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RESEARCH ARTICLE
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GENERIC NAVAL VESSEL WASTE MANAGEMENT MODEL DEVELOPMENT IN SHIP-LIFE CYCLE ASSESSMENT (SLCA) AND COST (SLCC)*

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ABSTRACT

Naval vessels are exposed to many of the rules and regulations determined by international treaties, there are few studies on life cycle analysis of these ships. The aim of study is to calculate life cycle impacts and cost analysis of two vital parts of a generic warship and investigate the emission reduction by using Life Cycle Assessment (LCA). Two important parts (valve and lubricating oil) of a generic warship are selected and the wastes and emissions of these parts are calculated by using licensed SimaPro software. The whole life cycle of the valve and lubricating oil is considered including transportation and recycling phases. Besides, Life Cycle Cost (LCC) analysis is implemented to the samples to calculate the benefits obtained by using LCA method. LCC is implemented on the system and its resulting total benefits, which is obtained by recycling process, is approximately 46,400 €. The environmental impacts of waste valve and lubricating oil are calculated by the help of licensed SimaPro software. The results show that recycling waste oil recovers the cost of waste oil separator by 30 % per ship.

Keywords: *Life Cycle Assessment, Life Cycle Cost, Warship, Recycling, Ship Emissions.*

JENERİK BİR SAVAŞ GEMİSİNDE GEMİ-YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ (SLCA) VE MALİYET MODELİ (SLCC) GELİŞTİRİLMESİ

ÖZ

Savaş gemileri, uluslararası anlaşmalar tarafından belirlenen pek çok kural ve yönetmeliklerden muaf tutulduğundan, bu gemilerin atık ve emisyon yönünden yaşam döngüsü analizi üzerine çok az çalışma vardır. Bu çalışmanın amacı, jenerik bir savaş gemisinin iki bileşeninin çevresel etkilerini ve maliyet analizini hesaplamak ve Yaşam Döngüsü Değerlendirmesi'ni (LCA) kullanarak emisyon azaltımını araştırmaktır. Jenerik bir savaş gemisinin valf ve yağlama yağı sistemleri atıkları, valf ve yağlama yağının tüm kullanım ömrü, nakliye ve geri dönüşüm aşamaları da dahil olmak üzere lisanslı SimaPro yazılımı kullanılarak hesaplanmıştır. Ayrıca, LCA yöntemi kullanılarak elde edilen faydaları hesaplamak için Yaşam Döngüsü Maliyet analizi (LCC) uygulanmıştır ve geri dönüşüm işlemiyle elde edilen toplam faydaların yaklaşık 46.400 € olduğu sonucuna ulaşılmıştır. Atık valf ve yağlama yağının çevresel etkileri hesaplanarak, atık yağın geri dönüşümünün gemi başına atık yağ ayrıştırma maliyetini %30 oranında azalttığını göstermektedir.

Anahtar Kelimeler: *Yaşam Döngüsü Analizi, Yaşam Döngüsü Maliyeti, Savaş Gemisi, Geri Dönüşüm, Gemi Emisyonları.*

1. INTRODUCTION

For Life Cycle Assessment (LCA) to be a holistic approach, a good co-operation should be done between the processes to achieve adequate success (Bilgili & Çelebi, 2013). Navies are very important parts of armed forces in order to protect territorial waters. Fully mission capable navies are strongly relying upon effective logistics and maintenance/repair capability. Ship Life Cycle consist of manufacturing, operation, maintenance/repair, dismantling. The operational phase of naval vessel starts with launching of the ships. Maintenance and repair processes are regularly implemented to the naval vessel by ship and shipyard crew in order to provide excellence in war tasks. LCA can be identified as a holistic assessment of product environmental performance of system including manufacturing, usage and disposal phases. Ship Life Cycle Assessment (SLCA) is a term used to identify LCA methods implemented on ships. SLCA focuses on four main stages (manufacturing, operation, repair/maintenance, dismantling) and their environmental impacts, energy consumptions and minimization techniques. Although there are few studies on SLCA, some comprehensive and innovative studies have been realized particularly over the last decade.

After the industrial revolution, steam powered and steel ships came into prominence for navies. On the other hand, these new ships began to be manufactured by using new and difficult-to-recycle material, which brings new environmental problems. Vessels generate various types of waste. (Stefano, Elvis & Boris, 2009). Hull and machinery systems have their own waste types and, although the main material is same - steel-, the waste management systems must be considered separately (Tamer, Bilgili & Çelebi, 2016).

Solid wastes include packages, rubbish, plastics etc. Liquid wastes include bilge water, ballast water, grey and black water. Gas wastes include emissions to air such as nitrogen oxides, sulfur oxides, carbon dioxide etc. A ship's life cycle (SLCA) can be divided into four main sub-categories as follows: 1. Ship Design and Manufacturing 2. Ship Operation 3. Ship Maintaining 4. Ship Recycling Life Cycle Assessment (LCA) which is a holistic, innovative and sustainable approach for all kinds of materials and products in order to make the production processes more environment-friendly and efficient. LCA systems use material databases to develop an optimization for products. Since recycling phase is a first phase of a different product, LCA is an infinite process. An efficient design of LCA can reduce the energy consumption, used material amounts and production duration, considerably. Energy and raw materials are accepted as inputs whereas wastes and products are accepted as outputs in LCA. LCA focuses on comparing the environmental performances of different materials, analyzing the environmental impacts of production processes, developing models and evaluating of energy-environment relationship. The general concept of LCA is shown in Figure 1 (Bilgili, Unlugencoglu & Çelebi, 2014).

LCA adopts a holistic approach by analyzing the entire life cycle of a product from raw materials extraction and acquisition, materials processing and manufacture, materials transportation, product fabrication, transportation, distribution, operation, consumption, maintenance, repair and finally disposal/scrapping. (Bilgili & Çelebi, 2013; Tamer, Bilgili & Çelebi, 2016; Shama, 2005). LCA realizes the evaluations with successive and independent processes perspective and it is used for estimating the total environmental impacts caused by the all phases of life cycle including the processes not considered in traditional analysis (SAIC, 2006). LCA can be identified by the help of 6 RE philosophy: Re-think (detailed analyses for the product and its function), re-duce (minimizing the raw material and energy consumption), re-place (using less harmful materials instead of more harmful ones), re-cycle (recyclable materials are chosen), re-use (the product is produced as reusable), re-pair (the product is produced as appropriate for repair) (UNEP, 2006). Figure 1 presents the life cycle of a ship.

In his study, Fet, (2002) presented that LCA method can be used for environmental impact calculation of a ship. He explained that the processes in LCA may change according to explicator and it was emphasized the importance of system constraints that may conflict with each other. Finnveden et al., (2009) reported that LCA is a tool that includes and determines all sources which are used during all phases of life cycle (raw material, manufacturing, operation and disposal). Bilgili & Celebi, (2013) prioritizes waste management model and investigated the impact of LCA method on reducing ship-related wastes and emissions produced during operation phase. The authors resulted that LCA is an innovative, sustainable and holistic method which increases efficiency, decreases costs, emissions and duration. Chatzinikolaou et al., (2016) highlighted that ship life cycle can be subcategorized as manufacturing, operation, maintenance and disposal/recycling and presented that most of the emissions are produced during operation phase. The authors identified a comprehensive LCA concept for ships. They also supported this study with the results of another study which is about greenhouse gases (GHG's). Chatzinikolaou & Ventikos, (2015a) also integrated LCA method to the ship emission estimation studies in order to calculate the impacts of shipping emissions. The authors investigated the difficulties occurred during transportation, adaptation problems of methodology, complexity of choosing suitable system constraints and determining life cycle inventories in their study. Chatzinikolaou & Ventikos, (2015b) developed a new mathematical model, which is related with LCA method, which can analyze ship emissions. They also mentioned that LCA presents alternatives for maintenance/repair and disposal processes of ships. The authors indicated that using LCA increases the environmental performances. Thus, they resulted that LCA must be compounded with transportation process. Celebi et al., (2019) studied implementation of LCA and LCC to a naval vessels.

Kameyama et al., (2004) developed comprehensive software called LIME which can calculate the potential environmental impacts of ships during life cycle. The authors considered the whole life cycle of a bulk carrier including manufacturing, repair, operation and recycling processes. Alkaner & Zhou, (2005) studied on LCA of molten carbonate fuel cells (MCFC) used in shipping sector. They particularly emphasized on LCA of fuel cells which include diesel fuel. Bijwaard & Knapp, (2008) resulted that shipping is relatively safe comparing with other sectors and they indicated that adapting LCA to shipping sector and increasing of inspections will reduce the number of accidents and thus, costs. Chiffi et al., (2009) investigated on the impacts of energy consumption on ships to the environment. As a result of this study, it is reported that energy consumption of shipping increased and thus, development of abatement technologies increased, as well. Vlad (2009) investigated the contribution of mathematical programming to LCA. He used various formulas for various inventory calculations. By the help of

LCA performance analysis, Okasha et al., (2010) studied on the impacts of variable sea conditions to the ship's structural condition. In a recent report published by NATO, there are some studies on the costs of naval systems in LCA of a ship. The report indicates that Life Cycle Cost (LCC) includes all expenses occurred during operation, maintenance and disposal phases. The report also mentions that LCC is a very systematic to create cost allocation for any war program. It is indicated in the report that the obtained cost allocation must be developable, comparable with other methods and be clearly understood (NATO, 2003).

Carvalho et al., (2011) worked on modeling the environmental impacts of ship dismantling process whose data is obtained from Portuguese ship-breaking industry. They used different environmental assessment methods for different ships and they resulted that the impacts are similar. Besides, the authors indicated that environmental performance of a ship is not only related with hull type but also strongly depend on the combining effect of hull and equipment. Bengtsson et al., (2011) indicated that due to the possible future enforcements on fuel quality and exhaust emissions in Emission Control Areas (ECAs), the need for alternative fuel systems or innovative abatement technologies will increase. 4 different fuel types investigated and it was observed that fuels used in ships cause remarkable impacts on environment. Choia et al., (2015) realized the environmental performance and economic feasibility calculations for management of expired materials by using LCA and cost-benefit analysis. Seoa et al., (2015) studied on 4 different CO_2 liquefaction methods for catching and storage of carbons produced related with shipping activities in terms of LCA.

Another important issue in LCA is to evaluate the effect of assumptions taken and uncertainties of the elaborated data (Chatzinikolaou & Ventikos, 2014). LCA calculations processes were based upon the ISO 14040:2006 standards. First, a functional unit was defined in order to determine the restrictions of the system (Bilgili, 2019). Military vessels are very complex products that may be composed of millions of items (Pérez & Toman, 2014).

Thus, NATO, by considering the effects of scheduling and efficiency, takes an active role in cost application methods (NATO, (2008). In another report, NATO explained the subcomponents of warships and costs, in detail. The report presents the costs during the phases of the job definition of ships, pre-feasibility study, project definition, design and development, manufacturing and inventory (NATO, (2006). The main purposes of the document are to reveal the total cost estimation and annual expenses of the ships during design, operation, repair and maintenance processes and to reduce the costs by using LCA methods (US Department of Defense (1983).

In this study, the scheduled maintenance periods are obtained from the manufacturer and total wastes are calculated. A generic frigate is investigated and LCA and LCC are applied to the two types of wastes (lubricating oil and valve) of main and auxiliary engines.

2. MATERIALS AND METHODS

Waste management is a stage of LCA to reduce, minimize or prevent the harmful wastes. For SLCA consists all of the phases of a ship, it provides to see the whole picture and relationships. SLCA is a developing and totally new approach for ship building industry and it will have more usage and importance in the future of sustainable researches for environmental performance (Bilgili & Çelebi, 2013).

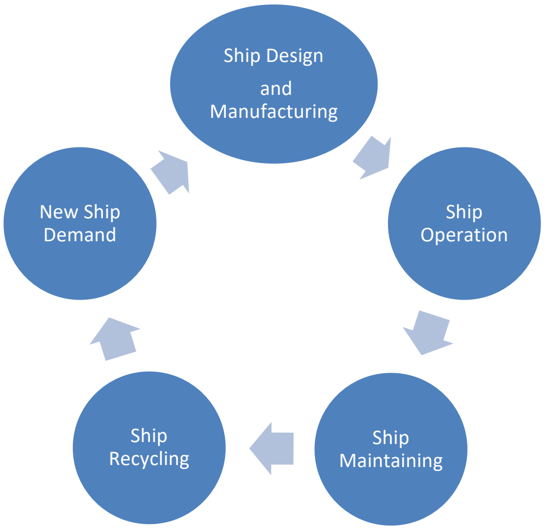

Figure 1. Structure overview of SLCA.

In conclusion, the use of a LCA model for analyzing ship waste management makes it possible to supply decision makers with quantitative and qualitative information at different levels, from the assessment of the environmental impacts of the overall system to the understanding of the effects of single operations and process (Stefano, Elvis & Boris, 2009). Cost prediction methods and models are exemplified in the report and a comprehensive guide is developed for LCC applications of multi-national military projects NATO (2007). NATO also identified the life cycle costs based on generic cost allocation and presented detailed information on these costs.

In 2007, the AAP-48 Procedure 'NATO System Life Cycle Stages and Processes' was published; this document became the standard handbook for implementation of a structure oriented towards life cycle management and to providing a common methodology for implementing the principles and terminology of this new means of administering 'systems of interest' (Galera, Maturana & Leiva, 2011).The maintenance periods of main and auxiliary engines consist of 5 repetitive phases. 300, 90, 30, 10 and 5 maintenances are predicted for phase number from 2 to 6, respectively for main engine. It is assumed that auxiliary engine needs 500, 125, 60, 20 and 5 maintenances for phase number from 2 to 6, respectively. The wastes are identified according to these numbers of maintenances and they are presented in Table 4-8, in detail. Fault status wastes are identified based on recent experiences. The total wastes occurred during scheduled maintenances and fault status is subsequently calculated according to Scenario-1. These wastes are used as input in waste management system based on SLCA. Licensed SimaPro 8.2.3.0 software is used for LCA calculations.

Additionally, SimaPro software is used to calculate environmental LCA impacts of wastes. The software provides an infrastructure for determining the environmental impacts and improvement opportunities, analyzing the total environmental impacts of all life cycle phases, comparing the external factors with internals, developing standards, helping companies to determine the final decisions on life cycle processes. LCA study is implemented for vital parts (valve and lubricating oil) of the generic ship.

3. RESULTS AND DISCUSSION

Repetitive periodical maintenances of main and auxiliary engines are extremely important and inevitable processes in order to maintain the presence of a naval vessel in war conditions. In accordance with this purpose, periodical maintenances, which are identified below, are determined and implemented by both the manufacturer and the navy.

3.1. Main Engine Maintenance Periods

Keeping the engines active and the operating and maintenance costs at minimum is merely possible when the maintenance processes are implemented in time and convenient with the directives of the manufacturer. Table 1 presents the maintenance periods of main engine.

Table 1. Maintenance periods of main engine.

No	Scheduled Maintenance	Periods
1	Daily checks	Daily
2	Periodic maintenances are applied in the port without removing the engine	150 hours / 6 months
3	Periodic maintenances are applied in the port without removing the engine	300 hours / 1 year
4	Periodic maintenances are applied in the port without removing the engine	1500 hours / 2 years
5	Pre-overhaul is partial overhaul and the engine is removed partially	4500 hours / 6 years
6	Full overhaul is the main overhaul and the engine is completely removed	9000 hours / 12 years

3.2. Auxiliary Engine Maintenance Periods

The amount of waste material is calculated considering that total working hours for main and auxiliary engines are 1800 and 5000, respectively. According to these periods, the total waste produced from the engines is presented in Table 3. The information about the amounts of wastes carried out during 5 and 6 maintenance periods are obtained from shipyard.

The lifespan of the generic warship is estimated as 30 years. Because the values in the total column presents the total wastes occurred during a six years period, multiplying these amounts by 5 will give the overall waste amounts during lifespan of the ship. Thus, Table 3 shows that 95,500- and 28,200-liter waste oil, 9,020 and 8,360 lubricating oil/fuel filter waste, 13.5 and 2.5 tons of alloyed scrap steel for main and auxiliary engines, respectively. Table 2 presents the maintenance periods of auxiliary engine

Table 2. Maintenance periods of auxiliary engine.

No	Scheduled Maintenance	Periods
1	Daily checks	Daily
2	The maintenance is applied in the port (or at sea) without removing the engine	250 hours / 6 months
3	The maintenance is applied in the port (or at sea) without removing the engine	1000 hours / 1 year
4	The maintenance is applied in the port (or at sea) without removing the engine	2000 hours / 2 years
5	Pre-overhaul is partial overhaul and the engine is removed partially	6000 hours / 6 years
6	Full overhaul is the main overhaul and the engine is completely removed	24000 hours / 12 years

3.3. Life Cycle Analysis of Valve

The alloys of valves produced for main and auxiliary engines are the same. After the end of the lifetime of valves, they are collected and sent to waste collection center. Scrap iron wastes all across the navy are delivered to a facility and recycling process is finished there.

The emissions occurred during manufacturing and recycling processes of the valve is calculated by SimaPro and the results are shown in the following tables. The valve is manufactured in a foreign country, used by the navy and after the end of the lifetime, is sent to iron and steel plant and recycled there. The total transportation distance is assumed as 315 km. Table 4, 5 presents the total amounts of significant wastes of valve.

3.4. Life Cycle Analysis of Lubricating Oil

The lubricating oil used in main and auxiliary engines is supplied from domestic market in accordance with the requirements of manufacturer of the engines. Lubricating oil is produced and after the end of the lifetime, is sent to recycling facility and categorized there. The transportation distance is assumed as 350 km. The categorization process is realized in accordance with the criterion determined in waste oil regulations. The waste oil is analyzed in accredited laboratories. Table 6, 7 presents the total amounts of significant wastes of lubricating oil.

Table 4-8-set out the total estimated amounts of significant wastes of valve and lubricating oil. Manufacturing refers to the wastes occurred during manufacturing phase and transportation phase identifies the wastes occurred during the transportation of valve and lubricating oil to a recycling facility. Recycling processes are different for valve and lubricating oil. Disposal is the last phase for both products. The final discharging region of the wastes is categorized as air, water and soil.

Although SimaPro provides a wide range of various types of wastes, only the wastes which occurred in significant amounts are considered in this paper. The negative values in the tables present the positive effect of the process. For instance, 3.11 kg of iron can be recovered instead of discharging by melting.

Table 3. Amounts of wastes of maine engine and auxiliary engine.

Type of Waste	**Amounts of Wastes of Maine Engine and Auxiliary Engine**						
	2	**3**	**4**	**5**	**6**	**Fault Status**	**Total**
Liner (Number)	-	-	-	4	20	5	29
Piston (Number)	-	-	-	4	4	1	9
Cylinder head (Number)	-	-	-	4	4	5	13
Injector (Number)	-	-	-	10	5	5	20
Valve (Number)	-	-	-	10	10	10	30
Pump and turbo charger bearing (Number)	-	-	-	14	80	10	104
O-ring/ring/gasket /screw (Number)	2400	720	240	820	175	100	4455
Fuel filter (Number)	-	36	12	4	2	5	59
Lubricating oil filter (Number)	1200	360	120	40	20	5	1745
Lubricating oil (Liter)*	14500	-	-	2000	1000	1600	19100
Thermocouple (Number)	-	-	-	2	2	-	4
Piping system (Meter)	-	-	-	-	6	-	6
Liner (Number)	-	-	-	4	8	2	14
Piston (Number)	-	-	-	4	4	1	9
Cylinder head (Number)	-	-	-	4	1	2	7
Injector (Number)	-	-	1	4	1	1	7
Valve (Number)	-	-	-	4	10	1	15
Pump and turbocharger bearing (Number)	-	-	-	16	25	1	42
O-ring/ring/gasket/screw (Number)	3500	1000	400	88	92	20	5100
Fuel filter (Number)	-	25	12	8	2	1	48
Lubricating oil filter (Number)	700	600	288	28	7	1	1624
Lubricating oil (Liter)*	5040	-	-	400	100	100	5640
Thermocouple (Number)	-	-	-	2	2	-	4
Piping system (Meter)	-	-	-	-	5	-	5

* Periodic change of lubricating oil is considered performed once in every 500 hours.

3.5. Life Cycle Cost

The formula for total system cost is presented in Equation 1. The equation includes various types of expenses which are explained below.

$$C = C_R + C_i + C_O \qquad \textbf{(1)}$$

Where;

C: Total system cost
C_R: Research and development cost
C_i: Investment cost
C_O: Operation and maintenance cost

Research and development cost consist of program management cost, advanced research and development cost, engineering and design cost and equipment development and test cost. While investment cost includes manufacturing cost, construction cost and initial logistic support cost, maintenance cost includes preventive/corrective cost and auxiliary equipment cost. Furthermore, logistics and transportation costs, maintenance training cost and technical data documentation cost are considered as major parts of total system cost.

SimaPro is a widely used and reliable software for obtaining LCA results. SimaPro 8.2.3 software and CML-IA methodology were used to determine environmental impacts categories of abiotic depletion, abiotic depletion (fossil fuels), acidification, eutrophication, global warming, ozone depletion, human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity and photochemical oxidation. The generic ship's environmental impacts of the relevant inputs and outputs defined as a result of the matrix calculations made on the environmental impact coefficients can be seen through the relevant categories.

It is predicted that purifying the waste lubricating oil by the help of waste oil separator onboard would raise the category of the lubricating oil. It is clear that recycling waste lubricating oil, which has an economic value in other industries, can provide numerous benefits for both economy and environment. The benefits obtained from both lubricating oil and waste scrap during life cycle can be seen in Table 6, 7. Table 8 shows that benefit obtained from recycling parts of main and auxiliary engines.

Table 4. The total amount of significant wastes of valve (Manufacturing, Transportation).

	Manufacturing			**Transportation**		
Wastes	**Air**	**Water**	**Soil**	**Air**	**Water**	**Soil**
CO_2	0.8 kg	-	-	10.1 kg	-	-
PM	4.5 kg	-	-	12.7 kg	-	-
Ozone	31.8 g	-	-	130.5 g	-	-
NMVOC	0.2 g	-	-	2.2 g	-	-
Mn	2.7 g	-	36 g	4.5 g	-	66.1 g
Mg	195.3 g	49.4 kg	66.1 g	162.7 g	178.4 kg	419.2 g
TSP	-	36.3 kg	-	-	81.8 kg	-
Si	-	7.6 kg	146.8 g	-	0.4 kg	218.8 g
Na	-	8.3 kg	-	-	16.7 kg	-
Fe	-	53 kg	64.3 g	-	116 kg	983 g
Boron	-	0.6 kg	-	-	3.4 kg	-
Pb	-	22.6 g	-	-	246.5 g	-
As	-	37.8 g	-	-	174.9 g	-
Xylene	-	3.7 g	-	-	176.1 g	-
V	-	36.1 g	70.1 mg	-	310.5 g	96.6 mg
Cr	-	0.8 g	0.06 mg	-	13.1 g	2.1 mg
Cyanide	-	3 g	-	-	62.9 g	-
Al	-	-	48.4 g	-	-	481.7 g
Zn	-	-	3.3 g	-	-	13.4 g
Cu	-	-	276.9 mg	-	-	547.7 mg

Table 5. The total amount of significant wastes of valve (Melting, Disposal).

	Melting			Disposal		
Wastes	**Air**	**Water**	**Soil**	**Air**	**Water**	**Soil**
CO_2	-0.001 kg	-	-	11 kg	-	-
PM	-0.002 kg	-	-	17 kg	-	-
Ozone	-0.01 g	-	-	162 g	-	-
NMVOC	-0.0002 g	-	-	2.3 g	-	-
Mn	-0.001 g	-	-0.01 g	7.2 g	-	102 g
Mg	-0.05 g	-0.01 kg	-0.05 g	358 g	227.9 kg	485.2 g
TSP	-	-0.006 kg	-	-	118.1 kg	-
Si	-	-0.1 kg	-0.04 g	-	7.4 kg	365.5 g
Na	-	-0.001 kg	-	-	25 kg	-
Fe	-	-3.1 kg	-0.12 g	-	165.6 kg	1047.2 g
Boron	-	-0.0001 kg	-	-	4 kg	-
Pb	-	-0.01 g	-	-	269.1 g	-
As	-	-0.01 g	-	-	212.6 g	-
Xylene	-	-0.02 g	-	-	179.7 g	-
V	-	-0.01 g	-0.02 mg	-	346.6 g	166.7 mg
Cr	-	-0.001 g	-0.0002 mg	-	13.9 g	2.2 mg
Cyanide	-	-0.002 g	-	-	65.9 g	-
Al	-	-	-0.06 g	-	-	530 g
Zn	-	-	-0.02 g	-	-	16.7 g
Cu	-	-	-0.1 mg	-	-	824.5 mg

Table 6. The total amount of significant wastes of lubricating oil (Manufacturing, Transportation).

	Manufacturing			Transportation		
Wastes	**Air**	**Water**	**Soil**	**Air**	**Water**	**Soil**
CO_2	301 tn.lg	-	-	0.002 tn.lg	-	-
PM	51.5 kg	-	-	12.7 kg	-	-
Ozone	1.5 kg	-	-	0.03 kg	-	-
NMVOC	36.4 kg	-	-	2.4 kg	-	-
Mn	118 g	-	0.3 kg	582.6 g	-	0.01 kg
Mg	298.8 g	115.7 kg	0.5 kg	0.1 g	0.2 kg	0.01 kg
TSP	-	64.9 kg	-	-	0.2 kg	-
Si	-	1.8 kg	1.8 kg	-	0.04 kg	0.04 kg
Na	-	297.9 kg	-	-	0.1 kg	-
Fe	-	695.2 kg	0.5 kg	-	0.1 kg	0.03 kg
Boron	-	3.1 kg	-	-	0.01 kg	-
Pb	-	1.4 kg	-	-	0.05 kg	-
Xylene	-	2.4 kg	-	-	0.04 kg	-
V	-	2.1 g	-	-	0.01 g	-
Cr	-	26.6 g	-	-	2.8 g	-
Cyanide	-	404.7 g	-	-	0.8 g	-
Al	-	0.5 kg	0.3 kg	-	0.006 kg	0.01 kg
Zn	-	118.4 kg	-	-	0.2 kg	-
Cr-VI	-	1.8 kg	-	-	0.1 kg	-
CO_2	301 tn.lg	-	-	0.002 tn.lg	-	-

Table 7. The total amount of significant wastes of lubricating oil (Incineration, Disposal).

	Incineration			Disposal		
Wastes	**Air**	**Water**	**Soil**	**Air**	**Water**	**Soil**
CO_2	1.6 tn.lg	-	-	302.5 tn.lg	-	-
PM	273 kg	-	-	620.3 kg	-	-
Ozone	5.9 kg	-	-	7.4 kg	-	-
NMVOC	160 kg	-	-	198.5 kg	-	-
Mn	2.1 g	-	2.2 kg	702.8 g	-	2.5 kg
Mg	27.2 g	71 kg	3.5 kg	326.2 g	187 kg	4 kg
TSP	-	121.6 kg	-	-	186.8 kg	-
Si	-	17.3 kg	9 kg	-	19.1 kg	10.9 kg
Na	-	70.3 kg	-	-	368.3 kg	-
Fe	-	20.2 kg	3.1 kg	-	715.6 kg	3.6 kg
Boron	-	2.4 kg	-	-	5.5 kg	-
Pb	-	87.7 kg	-	-	89.1 kg	-
Xylene	-	1.9 kg	-	-	4.4 kg	-
V	-	3.1 g	-	-	5.2 g	-
Cr	-	206.5 g	-	-	235.9 g	-
Cyanide	-	1083.7 g	-	-	1489.2 g	-
Al	-	2.3 kg	2.3 kg	-	2.8 kg	2.6 kg
Zn	-	4.9 kg	-	-	123.5 kg	-
Cr-VI	-	1.6 kg	-	-	3.5 kg	-
CO_2	1.6 tn.lg	-	-	302.5 tn.lg	-	-

Table 8. Benefit obtained from recycling parts of main and auxiliary engines.

Supplies	Change Amount	Unit Price	Change Period	Total Changed Amount	Benefit
Lubricating oil	~900 liter	0.35 €/l	In every 500 working hours	~124,000 liter	~43,500 €
Scrap iron	~3.2 tons	178 €/ton	In every 5 years	~16 ton	~2,900 €
TOTAL					**~46,400 €**

4. CONCLUSION

Life Cycle Assessment (LCA) of a product is used to identify, evaluate and minimize energy consumption and environmental impacts, holistically, across the entire life of the product. Naval vessels have been used for defensive purposes by the countries that have a coastal line for centuries. Production and maintenance of these vessels include many complex processes depending on their missions, weapons and sea condition. Investigating the published military rules show that there are no enough documents and reports on life cycle analysis of military ships. Naval vessels are exempted from the rules and regulations that are determined by international treaties. Extensive using of military and commercial ships results with environmental pollution, waste of energy and misusage of natural resources.

The environmental impacts of valve and waste oil of main and auxiliary engines are calculated by the help of SimaPro. Waste oil cannot be reused as waste oil, again. After analyzing, waste oil is categorized and treated to be proper for disposal or using in different sectors such as construction. Waste oil produced in main and auxiliary engines is categorized as Category-3 and it is disposed by incineration or discharging to soil or water. Discharging waste oil causes great damage to the environment. It is resulted that the total cost of waste oil separator system is 150,000 € and estimated profit by using SLCA method is 50,000 €. The results show that recycling waste oil recovers the cost of waste oil separator by 30 %.

The analysis shows emissions that occur during transportation are non-negligible. It is determined that establishing the shipyards near to recycling/reusing/disposal facilities and modeling the valve and waste oil produced in main and auxiliary engines of a naval vessels by the help of SLCA methodology have positive contribution for both environmental performance and economy. Considering that a war ship has hundreds of systems and devices, it can be concluded that implementing SLCA methodology to whole ship may provide better environmental performance and resulted in benefits on economy.

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