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LIFE CYCLE ANALYSIS OF AN EXPANDABLE POLYSTYRENE PRODUCT

BİR GENLEŞEBİLİR POLİSTİREN ÜRÜNÜNÜN YAŞAM DÖNGÜSÜ ANALİZİ

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ABSTRACT

Energy sustainability and efficiency for buildings is of great importance for cities. For this reason, insulation systems are used in buildings. Expandable polystyrene (EPS) is one of these systems. EPS is produced by suspension polymerization. The beads formed in this reaction are coated and packaged. EPS blocks are produced in 3 stages. The first is the pre-expansion and maturation phase. At this stage, steam is applied to the EPS beads and allowed to swell. These swollen particles are then taken into the ripening silos for a certain period of time. In the second step, the matured and inflated beads are taken to the block machine and steam is applied again to obtain the block. The beads fuse together and form blocks in the machine under high temperature and pressure. The third stage is resting and cutting. The EPS blocks are then applied to the building surface to provide good insulation. Storage, recycling (reuse) and recovery (incineration) are the methods of evaluation of EPS wastes. In this study, it is aimed to reduce the environmental impact of each step of EPS life cycle by using Cradle to Grave Life Cycle Analysis. LCA is a very useful method to determine the detailed environmental impacts of the whole process. This analysis consists of 3 steps. The first step is the definition of purpose and scope. The second is inventory analysis. The third step is to assess the environmental impact and the final step is to decide and implement the conservation process. As a result, in this study, the process that causes the most environmental impact is determined by using LCA during the EPS lifecycle and a solution will be developed to reduce this impact as soon as possible.

Keywords: Cradle to Grave, Energy Efficiency, EPS, Environmental Impact, LCA.

ÖZET

Binalar için enerji sürdürülebilirliği ve verimliliği şehirler için büyük önem taşımaktadır. Binalarda bu sebeple yalıtım sistemleri kullanılmaktadır. Genleştirilebilir polistiren (EPS) bu sistemlerden biridir. EPS süspansiyon polimerizasyonu ile üretilir. Bu reaksiyonda oluşan boncuklar kaplanır ve paketlenir. EPS blokları 3 aşamada üretilmektedir. Birincisi ön genişleme ve olgunlaşma aşamasıdır. Bu aşamada buhar, EPS boncuklarına uygulanır ve şişmesi sağlanır. Daha sonra bu şişmiş tanecikler belirli bir süreliğine olgunlaşma silolarına alınır. İkinci aşamada, blok elde etmek için olgunlaştırılmış ve şişirilmiş boncuklar blok makinesine alınır ve tekrar buhar uygulanır. Boncuklar birbirine kaynaşır ve makinede yüksek sıcaklık ve basınç altında blok oluşur. Üçüncü aşama dinlenme ve kesme işlemidir. Daha sonra EPS blokları iyi yalıtım sağlamak için bina yüzeyine uygulanır. Depolama, geri dönüşüm (yeniden kullanma) ve geri kazanım (yakma), EPS atıklarının değerlendirme yöntemleridir. Bu çalışmada, Beşikten Mezara Yaşam Döngüsü Analizi (YDA) kullanarak EPS yaşam döngüsünün her bir adımının çevresel etkisinin azaltılması amaçlanmıştır. YDA, tüm sürecin ayrıntılı çevresel etkilerini belirlemek için çok faydalı bir yöntemdir. Bu analiz 3 adımdan oluşmaktadır. İlk adım, amaç ve kapsam tanımıdır. İkincisi envanter analizidir. Üçüncü adım, çevresel etkinin değerlendirilmesi ve son adım ise karar vermek ve koruma sürecini uygulamaktır. Sonuç olarak, bu çalışmada EPS yaşam döngüsü boyunca YDA kullanılarak en fazla çevresel etkiye sebep olan süreç tespit edilip, bu süreç için mümkün olan en kısa sürede bu etkiyi azaltmak için çözüm geliştirilecektir.

Anahtar Kelimeler: Beşikten Mezara, Enerji Verimliliği, EPS, Çevresel Etki, YDA

INTRODUCTION

Last years, concerns of environment, particularly have been increased the demand for sustainable building and developments. Because of this, for construction industry have been need correct information about environmental impact of used building materials and products. The most suitable way to reach this information has been defined to be the Life Cycle Assessment (LCA) approach. LCA defines environmental impacts of whole processes that includes from production till recycle (cradle to grave).

Expanded polystyrene (EPS) is used in the construction sector, mostly for insulation purposes, and also in the packaging industry. Additionally, it have advantages such as be a cheap, sound and thermal insulator, humidity resistance, easily recyclable [1]

In one of the recent studies, the environmental impacts of insulation materials were evaluated using software, where the environmental impacts of EPS were found to be less for all environmental impact classes than stone wool. In addition, environmental impacts were mostly observed during the production phase. [2]

In the world and in Turkey under study it focused on the intensive use of thermal insulation materials. These materials are Glass wool, Rockwool, Expanded Polystyrene Foam (EPS), Extruded Polystyrene Foam (XPS) and Polyurethane Foam (PUR). In the life cycles of the said insulation materials, waste and emissions released to the environment at different stages such as raw material supply, production, use, transportation and disposal as waste are evaluated. In this context, environmental impact categories mentioned in YDA studies are: global warming, energy consumption, water consumption, acidification, eutrophication and photochemical ozone formation. [3]

In another study, a new approach was developed in which optimum results are obtained by evaluating the life cycle energy consumption, carbon emission and cost of thermal insulation material and optimum insulation thickness. According to the results of the study, XPS and glass wool for Istanbul and Izmir, and stone wool for Erzurum, thermal insulation materials have come to the fore as the materials having optimum life-cycle performance. Furthermore, according to the results of the study, it is recommended that standards for thermal insulation and energy performance in buildings should be revised to take into account the life cycle of the materials. [4]

A life-cycle analysis was performed for a foamed polystyrene (PS) tray used for fresh meat packaging, and the highest environmental impacts were due to PS granule production and electricity consumption. Turning the energy source into a renewable source (for example by building a wind farm) leads to a 14% gain. In this way, the authors documented that there may be alternative ways to improve the global environmental improvement of the analyzed system and thereby improve the environmental sustainability of food packaging systems. [5]

EPS PRODUCTION

EPS (Expandable Polystyrene) is produced by suspension polymerization method and batch process form. In suspension polymerization, the monomer is formed by immersing the monomer in water which is not mixed. The polymer was eluted at 0.01-0.5 cm in aqueous phase. it is dispersed in diameter, ie the suspension of the monomer in water. In order to ensure that the suspension is stable and the formed polymer particles do not adhere to each other, chemicals called stabilizers are added. These suspension-forming substances wrap around the monomer. If necessary precautions are not taken, the particle s are clustered and block. As stabilizers, water-insoluble inorganic compounds such as gelatin, kaolin, powder, bentonite, barium, calcium and magnesium carbonates, aluminum hydroxide are generally used. In addition, mechanical mixing prevents the droplets from sticking together. As initiators of the polymerization, initiators are dissolved in the monomer (organic phase). At the end of the polymerization, the resulting powdered polymer is filtered out of the water and dried. The polymer is produced in granular form. Styrene, methyl methacrylate, vinyl chloride, vinyl acetate can be polymerized by these methods. This type of polymerization is called pearl or grain polymerization by looking at the final product obtained.

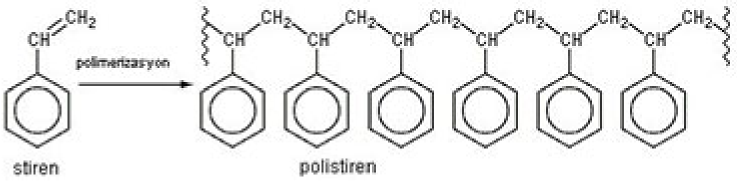


Figure 1: Polymerization reaction of Styrene Monomer

Suspension polymerization is a polymerization method that is very frequently used in industry. During this process, styrene, organic inhibitors, water and solids are added to the reactor. This procedure creates a suspension system that will subsequently form styrene droplets. The droplets polymerize into polystyrene by free radical polymerization. Then the chemical is added to the reactor for the purpose of blowing. The final product is absorbed into the polymer and the expandable polystyrene beads are obtained. After the conversion of the styrene monomer droplets to the expandable polystyrene beads, the reactor is cooled and the particles separated from the water. These particles are then dried, sieved and then separated into different particle fractions and coated with suitable additives according to their size and intended use.

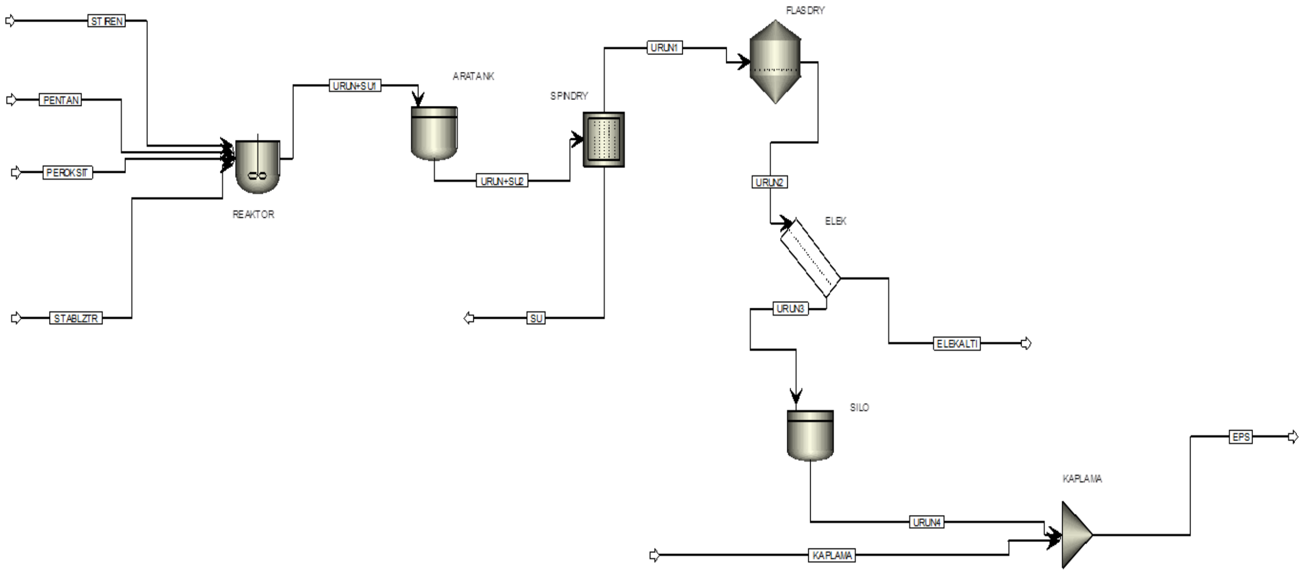


Figure 2: Expandable Polystyrene (EPS) Production Process

Pentane is injected in polystyrene as a blowing agent and then steam is applied to form EPS beads. The beads are then being molded in molding machines to make insulation panels, blocks or special shapes for the building and packaging industry. [1]

The particles are swollen at a temperature of 80-100 ^{0}C. with pentane and subjected to steam. The inflated particles still contain a very small amount of condensed steam and pentane gas. At this stage, when the particles are cooled, the porous structure starts to fill air instead of pentane gas. After pre-inflation, the EPS particles taken into the rest silos are held for 6-12 hours to allow the air - pentane exchange to be at the desired level. The block is molded in order to form a block to EPS and then to obtain a sheet from this block. At this stage, steam is used to maintain the foam shape and to continue the expansion. The use of steam also allows the particles to fuse together. After a short cooling phase, the molded EPS block is shaped by cutting methods. The use of hot wire or by another method is done.

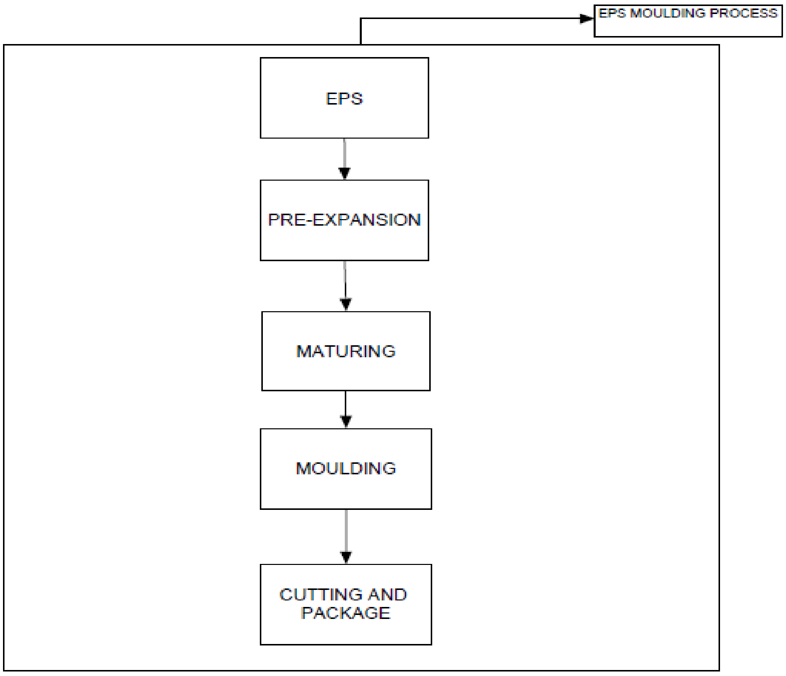


Figure 3: EPS Molding Process

LIFE CYCLE ANALYSIS

Life Cycle Analysis (LCA) is accepted as a scientific method for detailed evaluations and environmental sustainability during whole life cycle of a product from raw material to recycle. This life cycle steps are shown in Figure 4. [6]

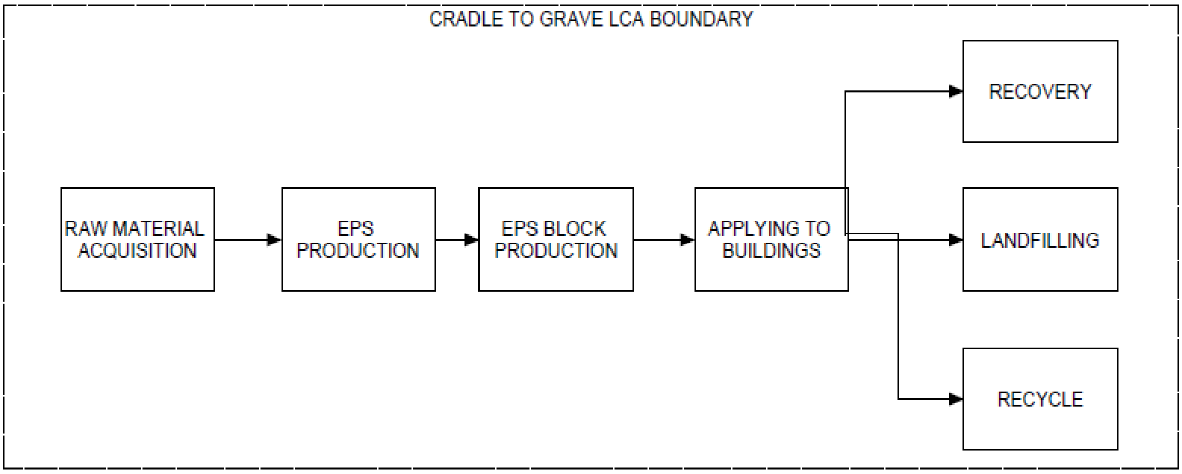


Figure 4: Flow diagram for cradle to grave life cycle of an EPS system

The analysis shows us the environmental impact caused by production steps. Results of LCA can be used for studies that include developing of using resources, environmental impacts of production systems. Also with these results, we can be observing decreasing energy usage and its possible impacts. In this study life cycle inventory (LCI) and life cycle impact assessment gives us evaluations of total energy requirement, energy usage, water consumption, air pollution, water source pollution and solid waste for EPS production. ISO 14040 and ISO 14044 international standards are followed to use methods for LCI and LCIA in this study. The steps of a life cycle assessment (LCA) generally examines , beginning with raw material production, continuing on through material production, product fabrication, use, ends with reuse or recycling. [6]

An LCA consists of four phases:

- Goal and scope definition
- Life cycle inventory (LCI)
- Life cycle impact assessment (LCIA)
- Interpretation of results

In the LCIA phase, the inventory of emissions is classified as different categories which may cause to adverse impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance. [6]

LIFE CYCLE ANALYSIS OF EXPANDABLE POLYSTYRENE

Goal and Scope Definition

The aim of this study is to evaluate the environmental impacts caused by all stages of EPS life cycle from cradle to grave, to determine important environmental inputs and outputs and to determine effective points on the basis of environmental impact.

This study includes raw material procurement, industrial production, further processing, packaging, transportation, consumption and waste management processes for the said EPS product. In addition, energy consumption and emissions were evaluated and their potential environmental impacts were examined.

For this purpose, at this stage, the EPS product, assumptions, functional unit, system boundaries, distribution methods and data quality requirements considered within the scope of the case study are defined; decisions are taken regarding critical review and report preparation.

It is a kind of polystyrene which is used extensively in the insulation industry, where pentane is found as a blowing agent in EPS product and it is replaced with 40 times in steam application. Since most of the raw materials in EPS are less than 1%, styrene monomer and pentane are assumed to be active substances. This ratio is 93% styrene monomer and 7% pentane.

For the analysis to be understandable, functional unit definition should be made. The functional unit in this study was determined as 1000 kg EPS product.

Production and supply of raw materials for the production of EPS in the cradle-to-grave life cycle analyzer, production, further processing, use and recovery of the EPS product are the unit operations in this study. The methods used for these processes and the input flows such as material, energy, water in each method and air / water / soil emissions, water based wastes, solid wastes and by-products are the system boundaries in the case study. [7]

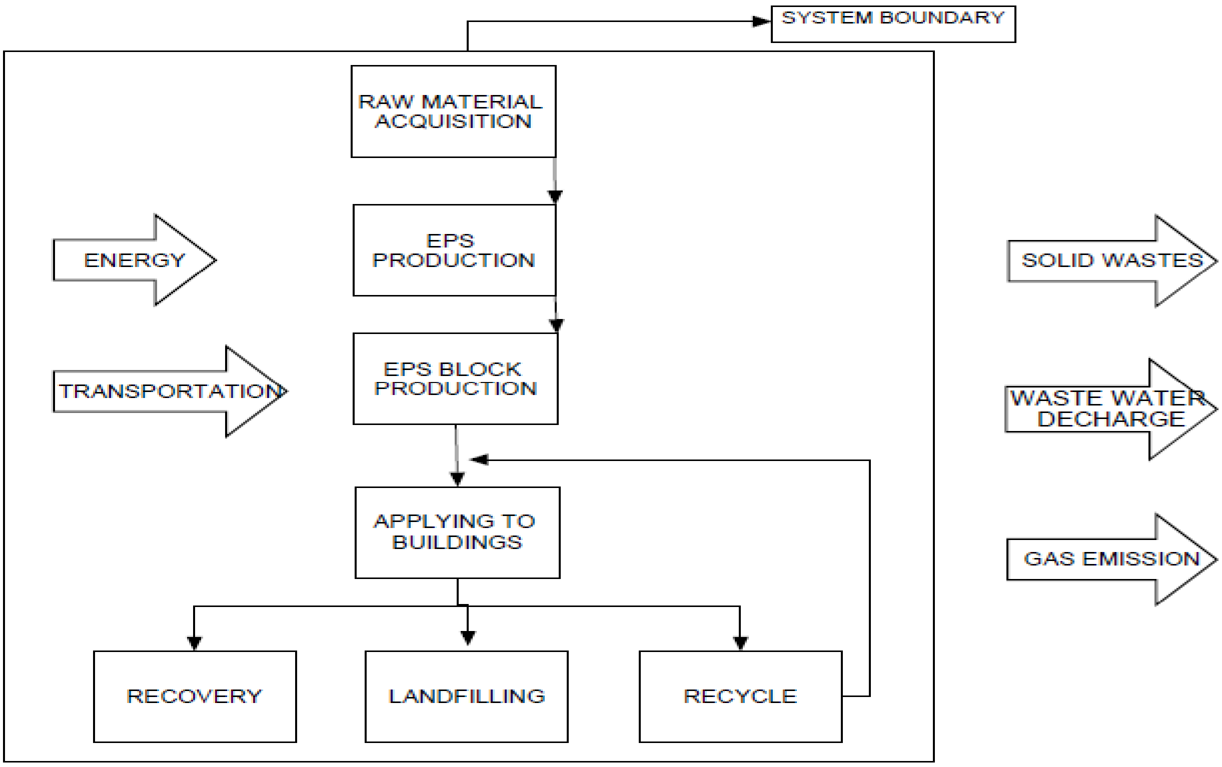


Figure 5: System Boundary for cradle to grave life cycle analysis of EPS

In the case study, mass, energy and exergy balances in unit operations which constitute system boundaries are taken into account when distributing input and output flows to unit operations.

The data quality requirements cover the time, geography and technology variables of the data to be collected for the EPS product. The data obtained and used in the sample study;

- are data that can be calculated and calculated by experience.
- 90% of the primary data and 10% of the literature were obtained and calculated from the literature and databases.
- the data in the last 3 years is current and is currently being implemented.
- are common data in our country and internationally.
- is related to EPS products produced on an international scale and with traditional technology. Secondary data from literature or databases are valid data for current technology.
- represents the system precisely
- Consistent and repeatable.
- Data gaps are filled with database and experience based estimates. [7]

Inventory and Impact Assessment

Results of inventory of this study have been expected to be detailed and long, its mean that is very difficult to evaluate as a short and meaningful. Life cycle impact assessment (LCIA) gives us the opportunity for evaluation of the emissions inventory. LCIA is defined in ISO 14044 Section 3.4 as the “phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.” In the LCIA phase, the inventory of emissions is firstly classified into categories for impacts on human health or the environment. Each impact category, the emissions are then normalized using characterization factors that give the impact of each substance related to a reference substance. [8,9]

The LCI and LCIA results categories and methods used in this study are given in Table 1. This study includes regional and local impact categories.

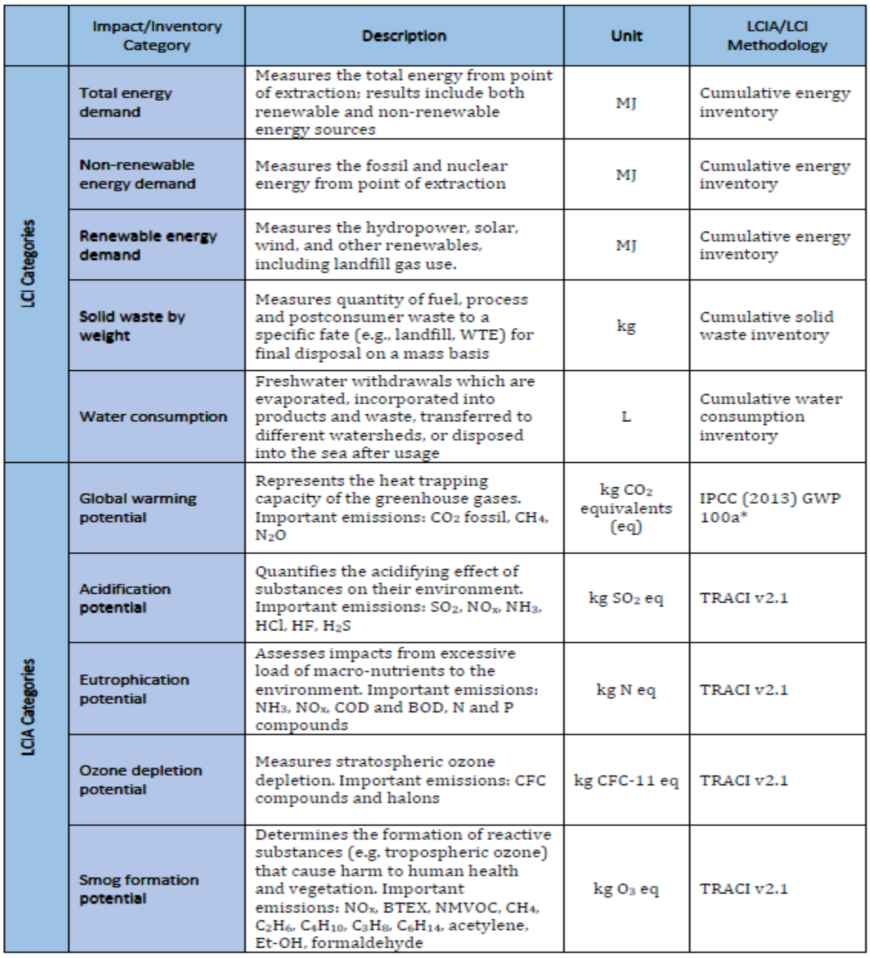
Some life cycle inventory (LCI) results:

• Energy demand: this method is not an impact assessment, but it is a total inventory of all kind of energy used for processing , transportation , and feedstock . Energy is also categorized by individual fuel types.

• Solid waste is evaluated as a total inventory values dealing with this category.

• Water consumption is evaluated as a total inventory values dealing with this category **[6]**

Table 1: Summary of LCI/LCIA Impact Categories [6]



	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
LCI Categories	Total energy demand	Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources	MJ	Cumulative energy inventory
	Non-renewable energy demand	Measures the fossil and nuclear energy from point of extraction	MJ	Cumulative energy inventory
	Renewable energy demand	Measures the hydropower, solar, wind, and other renewables, including landfill gas use.	MJ	Cumulative energy inventory
	Solid waste by weight	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a mass basis	kg	Cumulative solid waste inventory
	Water consumption	Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the sea after usage	L	Cumulative water consumption inventory
LCIA Categories	Global warming potential	Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	kg CO_2 equivalents (eq)	IPCC (2013) GWP 100a*
	Acidification potential	Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	kg SO_2 eq	TRACI v2.1
	Eutrophication potential	Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, COD and BOD, N and P compounds	kg N eq	TRACI v2.1
	Ozone depletion potential	Measures stratospheric ozone depletion. Important emissions: CFC compounds and halons	kg CFC-11 eq	TRACI v2.1
	Smog formation potential	Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, BTEX, NMVOC, CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	kg O_3 eq	TRACI v2.1

Interpretation of Result

The last phase of life cycle assessment is life cycle interpretation. Life cycle interpretations include LCIA data composed from LCI and these data has become a basis of decision making related to goal and scope definitions. So, life cycle analysis starts with goal and scope definition and completes with trusted data interpretation.

CONCLUSIONS

In this study, in general, the data from raw material production to recycling are evaluated in detail. Goals and scopes were identified, functional units were defined and some assumptions were made for life cycle analysis. Inventory analysis has started and the most comprehensive part of this study is this section. The data obtained as a result of inventory analysis will be used in the calculation of environmental impact by using databases within the framework of assumptions. Subsequently, these impacts will be reduced to a single dimension by a common impact factor, and the part with the most environmental impact will be determined in this way. Determined environmental impacts will be evaluated and changes will be made on these points. After this evaluation, the points that need to be changed or improved on the system will be determined and necessary actions will be taken. After the actions to be taken, life cycle environmental impact analysis will be performed again and it will be determined whether there is a decrease in environmental impacts. In previous studies, the life cycle analysis of EPS raw material styrene monomer and packaging materials obtained from EPS were performed. It was seen that the most environmental impact was caused by exergy losses during the production of Styrene Monomer. On the other hand, the most significant environmental impact in EPS packaging is due to the steam and energy consumption in the injection part. Compared to styrene monomer production, the environmental impact in packaging production is lower.

However environmental impact is expected to be highest in EPS polymerization process due to energy losses. In this process, the reactor is heated from 60 ° C to 90 ° C (2 hours) to initiate the polymerization reaction, after which the reaction is cooled for 4 hours to maintain the reactor at constant temperature (exothermic reaction), when the reaction is complete, the reactor is heated to 120 ° C for pentane diffusion. It is allowed to cure at this temperature for 3 hours. After curing, the reactor is cooled to 30 ° C in 3 hours to remove the product from the reactor. Environmental impact analysis is not yet clear, because inventory analysis is in progress. As a result, this study will show us how we can reduce the environmental impact of the EPS production system, especially losses in the polymerization reaction and curing section, and what changes we need to make to reduce certain environmental impacts.

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