related with the manufacturing of the refrigerators. Potential solutions are listed above. Although hazardous waste amount produced may seem low, these wastes may still require attention due to their hazardous properties.

CHAPTER 6

RECOMMENDATIONS FOR FUTURE STUDIES

In this thesis, process of refrigerator production plant and inventory of hazardous, non-hazardous and packaging wastes produced were conducted. Future studies on household appliances especially related with refrigerator production and waste minimization can be conducted. Different refrigerator production plants with different production schemes can be assessed and compared.

The data range covered a 5 years period for waste inventory calculations and 4 years for mass balance calculations in this study. The data size can be increased to generate models for prediction of expected waste production amounts. In this thesis, mass balance study was made for the refrigerator production area only.

The records of waste data, input and output material can be kept separately for each process. Thus, mass balance can be made for each process to evaluate the environmental performance of each process.

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