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Life cycle assessment analysis of plastic coupling

Plastik manşonun yaşam döngüsü değerlendirme analizi

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Abstract

Plastics are often used in every industry today due to their light weight, durable and insulating materials. As a result of the widespread use of petroleum-based plastics, there is also an inevitable increase in the amount of waste. Therefore, it is important to determine the effects of plastics on the environment. In this study, the life cycle assessment of couplings, which are commonly used pipe fittings in irrigation and drinking water pipes, was investigated. The environmental effects of the production and disposal stages of the coupling were determined using the Eco-Indicator 99 method of SimaPro 8.0.2 software. At the end of the study, the highest environmental impact occurred during the production of the coupling (79.9%) and it was determined that the most important factor causing this was the use of polypropylene plastics (48.1%).

Keywords: life cycle assessment, Landfilling, plastic coupling, Plastic waste, Endpoint.

Öz

Plastikler hafif, dayanıklı ve yalıtkan malzemeler olması nedeniyle günümüzde her sektörde sıklıkla kullanılmaktadır. Petrol bazlı plastiklerin yaygın olarak kullanılması sonucu atık miktarında da kaçınılmaz olarak artış olmaktadır. Bu nedenle plastiklerin çevreye olan etkilerinin belirlenmesi önemlidir. Bu çalışmada, sulama ve içme suyu borularında yaygın olarak kullanılan boru bağlantı parçası olan manşonların yaşam döngüsü değerlendirmesi incelenmiştir. Manşonun yaşam döngü değerlendirmesi aşamaları, hammaddenin nakliyesi, manşon parçalarının üretimi, montajı, ambalajlanması ve düzenli depolama alanında bertarafını içermektedir. Manşonun üretim ve bertaraf aşamalarının çevresel etkileri SimaPro 8.0.2 yazılımının Eco-Indicator 99 yöntemi kullanılarak belirlenmiştir. Çalışma sonunda en yüksek çevresel etki manşonun üretimi (%79.9) esnasında ortaya çıkmış ve buna sebep olan en önemli faktörün ise polipropilen plastik (%48.1) kullanımından kaynaklandığı tespit edilmiştir.

Anahtar kelimeler: Yaşam döngüsü değerlendirmesi, Düzenli depolama, Plastik manşon, Plastik atık, Son nokta.

1 Introduction

Plastics are durable, insulating and lightweight materials. In addition, since it can be shaped and produced easily, its usage areas are very wide [1]. During the production of plastics, high energy is also needed while using petrochemical and fossil raw materials. In the production of plastics, 99% of the raw materials are fossil fuels, accounting for 8-9% of the global oil and natural gas consumption [2]. It is estimated that the total plastic raw material production in 2019 was around 1 million 14 thousand tons According to Turkish Plastic Industry Foundation 2019 annual report, it is stated that the plastic type with the highest production volume is thermoplastic [3].

Apart from the production of plastics, waste plastics that have completed their life are a separate problem. Due to plastic's resistance to corrosion, the difficulty of breaking it apart means it can last for hundreds of years without degradation. Plastic pollution occurs because of these wastes that are not non-biodegradable in nature [4]. Globally, plastic pollution is estimated to cause at least $13 million in financial losses per year [5]. Inadequate waste management is cited as the main problem behind plastic pollution worldwide. Although the EU is considered among the best performers in the collection of plastic waste, it is known that it can only collect 30% of its waste [6]. According to the statistics, 38% of the plastics in Europe are disposed of in landfills, 26% are recycled, and the remaining 36% are reused for energy production [7]. Apart from this, most of the European countries ship their wastes to third-world countries for processing [2]. Plastic waste export to Turkey is quite high. Turkey is the largest waste point importing approximately 11.4 million tons of waste from the EU in 2019 [1]. Although recycling, composting and incineration systems are used for waste disposal in Turkey, the most commonly used disposal method is landfill.

With the rapid production of plastic products, waste generation is also increasing. In this situation it is very difficult to leave behind a sustainable environment for future generations. While improving economic efficiency and quality of life for the development of a sustainable system, the environment should be protected [8]. In order to achieve environmental sustainability, approaches such as clean production, waste minimization, industrial symbiosis, green engineering, design for the environment (DfE) and life cycle assessment (LCA) should be adopted [9]. One of the most used approaches for maintaining sustainability is the LCA, which enables the identification and minimization of environmental impacts [10], [11]. LCA is a system that detects the raw materials used in the production of a process or product, calculates the emissions and energy consumption of the product, assesses the transport of the product, evaluates the environmental effects of distribution and use of the product, and also examines the environmental impact of the waste disposal [12]. LCA evaluates environmental impacts such as depletion of abiotic resources, photochemical oxidation formation, global warming, climate change, acidification, eutrophication, ozone depletion and human toxicity, from raw material intake to disposal [13]. With

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this approach, it is ensured that the environmental effects of the products or processes are correctly interpreted. LCA is a method of identifying impacts through modeling and can be used to guide process improvement [14]. A typical LCA study consists of four parts: Goal and scope, life cycle inventory analysis, life cycle impact analysis (LCIA), and interpretation [15]. The system boundaries of LCA studies are named according to the stage at which they end and begin. Obtaining the raw material: the cradle, the stage in which the raw material is shipped to the factory: the door, and the disposal of the product after its final use: the grave [13]. During the LCA in the transportation of raw materials, the production, use and disposal of the product stages; potential cradle-to-grave impacts of the product or process during its life-time, natural resources, emissions into the air, water and soil, energy consumption and their environmental status are assessed [15],[16].

The logic of life cycle thinking is not dependent on a single environmental parameter. It focuses on solving problems by developing a holistic and analytical system [17]. This assessment is a decision-making aid rather than an absolute decision-making tool in environmentally friendly choice of products and processes [18]. Such a system makes cooperation between all stakeholders of the product or process compulsory. In this context, it is necessary to consider LCA along with issues such as clean production, industrial ecology, risk assessment, technological developments, environmental impact assessment, and product management [17]. This is why LCA is not a single study, but rather a system that requires the study of common disciplines.

Plastic pipes and couplings used in the landscaping sector and drinking water network lines are preferred due to their elasticity and easy production, although they have much more significant greenhouse gas emissions compared to other material types. In a study by Recio et al. [19], greenhouse gas emissions and energy consumption of pipes made of different materials such as polyethylene, polyvinyl chloride, polypropylene, stereo casting and concrete were investigated. At the end of the study, considering the energy consumption and CO_2 emissions, it was determined that polyethylene and concrete could be the most suitable materials. Table 1 summarizes the LCA studies on piping systems.

Plastic couplings, which are produced by injection technology and provide connection of pipes, are frequently used in landscape sector and drinking water network lines. Due to the frequent use of the couplings and the raw material being plastic, the impact on the environment is high both in production and disposal. In order to determine the full environmental impacts, it is important to evaluate the life cycle of plastic couplings. For this purpose, in this study, the life cycle assessment of plastic couplings frequently used in water delivery and irrigation systems was investigated from cradle-to-grave and environmental effects were determined. As a result of the study, it is aimed to reinforce the role of fossil resources and energy in the production and disposal of the coupling by emphasizing the areas that need improvement. In addition, it is targeted to assist decision-makers in the environmental processes of the coupling and the use of alternative bio-based polymers has been suggested.

2 Material and method

2.1 Goal and scope definition of LCA

At this stage, the goal and scope are determined according to the intended applications and assumptions of the study. The purpose of the study is defined by the functional unit and system boundaries [24].

The aim of the study is to determine the environmental impact at the life cycle assessment of the coupling that is used to connect pipes. It is targeted to determine the environmental effects of a small connection piece, such as coupling and understanding its importance for the environment.

Table 1. Previous studies using the LCA software program and different methods.

Title	Software/Method	Results	Reference
Combined MFA-LCA for analysis of wastewater pipeline networks	SimaPro/CML2002	It has been determined that greenhouse gas emissions have an effect during the production and manufacture	[20]
Life cycle sustainability assessment (LCSA) for selection of sewer pipe materials	SimaPro 7.1/Eco-indicator 99	At the end of the study, they decided that the PVC pipe was the most environmentally and financially feasible.	[21]
Environmental life cycle analysis of pipe materials for sewer systems	SimaPro 8/TRACI	As a result of the study, reinforced concrete was determined as the most environmentally friendly material.	[22]
Environmental and economic life cycle assessment of PEX and copper plumbing systems: A case study	SimaPro 8/TRACI	PEX pipes are less costly than copper pipes. According to the results of the analysis, PEX pipe replaces the classical copper pipe in terms of environmental impacts.	[23]
Life cycle assessment of pipes and piping process in drinking water distribution to reduce environmental impact	SimaPro 8/CML2002	Ductile iron was identified as the material with the highest environmental impact during the production phase. In the transport phase, fibro cement pipe was found to be the material with the highest environmental impact.	[24]
Comparative life cycle assessment of water supply pipes made from bamboo vs. polyvinyl chloride	SimaPro 8.5/Eco-Indicator 99	The results showed that all major indices of environmental impacts (except eutrophication index) were significantly reduced when bamboo-winding composite pipes were used instead of polyvinyl chloride.	[25]

2.1.1 Functional unit

The functional unit defines the basic function performed by the product or system and indicates the extent to which this function will be included in the planned LCA study [15].

The functional unit was selected as a product (coupling) in the study. A coupling diameter is 20x20 cm and consists of nine parts [26]. These parts are the nut, the pipe holder, the gasket holder, the o-ring and the coupling body. Two pieces are produced for each piece except for the coupling body. Three different types of plastic are used in the production of parts. The coupling body, nut and gasket holder parts are made of polypropylene (PP) plastic, the pipe holder part is made of high density polyethylene (HDPE) plastic, and the o-ring part is made of polyurethane (PU) plastic. Apart from the o-ring, in the production phase of the plastic parts the granular polymers are discharged into the plastic injection machines, melted at high temperature, and transferred into liquid form. The polymers in liquid form are then injected into the mold and finally passed through the cooling water to form solid plastic. Aside from the actual part that comes out of the mold, the remaining pieces of the mold, called runners, as well as the products that are determined to be defective, are collected and sent to the crushing machines for later use as raw material. Here, particles the size of very small granules are returned to the system. It is possible to use these plastics repeatedly. This is because polypropylene and high density polyethylene plastic is thermoplastic. For this reason, there is no waste formed in the system during the production phase and a 100% recycling rate is possible. The o-ring is a thermoset plastic, so the production method is different from the other parts. The raw polyurethane cut in strips is placed in a plastic molding machine and cooked. As the chemical structure of the plastic is changed during this process, the runner formed in the o-ring production and the defective products are not used again.

The end of-life is also included in the assessment. The end-of-life disposal scenario of the plastic coupling was chosen as disposal at the landfill.

2.1.2 Boundaries

This study assessed the life cycle of one coupling, production and disposal phase after use. As a scenario of the disposal phase, disposal in landfill is selected. Information on system boundaries is shown in Figure 1.

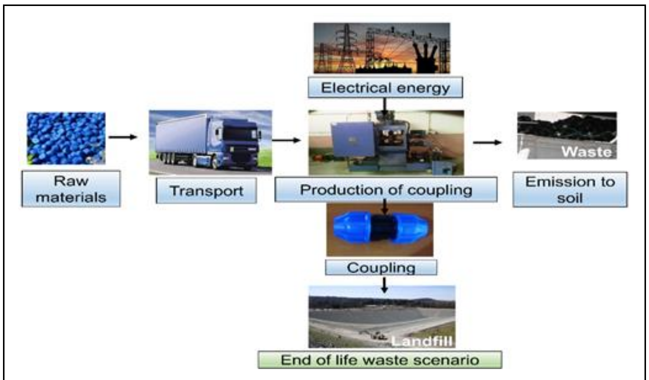

Figure 1. System boundaries.

The manufacturing phase of the coupling includes transporting the raw material to the facility, manufacturing the coupling parts, assembling these parts, carrying out the quality control of the produced products, and packaging the products. Transportation of the raw material to be used in production is road transportation. Energy usage data related to the transport of raw material to the factory is entered into the inventory of the program. During the production of the raw material, plastic injection molding machines are used and these machines use electrical energy. In the production of o-rings, the recycling of defective products and gaps formed during production is not possible. Therefore, up to 10% of the input raw material is formed as solid waste. It is sent for use as an asphalt additive in these wastes. This part is not included in the waste scenario. Wastewater and air emissions are not produced during production. After the production of the coupling parts is completed, assembly of these parts is performed by workers in the factory. Therefore, there is no energy consumption. After the assembly of the coupling is completed, the quality of the product is checked. Quality control is carried out by factory workers. For this reason, energy use is not a concern and there is no emission to the environment. Since these parts are included in the production stage, they are introduced into the program. The products that pass the quality check come to the packaging section. When packaging is done, the couplings are first placed in the plastic bags. Low density polyethylene plastic is used as the packaging material of the plastic bags. There are 25 couplings in one bag. The bags are then placed inside the parcels. Corrugated cardboard is used as packaging material for the parcels. There are 18 plastic bags in one parcel. No energy is used because packaging is done by workers. Packaging materials and quantities are entered into the life cycle inventory. The products that have been packaged are sent out from the factory and sent to consumers. The products are sent to the consumer by road. At this point, the energy consumption data during transportation is entered into the inventory of the program. A waste scenario has been created for products that have been used by the consumer and can no longer be used. As a waste scenario, a landfill disposal method that is widely used in Turkey has been chosen.

2.2 Life cycle inventory analysis (LCI)

This stage, which constitutes the second step of the LCA, includes the collection of input and output data including raw material usage, energy consumption, and emissions of the processes in the system [24]. The coupling's production data is from a factory in Samsun, Turkey [26], [27]. In addition, the electrical energy data used in the production of the coupling were obtained from the Turkish Electricity Transmission Company (TEIAS). Electrical data are explained in detail in section 2.2.1 and Table 3. In order to clarify the LCA inventory, the data included in the transportation of the raw material, production, installation and disposal are given in Table 2. After the input information is determined, the Ecoinvent database is used to determine the environmental effects of the resource consumption, waste and emissions of the processes. Ecoinvent is a universal database that provides numerous and reliable data (electricity, production processes, metals, transportation, waste management, etc.) [24]. SimaPro 8.0.1 software [28] containing database information from Ecoinvent (v 2.2) was used to evaluate the environmental impact of the coupling. Since the raw material is transported to the facility from a long distance (Izmir-Samsun, 1085 km), it is thought that it may have an impact on the environment.

Table 2. Production and end-of life scenario data of coupling.

Production Stage	
Parts of coupling/used raw material/amount(g)/transport distance (Lorry 16-32t, EURO4/RER U) (km)	Used energy (Electricity, medium voltage)
Nut/ PP/15/1085	0.041 kWh Electrical energy
Gasket holder/PP/2.3/1085	0.003 kWh Electrical energy
Coupling body /PP/23/1085	0.038 kWh Electrical energy
Pipe holder/HDPE/2.67/1085	0.0058 kWh Electrical energy
O-ring/PU/1/1085	0.005 kWh Electrical energy
Packaging	Comment
Packaging film /LDPE/0.932	Weight of 1 bag is 23 g. There are 25 couplings in 1 bag.
Corrugated board/Recycling fibre/0.333	1 box weight is 150 g. There are 450 products in 1 box.
Waste Disposal Stage	
Waste disposal scenario (Landfill/CH U)	Distance between consumer and landfill site (km)
Coupling -Disposal-nut (%100) -Disposal-gasket holder (%100) -Disposal-coupling body (%100) -Disposal-pipe holder (%100) -Disposal-o-ring (%100)	20 (Transport, lorry, 3.5-7.5t, EURO3/RER U)

The total weight of a 20 cm diameter coupling is 64.94 g, of which 30 g are nuts, 4.6 g are gasket holders, 5.34 g are pipe holders, 2 g are o-rings, and 23 g is coupling body. Electricity consumption (kWh) of the parts produced for coupling production is entered into the system. A total of 0.1476 kWh electrical energy is used for the production of one coupling. Since there is no energy consumption in the assembly and quality-control stages of the coupling, there is no environmental impact. However, these steps were entered into the system. Since the packaging material data used in the packaging of the coupling will have an environmental impact, they are entered into the system. The packaging film used for packaging one coupling is 0.932 g and the corrugated board weight is 0.333 g per coupling. Finally, the end-of-life scenario was created by determining the service life of the coupling at the customer as 50 years. The data-sets sanitary landfill/CH, disposal of the Ecoinvent database (version 2.2) were applied to represent the end-of life scenario of the product analyzed [29]. Road transport is selected during the transport of waste to the landfill and energy consumption data during transport is entered into the life cycle inventory. During transportation, the distance between the consumer and the landfill site was selected as 20 km.

2.2.1 Assumptions

Raw material is considered for transportation to the factory by road in a truck with a capacity of 16-32 tons. Data related to the ratios of the resources used in electricity generation are provided by the Turkish Electricity Transmission Company (TEIAS). Table 3 lists the resources used in electricity generation in Turkey and their ratios. The data obtained from TEİAS is combined with the medium voltage power line profile data in the database of SimaPro 8.0.2 software and the data used in the program is created [30].

Table 3. Electrical energy sources and rates of Turkey (calculated from 2019 TEIAS program[a]) [30].

Energy Sources	Contribution of Energy Sources (%)
Natural gas	29
Lignite	11
Coal	9.8
Hydraulic energy	31
Flue-oil	0.5
Wind energy	8.3
Solar energy	7.4
Geothermal	1.7
Biomass+waste heat	1.3
Total	100

[a]TEIAS: The transmission system operator of Turkey.

2.3 Life cycle impact assessment (LCIA)

In this phase of the LCA, the significance of the potential environmental impacts resulting from associating data generated using life cycle inventory results is assessed (ISO, 2006). In Table 1, it has been found that the CML2 Baseline 2000, Tool for Reduction ans Assessment of Chemical and Other Environmental Impacts (TRACI) and Eco-Indicator 99 (H) methods are widely used in the LCA literature studies on water systems. Acidification, eutrophication, land use, global warming, ozone layer depletion etc. effects are data characterized at the midpoint. Unlike the CML2 baseline 2000 and TRACI methods, the Eco-Indicator 99 is a method defined by the endpoint category that combines midpoint levels. For this reason, the evaluation of the inventory results is carried out using the Eco-Indicator 99 (H) method, which is included in SimaPro 8.0.2 (Pré Consultants, The Netherlands). The reason for the selection of the Eco-Indicator 99 (H) method is that it is more understandable and interpretable than other assessment methods, according to the end point assessment. The parameters in the impact categories in the Eco-Indicator 99 (H) method are carcinogens, respirable organics, respirable inorganics, climate change, radiation, ozone layer destruction, ecotoxicity, acidification, eutrophication, land use, minerals, and fossil fuels. These parameters form the midpoint of the Eco-Indicator 99 (H) method. The middle points are gathered in the common denominator and the end points are formed. The end points in the Eco-Indicator 99 (H) method are interpreted and the related data are given in Table 4.

Table 4. Endpoints and impact categories in Eco-Indicator 99(H) [28].

Endpoints	Impact category indicators (with their unit)
Resources	Depletion of fossil fuel (expressed as MJ surplus /kg)
	Depletion of minerals (expressed as MJ surplus energy/kg)
Ecosystem quality	Land use (expressed as PDF m^2.year)
	Acidification/eutrophication (expressed as PDF m^2.year)
	Ecotoxicity (PAF m^2.year)
Human health	Climate change (expressed as DALY)
	Ozone layer depletion (expressed as DALY)
	Carcinogenic substances (expressed as DALY)
	Radiation (expressed as DALY)
	Respiratory effects (organic) (expressed as DALY)
	Respiratory effects (inorganic) (expressed as DALY)

In addition, the impact categories included in the method consist of three groups - "human health," "ecosystem quality" and "natural resources" - according to the end point method. After weighting the three endpoint groups, the final result is a dimensionless numerical value called the Eco-Indicator index denoted by pt (point). One Pt unit represents the average load (ecological footprint) of 1000 Europeans on the environment during a year [31]. The life cycle assessment of one coupling is assessed according to this method and interpreted according to impact categories. The assessment results are given in percentages. Figure 2 summarizes the steps of the coupling's LCA and the environmental effects summarized.

The midpoints that make up the last point of natural resources are minerals and fossil fuels. Humans will always extract the best resources first and leave lower quality resources for future implications. The damage to resources will be experienced by future generations, as they will have to make more effort to extract the remaining resources. Extra effort is needed to ensure that damage to the natural resources can be used by subsequent generations. This extra effort is described as surplus energy in the program and the measurement unit is MJ surplus energy/kg. The midpoints that create the end point of ecosystem quality are land use, acidification/eutrophication and ecotoxicity. The effect unit of land use and acidification/eutrophication midpoints is measured in the potentially disappeared fraction (PDF) of plants annually and in the area, while ecotoxicity is measured in the potentially affected fraction (PAF) annually and in the area. The middle points that make up the end point of human health are climate change, ozone depletion, carcinogenic substances, radiation, effects of respiratory organics and inorganics. These midpoints are measured in the Disability-adjusted life year unit (DALY). This unit was developed by the World Health Organization (WHO) and World Bank to describe the health effects that cause disease and death [28].

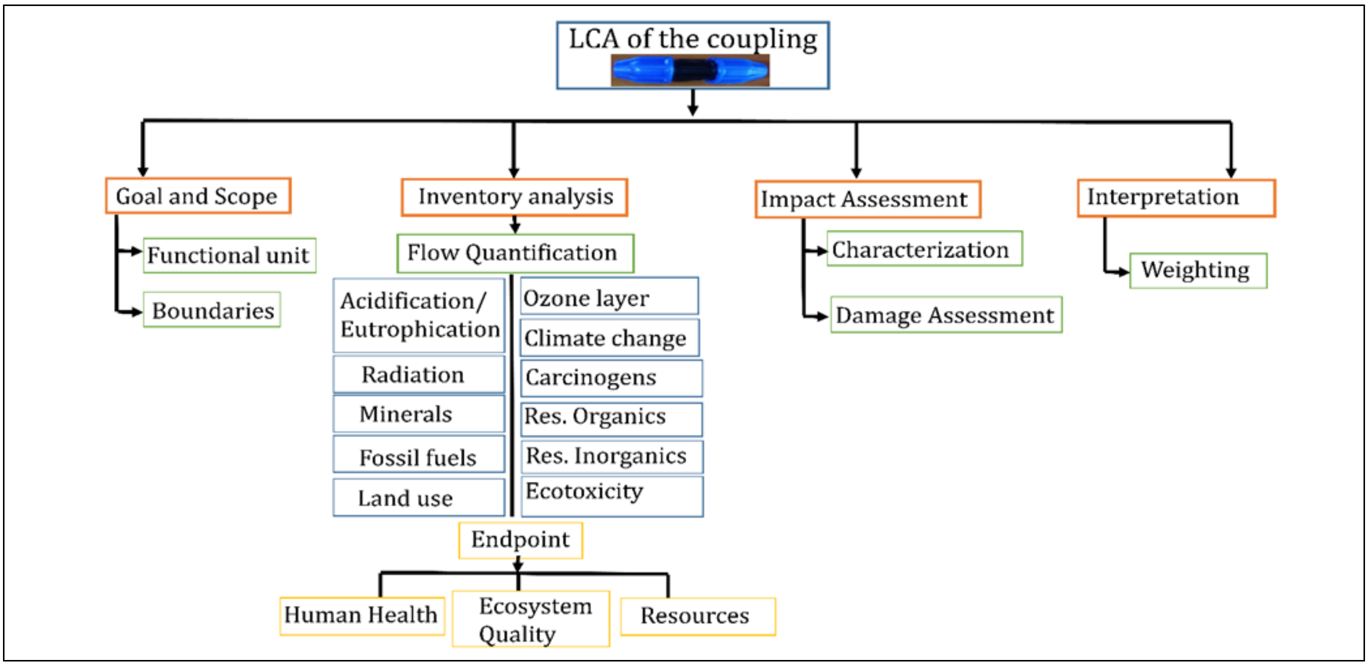

Figure 2. LCA of the coupling and its environmental effects.

3 Results and Discussions

The life cycle of the coupling was created as a cradle-to-grave, and the end of life waste scenario was selected as a landfill disposal. Cradle to grave is a description used for analysis studies covering all life cycles and includes all processes that will be passed from raw material acquisition (cradle) to waste disposal (grave) [18]. When the LCA of the coupling is examined in the flow diagram in Figure 3, it is seen that the environmental impact of the production of the coupling is 79.9% and its disposal is 20.1%. It is seen that the most environmental impact in the production of the coupling is the polypropylene material used in the coupling body and nuts with a rate of 48%.

The life cycle of the coupling is assessed in two categories: Characterization factors and damage assessment.

Interpretation according to the characterization factor is made in the midpoints in the Eco-indicator 99 (H) method. The characterization factor results of the production and disposal stages of the coupling are given in Table 5. Weights were assigned according to these results and the weighting ratios were determined. According to this assessment, it was determined that the greatest environmental impact was due to the production phase of the coupling. Natural resources and energy are consumed during the supply of raw material. This causes depletion of fossil fuels, climate change and the depletion of the ozone layer. During the production phase of the coupling, the use of plastic material causes the increase of acidification/eutrophication, carcinogenic substances, respiratory organic and inorganic substances, and energy consumption, leading to the increase of parameters such as ozone layer damage, climate change, and ecotoxicity.

Table 5. Characterization results for production and waste disposal stages [a].

Impact Category	Unit	Production of Coupling	Disposal of Coupling
Carcinogens	DALY	$2.76*10^{-1}$	**1.53**
Resp. organics	DALY	**$3.77*10^{-3}$**	$4.62*10^{-5}$
Resp. inorganics	DALY	**1.04**	$1.09*10^{-2}$
Climate change	DALY	**$5.01*10^{-1}$**	$1.29*10^{-2}$
Radiation	DALY	**$5.65*10^{-4}$**	$3.53*10^{-5}$
Ozone layer	DALY	**$8.34*10^{-5}$**	$2.17*10^{-6}$
Ecotoxicity	PAF m^2.year	**0.034**	0.018
Acidification/ Eutrophication	PDF m^2. year	0.003	**0.0402**
Land use	PDF m^2. year	**0.0006**	0.00012
Minerals	Mj surplus energy/kg	**0.00073**	$3.00*10^{-5}$
Fossil fuels	Mj surplus energy/kg	**0.761**	0.002

[a]: Dominant impacts based on weighting are shown in bold.

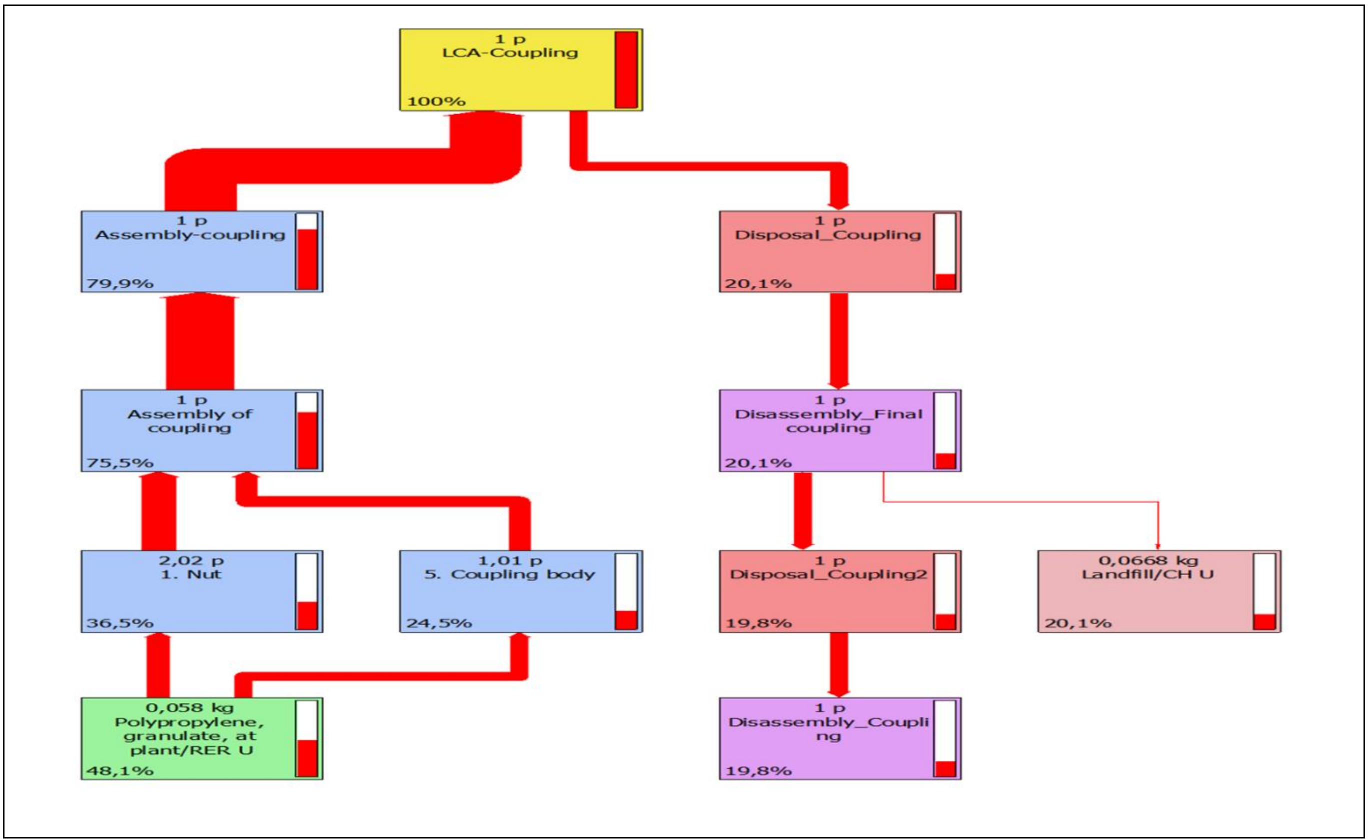

Figure 3. The life cycle diagram of coupling.

Impact categories with a high environmental impact as a result of weighting ratios are written in bold font. Selected categories, processes, materials and their impact ratios are shown with detail in Table 6.

Table 6. Impact categories and ratios of processes and materials with high environmental impact values.

Impact Category	Dominant Processes/İmpact Percent	Dominant Materials/Impact Percent
Carcinogens	Production of coupling / 0.84	Cadmium (ion)/0.97
Resp. organics	Production of coupling / 0.98	NMVOC, non-methane volatile organic compounds, unspecified origin/0.99
Resp. inorganics	Production of coupling /0.99	Nitrogen oxides/0.98
Climate change	Production of coupling /0.97	Carbon dioxide, fossil/0.99
Radiation	Production of coupling /0.94	Radon-222/0.94
Ozone layer	Production of coupling /0.97	Methane /0.99
Ecotoxicity	Production of coupling /0.66	Nickel (ion)/0.99
Acidification/ Eutrophication	Production of coupling /0.98	Nitrogen oxides/0.98
Land use	Production of coupling /0.83	Transformation, to arable, non-irrigated/0.99
Minerals	Production of coupling /0.96	Nickel, in ground/0.92
Fossil fuels	Production of coupling /0.99	0.761

The highest effect ratio in the table is 1.00. When Table 5 and Table 6 are examined, it is seen that the highest environmental effect is in the production stage. It has been observed that transportation of the raw material by road, the usage of plastic material, and the electricity consumption during usage all have a heavy environmental load. When the raw materials used are examined, it has been determined that the environmental load of polypropylene and polyurethane is higher than that of high density polyethylene. Since polypropylene is used a lot, it is considered that the transportation of raw materials leads to the consumption of natural resources due to the increase of fuel consumption and the consumption of electricity in the production stage. It is estimated that during the production of the polypropylene polymer, the proportion of respiratory organic materials increased due to the presence of non-methane volatile organic compounds [32],[33]. However, polypropylene can be used repeatedly in the system because it is a thermoplastic material. For this reason, waste generation is almost nonexistent and it is not a problem. Polyurethane is a thermoset plastic, so there is no recycling and it cannot be used again in the system. For this reason, the amount of waste for this type of plastic is higher than the other type of plastics. Furthermore, when the life cycle of the raw material is analyzed, the radioactivity ratio is also high. When the database of the program is examined, it is thought that this excess level of radiation is caused by the radon element. Radon gas in soil and in the atmosphere can be adsorbed by polyurethane materials [33]. For this reason, polyurethane is frequently used in the insulation systems of buildings and glass [34]. As o-ring is produced from polyurethane polymer, it is presumed that radioactivity originates from this element. When the other impact categories are examined, it is presumed that polluting gases and aromatic compounds derived from the use of coloring chemicals are released because of the fact that the raw material is plastic, as well as the stabilizers used in the polymer production stage and the metallic ions. In addition, the use of fossil fuels has increased because of the petroleum-based raw materials and the consumption of fuel during transportation. Ozone depletion, climate change, acidification/eutrophication, and the environmental load of respiratory inorganic substances in the system is higher in the production stage of the product due to the carbon dioxide, nitrogen oxides and methane gases that are given off to the environment during the transporting process.

According to the damage categories evaluation, the Eco-Indicator 99 (H) method, grouped according to the characteristics of the middle points and end points, is formed from these points. These end points are made up of human health, ecosystem quality and natural resources. The LCA results of the production and disposal phases of the coupling were compared to these endpoints and the stage with the highest environmental load was determined. When the analysis results are examined and all endpoints are compared, it is determined that the maximum environmental load is generated during the production of the coupling. Table 7 shows the results of this comparison. When the end points of the production stage are compared, it is seen that the environmental load of the natural resources end point is the highest. When the database of the program is examined, it is determined that the most important factor affecting natural resources is oil consumption. It is thought that the environmental load is high because the raw material is plastic and because of the oil used in the production of this plastic.

Table 7. Comparison of coupling production and its disposal stages according to damage assessment.

Damage Category	Unit	Production of Coupling	Disposal of Coupling	Total
Human health	DALY	$1.82*10^{-7}$	$1.56*10^{-7}$	$3.38*10^{-7}$
Ecosystem quality	PDF*m^2.year	0.00711	0.00191	0.00902
Resources	MJ surplus	0.762	0.00262	0.764

In addition, the environmental effects of the parts used in the production of the coupling are compared with each other in the weighting triangle, and the environmental loads from high to low are as follows: Coupling body, nut, gasket holder, pipe holder and o-ring. The environmental impact is shown in the weighting triangle. It is understood that if the area covered by the products is larger for the product, then the product has less environmental impact. If the weighting triangle is a single color, it is understood that the product has the lowest environmental impact in all three categories of impact (human health, ecosystem quality and natural resources), according to the loss assessment [28]. Figure 4 shows a comparison of the environmental effects of the o-ring and the coupling body. As it can be seen, the o-ring's environmental impact is very low compared to the environmental impact of the body. It has been determined that the environmental load of the coupling body is the greatest. This is because of the high amount of polypropylene used in the production of the products. For that reason, a monochromatic triangle is observed covering the entire triangular area.

3.1 Sensitivity analysis

A sensitivity analysis was conducted in accordance with ISO 14042 in order to check the results. In addition to the Eco-Indicator 99 (H) method, two different impact assessment methods - the ReCipe endpoint (H) and Impact 2002+ methods - were used in order to analyze their effects on the results. The results are given in Figure 5 as point units defined in the system.

The results were confirmed by sensitivity analysis. While performing the sensitivity analysis, all three methods were evaluated according to the endpoint method. According to the results of the analysis, it is found that the environmental impact from production is higher when the environmental effects of production and disposal of the coupling are compared. The reason for the higher environmental load of the production phase is due to the use of electric energy. Considering the efficiency of the injection machines used in production, less energy consuming systems could be integrated in the process. Although the environmental load of the production stage of the coupling is high in all three methods, it is seen that the endpoint distributions (human health, ecosystem quality and resources) are different from each other.

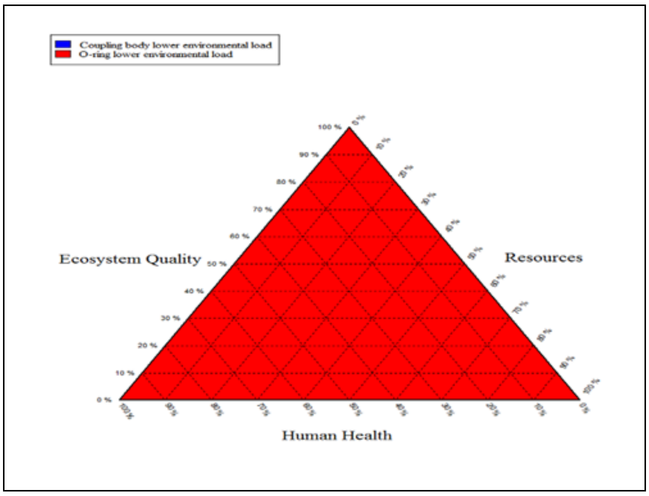

Figure 4. Comparison of environmental loads in weighting triangle of the o-ring and coupling body.

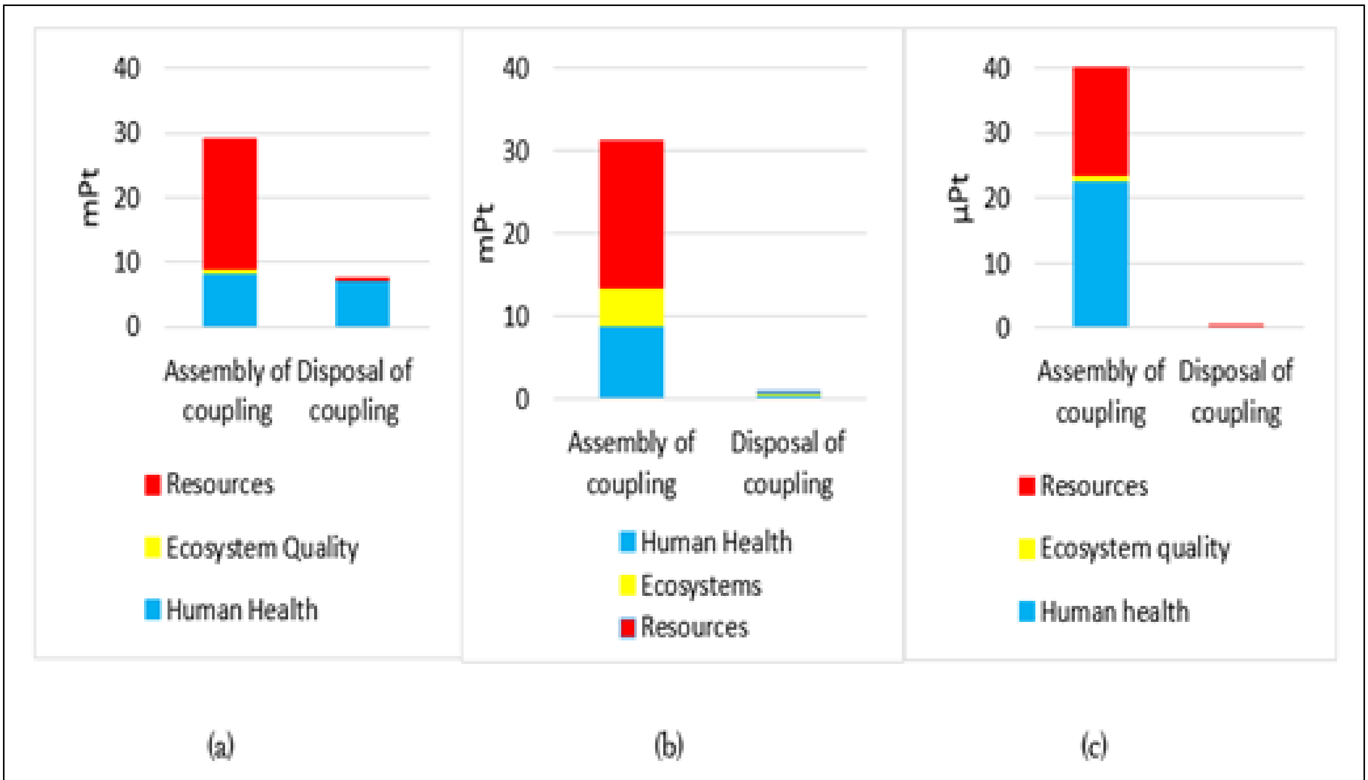

Figure 5. Sensitivity analysis results obtained by using different impact methods. (a): EI99 method, (b): The ReCipe Endpoint method, (c): Impact 2002+ method.

In the Eco-Indicator 99 method, while the resources have the most effect in the production phase, it is seen that the impact on human health is higher in the Impact 2002+ method during the production phase. In The ReciPe method, it is seen that the effect on the ecosystem quality in the production phase is higher than other methods. When the disposal stage of the coupling is examined for all three methods, it is seen that the environmental impact is very low in the ReciPe and the Impact 2002+ methods, but the impact of the disposal stage is high in the Eco-Indicator 99 method. According to the Eco-Indicator 99 method, it has been determined that the highest environmental load in the disposal phase is "human health".

When the environmental impact of the coupling parts was examined, it has been determined that the environmental load of the coupling body is the greatest. This is because of the high amount of polypropylene used in the production of the products. However, polypropylene can be used repeatedly in the system because it is a thermoplastic material. For this reason, waste generation is not an issue. Recycling of the o-ring is not possible in the system, as the o-ring is made of thermoset plastic material. For this reason, the o-ring produces the most waste in the system. It is sent for use as an asphalt additive in these wastes. Recently, the production and use of bio-based plastic polymers have come to the fore. In parallel with the developing technology, the bio-based polymer can be used in the production of coupling parts. Thus, the amount of greenhouse gas originating from production is reduced and the decomposition process in the landfill is accelerated. Improvement of the system can be achieved in this respect, with a waste generation being reduced and a sustainable approach being adopted. In general, it is recommended to use packages that are biodegradable in nature for the packaging of the coupling and for the packaging materials used for consumer transportation (low-density polyethylene and corrugated cardboard).

Finally, at the disposal stage in landfill, due to the nature of the product's plastic raw material, harmful wastes that are difficult to degrade biologically build up in the environment and land use also inevitably increases. As a result, it is observed that there is an increase in carcinogenic substances, radioactivity and land use.

4 Conclusions

The present study provides a cradle to grave LCA of plastic coupling. According to the results of this study that focused on environmental impacts of the plastic coupling, it was determined that the greatest environmental impact was due to the production phase of the coupling. While the production phase of the coupling strongly affects the end point index of resources, the impacts on ecosystem quality and human health availability are mainly due to the consumption of electrical energy and using of raw material. The life cycle assessment of this coupling with the highest environmental impact during the production phase was supported by sensitivity analysis tests. According to the sensitivity analysis, it was shown that methodological choices were helpful in understanding the effect of the results.

The main focus of this study is to examine the environmental effects of plastic couplings that prevent water leakage by connecting pipes and contribute to the literature. As a result of the study, it was stated how much environmental impact even small structures such as couplings can actually have. Instead of disposal of end-of-life plastics in landfills, reuse/recycling should be supported and waste management systems should be improved. In addition, instead of using fossil fuels as a raw material source in the production of plastic polymers, different types of bio-based raw materials should be focused on. Supporting the transition to alternative raw materials is of great importance for sustainability.

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6 Author contribution statements

All authors contributed to the study conception and design. Literature review, data collection and all analysis were performed by Sevde ÜSTÜN ODABAŞI. The study was supervised by Hanife BÜYÜKGÜNGÖR. The first of manuscript was written by Sevde ÜSTÜN ODABAŞI and all authors commented on previous versions of manuscript. All authors read and approved the final manuscript.

7 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person/institution in the article prepared.

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