ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

LIFE CYCLE ASSESSMENT OF NATURAL STONE AND TETRAPOD UTILIZATION ON BREAKWATERS

M.Sc. THESIS

Vasif VALIYEV

Department of Coastal Sciences and Engineering

Coastal Sciences and Engineering Programme

OCTOBER 2015

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

LIFE CYCLE ASSESSMENT OF NATURAL STONE AND TETRAPOD UTILIZATION ON BREAKWATERS

M.Sc. THESIS

Vasif VALIYEV
(517111004)

Department of Coastal Sciences and Engineering

Coastal Sciences and Engineering Programme

Thesis Advisor: Prof. Dr. Sedat KABDAŞLI

OCTOBER 2015

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

DALGAKIRANLARDA DOĞAL TAŞ VE TETRAPOD KULLANIMLARININ YAŞAM DÖNGÜSÜ DEĞERLENDİRİLMESİ

YÜKSEK LİSANS TEZİ

Vasif VALİYEV
(517111004)

Kıyı Bilimleri ve Mühendisliği Anabilim Dalı

Kıyı Bilimleri ve Mühendisliği Programı

Tez Danışmanı: Prof. Dr. Sedat KABDAŞLI

EKİM 2015

Vasif VALİYEV, a **M. Sc.** student of ITU **Institute of / Graduate School of Science Engineering and Technology** student ID **517111004** successfully defended the **thesis/dissertation** entitled "**LIFE CYCLE ASSESSMENT OF NATURAL STONE AND TETRAPOD UTILIZATION ON BREAKWATERS**", which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Mehmet Sedat KABDAŞLI** ....
İstanbul Technical University

Jury Members : **Prof. Dr. Emel İRTEM** ....
Balikesir University

Assoc. Prof. Dr. V. Ş. Özgür KIRCA ....
Istanbul Technical University

Date of Submission : 14 September 2015
Date of Defense : 26 October 2015

To my mother,

FOREWORD

This master thesis was prepared under the supervision of Assoc. Prof. Sedat Kabdasli. I would like to express my thanks to him for his orientation and encouragement in period of preparation of this thesis. His patience and heartiness are amongst the most important criterions for preparation of the thesis.

At the same time, I enunciate my special thanks to Dr. Nilay Elginöz for her courtesy and sincerity. She has provided every possible support even in hard cases.

I also want to thank to Assoc. Prof. Ş. Özgür Kırca for motivation from the first day in university and would like to thank to Assoc. Prof. Joost Vogtländer for his advices.

The Ministry of Education of Azerbaijan Republic provides scholarship for my graduate programme. I would like to state my thanks to the Ministry of Education for their support for students abroad and hope those students will be valuable people for the future of country.

I express my thanks to Doğan Çırakoğlu and other friends in Petlim Limancılık Ticaret A.Ş. for supporting my education and for ungrudging helps.

I would like to extend my heartily thanks to my mother Gülxar Vəliyeva and my father Bəylər Vəliyev and to my brother Dəyanət Vəli for their love and support during my study. I would also like to present my thanks to my wife Gülnarə Vəliyeva for her encouragement.

I thank to Soheil Farazi Majd for his support throughout the study and like to thank to Cenk Alter for technical support.

May 2015 Vasif VALIYEV

TABLE OF CONTENTS

Page

1. INTRODUCTION 1
1.1 Purpose of Thesis 4
1.2 Framework of Thesis 5
2. LITERATURE REVIEW 7
2.1 Breakwater 7
2.1.1 Natural stone breakwater 13
2.1.2 Tetrapod breakwater 17
2.2 Life cycle assessment 18
2.2.1 LCA Procedure 20
2.2.2 Life cycle assessment tools 35
2.2.3 Life cycle management 38
2.2.4 Social life cycle assessment (S-LCA) 38
2.2.5 Life cycle costing 39
2.2.6 Streamlined LCA 39
2.2.7 Importance of LCA 41
2.2.8 Life cycle approach for coastal structures 42
3. DESIGN OF NATURAL STONE AND TETRAPOD BREAKWATERS 51
3.1 Trunk Section stability 51
3.2 Construction Stages of Natural Stone and/or Tetrapod Breakwaters 52
3.3 Design Weight of Armoured Block 56
3.4 Design Weight of Tetrapod 57
4. LIFE CYCLE ASSESSMENT OF NATURAL STONE AND TETRAPOD BREAKWATERS 61
4.1 Goal and Scope Definition 61
4.1.1 Target audience 61
4.1.2 Method 61
4.1.3 System boundaries 63
4.1.4 Functional unit 63
4.1.5 Software and database 65
4.2 Inventory analysis 66
4.2.1 Life cycle of natural stone breakwater 66
4.2.2 Life cycle of tetrapod 70
5. RESULTS AND DISCUSSIONS 75
5.1 Global Warming Potential (GWP) 75
5.2 Acidification Potential (AP) 76
5.3 Eutrophication Potential (EP) 77
5.4 Ozone Depletion Potential (ODP) 77
5.5 Human and eco-toxicity (HTP) 78
5.6 Abiotic Depletion Potential (ADP) 79
5.7 Energy Consumption 80
5.8 Benchmarking with other researches 80

6. CONCLUSION..81

ABBREVIATIONS

$\boldsymbol{\alpha}$	: Slope angle
γ_s	: Specific weight of the stone
γ_t	: Specific weight of the tetrapod
γ_w	: Specific weight of water
ADP	: Abiotic depletion potential
AP	: Acidification potential
CEM	: Coastal engineering manual
CHE	: Cargo holding equipment
$\mathbf{D^4}$	: Damage value
EU	: European Union
EP	: Eutrophication potential
GaBi	: Ganzheitlichen Bilanzierung (Ger.), holistic balancing (Eng.)
GWP	: Global warming potential
$\mathbf{H_{1/10}}$	: Height of the highest 10% of waves
HTP	: Human toxicity potential
ICZM	: Integrated Coastal Zone Management^
$\mathbf{K_D}$	: Stability coefficient
LCA	: Life cycle assessment
LCI	: Life cycle inventory
LCIA	: Life cycle impact assessment
LCC	: Life cycle costing
LCM	: Life cycle management
ODP	: Ozone Depletion Potential
SETAP	: Society of Environmental Toxicology And Chemistry
S-LCA	: Social life cycle assessment
SME	: Small and Medium-sized Enterprises
SPM	: Shore protection manual
UNEP	: United Nations Environment Programme
USEPA	: United States Environmental Protection Agency
UTR	: Utility tractor rig
$\boldsymbol{W}$	: Weight of armour unit

LIST OF TABLES

Page

Table 2.1: Types and Functions of Coastal Structures (CEM, 2006) 9
Table 2.2: Projects and database with relation towards LCI.................................... 27
Table 2.3 : Calculation of impact categories.. 29
Table 2.4 : Benchmarking of methodologies. (PE INTERNATIONAL, 2014) 30
Table 2.5: List of LCA Softwares (Menke, Davis and Vigon,1996) 36
Table 2.6: Initial Review Categories (Menke, Davis and Vigon, 1996)................... 37
Table 2.7: Assessment of EC for each materals (Broekens, 2011)........................... 46
Table 2.8: CO_2 emissions for each construction materials (Mass, 2011).................. 47
Table 3.1: K_D values by SPM 1984, H=$H_{1/10}$. (SPM, 1984) 52
Table 3.2: List of Works During Natural Stone Breakwater Construction.............. 54
Table 3.3: Parameters for calculation weight of rock (Yüksel Proje, 2012)............ 56
Table 3.4: Parameters for calculation weight of tetrapod (Yüksel Proje, 2012)....... 57
Table 4.1: Processes of natural stone breakwaters construction.............................. 68
Table 4.2 : Processes of tetrapod breakwater construction...................................... 72
Table 5.1: Energy Use.. 80

LIST OF FIGURES

Page

Figure 2.1 : Myrina, Aliağa Turkey (Graauw, 2014). 7
Figure 2.2: Multilayer rubble mound breakwater (CEM, 2006). 14
Figure 2.3: Calculation the volumes of rock in a breakwater. (Sciortino, 2010). 16
Figure 2.4 : Existing types of armor blocks (CEM, 2006). 18
Figure 2.5: Factors of sustainability. 19
Figure 2.6: Phases of LCA. 20
Figure 2.7: LCA phases as iterative model (European Commission , 2010) 35
Figure 2.8: Life cycle assessment of breakwaters. 49
Figure 3.1: Places and distances used for LCA study. 52
Figure 3.2 : Construction of breakwater 55
Figure 3.3 : Cross-section of typical rubble mound breakwater. (URL-6) 56
Figure 3.4 : Tetrapods breakwater, Japan (URL-7) 58
Figure 3.5 : Tetrapod placement Methods (Çelikoğlu, 2014). 58
Figure 3.6 : Tetrapod placement. (Cengiz, 2010) 59
Figure 4.1 : Identification of difference between two breakwaters construction 62
Figure 4.2: Steamlined LCA: a restricted scope of study. 63
Figure 4.3 : Screenshot of GaBi 6 (Educational version). 65
Figure 4.4 : Flow chart of natural stone breakwater. 66
Figure 4.5 : Schematic view of natural stone breakwater construction. 69
Figure 4.6 : Flow chart of tetrapod breakwater. 70
Figure 4.7 : Schematic view of tetrapod breakwater construction. 73
Figure 5.1 : Global warming potential results. 75
Figure 5.2 : Acidification potential results. 76
Figure 5.3 : Eutrophication potential results. 77
Figure 5.4 : Ozone depletion potential results. 78
Figure 5.5 : Human toxicity potential results. 78
Figure 5.6 : Abiotic depletion fossil results. 79

LIFE CYCLE ASSESSMENT OF NATURAL STONE AND TETRAPOD UTILIZATION ON BREAKWATERS

SUMMARY

Because of its developing characterization, the environmentalist approach to surroundings becomes more detailed and sensitive. Coastal areas are one of the polluted areas and there are some mitigation and conservation projects about coast zones. Especially in Europe applications as integrated coast zone management and integrated watershed management are widespread. Factors of sustainability play an important role in this duration. Although there are not a lot of LCA samples about construction but these applications, have local and regional importance. Because of this, some institutions began life cycle assessment for port projects. At the same, LCA of coastal construction can be understood as integration of innovative environmental notions to fundamental engineering knowledge.

Selected breakwater in Aliağa peninsular is case study for this work. Aliağa peninsular is a strategic area for Turkey. In period of preparation of this thesis, two types of breakwaters are selected: natural stone and tetrapod breakwaters. According to construction phases, two different scenarios are stated for both breakwaters.

Firstly, all data and parameters about coastal zone and sea (wave parameters and etc.) are collected, since breakwaters are designed based on these features. Simultaneously, two different breakwaters have to accomplish the same work. There are some differences about raw materials and construction phases. For example: in the first scenario (natural stone breakwater), after selecting materials, the places from where these materials (stones) are carried to coastal zone are defined. In the second scenario (tetrapod breakwater) some part of materials are carried, but tetrapods are produced in factory near the coastal zone.

LCA is applied after determination of construction phases. LCA has various applications. Streamlined LCA is applied during this thesis. Main feature of this method is the assessment according defined differences. Generally, this method is used for benchmarking. Armoured parts of breakwaters are scope of study according this application.

There is some software, which is used during LCA. In this thesis, Education version of GaBi 6 is used for calculation of impact categories (global warming, ozone depletion etc.) after definition of processes in the scope of study. Finally, results are compared for selected impact categories.

DALGAKIRANLARDA DOĞAL TAŞ VE TETRAPOD KULLANIMLARININ YAŞAM DÖNGÜSÜ DEĞERLENDİRİLMESİ

ÖZET

Çevrenin devamlı etkilenmesi ve bu etkilenme sonuçları, gün geçtikçe sorunlara yol açmaktadır. Çevresel etki, alanına göre az veya çok olabilir. Günümüzde çevrenin etkilendiği yerlerden biri de nehir ve deniz gibi su havzaları ve kıyı alanlarıdır. Etkilenme nedenleri kıyı yapılarının inşaatı, kıyıya yakın sanayi merkezlerinin kurulması, turizm tesislerinin kontrol edilmeden genişletilmesidir.

Çevresel etkilerle alakalı dünyanın farklı yerlerinde farklı politikalar uygulanır. Örneğin, kıyı alanlarının planlanması ve yönetilmesi ile alakalı çevresel etkilerini değerlendirmek için birkaç uygulama vardır. Bunlara misal olarak, entegre kıyı alanı yönetimi, yaşam döngü fikri ve kirlilik arıtma teknolojileri gösterilebilir.

Projeler gibi uygulanan standartlar da önemlidir. Standartlar yalnız çevre yönünden değil aynı zamanda ekonomik ve sosyal yönden de yardımcı oluyor. Çevre ile alakalı standart dediğimizde aklımıza ilk ISO (International Standartization Organization) standartları geliyor. ISO 14000 çatısı altında çevre ile ilgili ayrı ayrı uygulanan alt standartlar vardır. Bunlardan biri de ISO 14040-14044 standartlarıdır. Diğer ismi ise yaşam döngüsü değerlendirmesidir(YDD). YDD'in üstünlüklerinden biri sürdürebilirlik faktörlerini de içermektedir. YDD tüm ürünlere ve hizmet alanlarına uygulanabilir.

Tezin çalışma kapsamında kıyı yapılarının yaşam döngüsü değerlendirilmesi yapılmıştır. Genellikle kıyı yapılarında YDD uygulaması iki safhaya ayrılıyor: Operasyon ve inşaat aşaması. Literatür araştırılması zamanı YDD' nin limandaki bazı operasyonlara uygulandığı görülür. Daha önce bu konuda birkaç çalışma olmasına rağmen, konu ile ilgili çok az çalışma vardır. Konteynerlerin elleçlenmesi zamanı sıfır emisyon hedefi ve limanlarda atık yönetimi için yapılan YDD çalışmaları örnek olarak gösterilebilir. İnşaat safhası için de çalışılmış YDD' e benzer uygulamaları vardır. Örnek olarak; farklı kıyı yapılarından beton blok dolgulu dalgakıranla, keson dalgakıranın karbon ayakizlerinin hesaplanması, aynı zamanda rıhtım duvarının tasarımında beton, çelik veya tahta kullanımda karbon emisyonu ile

alakalı çalışmalar gösterilebilir. Çalışmaların az olmasına rağmen Avrupa toplulukların 2011 senesinde başladıkları 'YDD modeli için Liman Projesi' (Port Projects for LCA model) 2015 senesi sonuna kadar devam edecektir. Bu bakımdan 'LCA4PORTS' programı mühim önem arz etmektedir. Bu program kapsamında uygulanan farklı projeler vardır.

Konunun araştırılması sırasında Aliağa yarımadasında liman inşaatında yapılan dalgakıran örnek olarak kabul edilmiştir. Aliağa yarımadası yerli ve bölgesel mevki olarak çok önemlidir. Bu yarımadada birçok petrol-kimya tesisleri, demir-çelik tesisleri ve başka ağır sanayi tesisleri vardır. Aynı zamanda bölgenin gelişimiyle beraber rafineri ve liman inşaatı işleri de devam etmektedir. Liman inşaatı sırasında yapılacak dalgakıran tez konusu için durum çalışmasıdır.

Konu çalışılırken dalgakıran tasarımı için iki farklı senaryo düşünüldü: doğal taş dolgulu dalgakıran ve tetrapod dalgakıranı. Bu aşamada bazı bilgi ve veriler araştırılıyor. Öncelikle, kıyı ve deniz (dalga parametreleri, deniz akış koşulu vs.) ile ilgili tüm verilerini ve parametrelerini toplanılır. Dalgakıranlar bu özellikler için tasarlanmış olduğundan iki farklı tip dalgakıran olmasına rağmen aynı görevi yapmak zorundalar. Aynı zamanda inşaat sırasında taşın nereden alınacağı, betonun nerde üretileceği de göz önünde bulundurulur.

Her iki dalgakıran için inşaat sırasında tüm aşamaları belirlendikten sonra YDD uygulamasına başlanılıyor. YDD uygulamasının birkaç farklı uygulaması var. Onlardan biri de 'Streamlined LCA' uygulamasıdır. Bu metodun özelliği farklılıklar üzerinden YDD uygulaması ve kıyaslamasıdır. İki dalgakıran arasındaki fark, dalgakıranların zırh malzemesidir. İki dalgakıranın çalışma prensipleri aynı olması sebebiyle, YDD yalnız zırh tabakasına uygulanacaktır.

Dalgakıranların tasarladıktan sonra, iki bağımsız LCA senaryolarını modellemek aşamasına geçiliyor. YDD uygulaması için birkaç bilgisayar yazılımı vardır. Örnek olarak, OpenLCA, SimaPro ve GaBi gösterilebilir. Konu araştırılması sırasında tezdeki tüm proseslerin modellemesini gerçekleştirmek için GaBi 6 bilgisayar yazılımının eğitim için tasarlanan 'Gabi Educational' versiyonu kullanılmıştır.

En sonunda iki farklı senaryo için YDD sonuçları bulunuyor. Sonuçlar birkaç kriter ile belirleniyor. Bu etki kriterlere global ısınma, ozon incelmesi, asidifikasyon, ötrofikasyon ve başka sonuçlar dâhildir. Aynı zamanda iki farklı senaryonun kıyaslanması için enerji tüketimi de önemlidir. LCA sonuçları belli olduktan sonra kıyaslama aşaması geliyor. Sonuçların seçilen etki kriterlerine (global ısınma, ozon incelmesi vs.) göre karşılaştırılması yapılıyor.

Konunun araştırılması için daha önce yapılmış çalışmaların da önemi vardır. En sonda dalgakıranların YDD uygulaması sonuçları ile daha önce yapılan çalışmaların sonuçları karşılaştırılmıştır.

1. INTRODUCTION

In this thesis, it will be seen the close connection between environmental sciences and coastal sciences. Although they are not far from each other, integrated condition of these two sections to each other will open a different view.

There are various applications about this relationship. Some groups are interested in coastal areas in scope of Integrated Watershed Management (IWM). The aim is to develop biological and socio-economic value and to expand integrated approach for obtaining IWM. There are some types of researches (Url-1):

- Hydrological studies: Main aim is to enlarge information on hydrological processes and to build connection between natural and countryside land uses. Developments on hydrological researches motivate institutions and stakeholders to step towards sustainable watershed management.
- Life cycle thinking: Calculation of carbon emission is one of the main goal for researchers. Environmental performance of products and services are evaluated with the way of life cycle assessment and carbon footprint investigations. Life Cycle Assessment (LCA) is another type of methods that can be applied in coastal zones for assessment of environmental impacts. European Union applies according this possibility, projects as LCA4Ports.
- Pollution treatment technologies: In industrial areas solid, liquid and gas emissions can be observed. For conservation coastal zones, pollution management methods are developing. Pollution management policies develop treatment technologies and aid industrial processes.
- Integrated coastal zone management: The aim can be understand as sustainable development and management of socio-economic resources in coastal areas. Policies are not applied only for present conditions but also for sustainable future. Relationship between environmental notions and coastal construction are assessed in a context of Integrated Coastal Zone Management (ICZM). In integrated management, natural factors are unavoidable. So before beginning of construction, a meeting should be held with the stakeholders (Construction Company, government and environment protection organizations). Prohibition of construction or applications of port project are according the result of meeting or some legislation. (Url-2)

Utilization of European coastal areas is source of problems about disruption of environmental and cultural resources in coastal areas. At the end of last century, the European Commission in cooperation with the EU coastal Member States and regions initiated new programme about remediation of worsen areas and to develop certain condition. There are some competitive sectors as tourism, port and industrial development, fisheries, and nature conservation over the coastal areas. There is a balance between them. If one of their development levels increase extremely, this situation may bring problems about unsustainablity and require more financial support for renovation in future. Numerous coastal authorities are planning appropriate approach about sustainable coastal zone utilization due to anticipated difficulties of purely sectoral methodology. In this phase, integrated coastal zone management (ICZM) is a beneficial method in comparison with purely sectoral methodology. European community is earned various lessons and experiences during implementation of ICZM programme. Even some initiatives are created in concept of ICZM. The OURCOAST initiative targets to share accessed experiences and practices with who are planning applications about sustainable solutions of problems in coastal areas. In period of decision-making, all stakeholders are participating in the coastal planning procedure. The participation of all sides is one of the main features of integrated approach.

Three main strategic policy intentions are include OURCOAST initiative:

- Adaptation to risk – Key purpose goal of this item is to management of influence of climate change and conservation of flexibility of coasts/coastal systems; Planning strategies about inhibition and managing natural hazards and technological (human made) hazards;
- Sustainable use of resources – Protection of the coastal and marine environment and increase of less resource utilization in processes/products are main feature of this plan.
- Sustainable economic growth – This policy can be understood as economic, social, and cultural development in balance with each other according developing the coastal zone and regional seas sustainably of Europe; Improving competitiveness.

OURCOAST is a three-year initiative and with a budget of this initiative is € 1 million. OURCOAST has started in 2009 after the European Parliament decision in 2008. In framework of this ICZM, 350 case study summaries are collected. These applications not only brought more experience and practice, but also made accessible database for using. Applications and experiences in this database are very beneficial and searchable. Best practices can be searched by:

- ✓ Geographical Selection
- ✓ Themes
- ✓ Key Approaches
- ✓ Free search

There are various good examples in practice can be found in framework of the OURCOAST initiative. One of them was a investigation in Cyprus. Because it is observed insufficient data and information about urban manner towards sustainability and sustainable development, ICZM and climate change. Main goal is to elucidate level of social sense about ICZM and climate change. As a result, this data is shared with as decision and policy-makers. During these investigations, financial support was one of the key criteria. Because this criteria influence level of effectiveness during investigation in certain area.

Case Study: Investigations are conducted under name of ‘‘Perceptions on Sustainable Development and Climate Change in Cyprus’’ on the 1st and 30th of November 2008. Main purpose was to collect data from both the Greek Cypriots and Turkish Cypriots about following topics:

- ✓ Consciousness and behaviour about climate change
- ✓ Consciousness about environmental issues (coastal erosion)
- ✓ Consciousness of organizations that give financial support for shore protection
- ✓ Consciousness about behaviour of breakwaters

Assessment of social opinion was with the way of telephone conversations and face-to-face meetings from both the urban and rural areas of the island. Generally, there were 670 interviews; 412 interviews were from Greek Cypriots and 248 interviews were from Turkish Cypriots. Some results were interesting and extraordinary. At the same time, these results are important. Sixty percent of the respondents said that they had no information about ‘sustainable development’. Other important point is old age people from both communities have more concern than young age people about coastal areas. More of respondents thought that island is affected by climate change. Moreover, they thought that they had no hope about participation during the decision-making process on environmental issues. (Url-3)

- Planning and environmental sustainability: Environmental policies and applications are one of the crucial steps for sustainable development of coastal areas. Some theories, concepts, instruments and decision-making procedures are produced for this target. Pollution management mechanisms, methodologies and implementations are developing day by day in framework of integrated policymaking.

During ICZM, project of construction can be applied or not, but the LCA results of project of construction make people apply Projects more ‘greeny’. Clearly sighted features of companies make them evaluate ecologically sustainable development with the way of integrated coastal zone management.

According to the sustainable development principles, determination of environmental impacts of the structuring in the coastal areas and deciding new preventions after analysis against the appeared results are one of the key applications of the modern coastal management (Kabdaşli et al, 1997).

1.1 Purpose of Thesis

Coastal areas are not only a natural wealth, but also an economic opportunity. Nowadays many marine structures are being constructed. Environmental effects on these constructions are becoming more crucial factor day by day. Although there are less investigations about life cycle assessment of ports, but it is more essential application for socio-economic development of coastal areas. In this thesis, coastal construction will be evaluated through environmental management aspect.

Life cycle assessment method can be understood as environmental management method that calculates environmental effects of products and services. In this thesis, LCA is applied in construction period of natural stone and tetrapod breakwaters. LCA of breakwaters will give detailed and comprehensive information about environmental effects. Aim of this thesis, is to use LCA method to compare environmental performance of construction of different structures. According this all processes during construction of natural stone and tetrapod breakwaters are taken into account. Because different scenarios have distinct and analogous processes. That is why environmental effects might be different or similar. Moreover, application of LCA formalizes environmental policy and increase level of sustainability in local or regional area.

1.2 Framework of Thesis

There are seven chapters in this thesis:

In Chapter 1, some information about relationship between coastal sciences and environmental sciences is stated. Purpose and framework of thesis are also expressed in this stage.

In Chapter 2, general information about different types of breakwaters, life cycle assessment, and different methodologies of LCA and application of them on coastal structures are mentioned comprehensively and detailed. At the same time, some surveys about these applications are presented and different points of views are observed about LCA.

In Chapter 3, construction of breakwaters and their measurements are stated in this chapter. These dimensions are done either for natural stone breakwater or for tetrapod breakwater. Accuracy about calculation is important for obtaining right results for LCA application.

In Chapter 4, LCA is applied to both of breakwaters; natural stone and tetrapod. All phases during construction were taken into account. After this, all processes during construction were modelled in GaBi software program.

In Chapter 5, After LCA of breakwater, there will be quantitative results for estimation of impact categories. The comparison between two different breakwaters was done according values of these impact categories. These impact categories are presented with diagrams and figures.

In Chapter 6, after obtaining results, there will be discussion in conclusion chapter. Results of comparison enclose also the results of LCA application, which is followed by discussions and recommendations.

2. LITERATURE REVIEW

2.1 Breakwater

In ancient times, breakwaters have been built to keep and protect structures in coastal areas. Some of them have been preserved and have survived for 2000 years, but most of old breakwaters were demolished by wave actions and now they are observed as “submerged breakwaters” (Figure 2.1). Rubble-mound breakwaters consist of stones bulk, which varies according to their unit weight: smaller stones for the core and larger stones as an armour layer protecting the core from wave attacks.

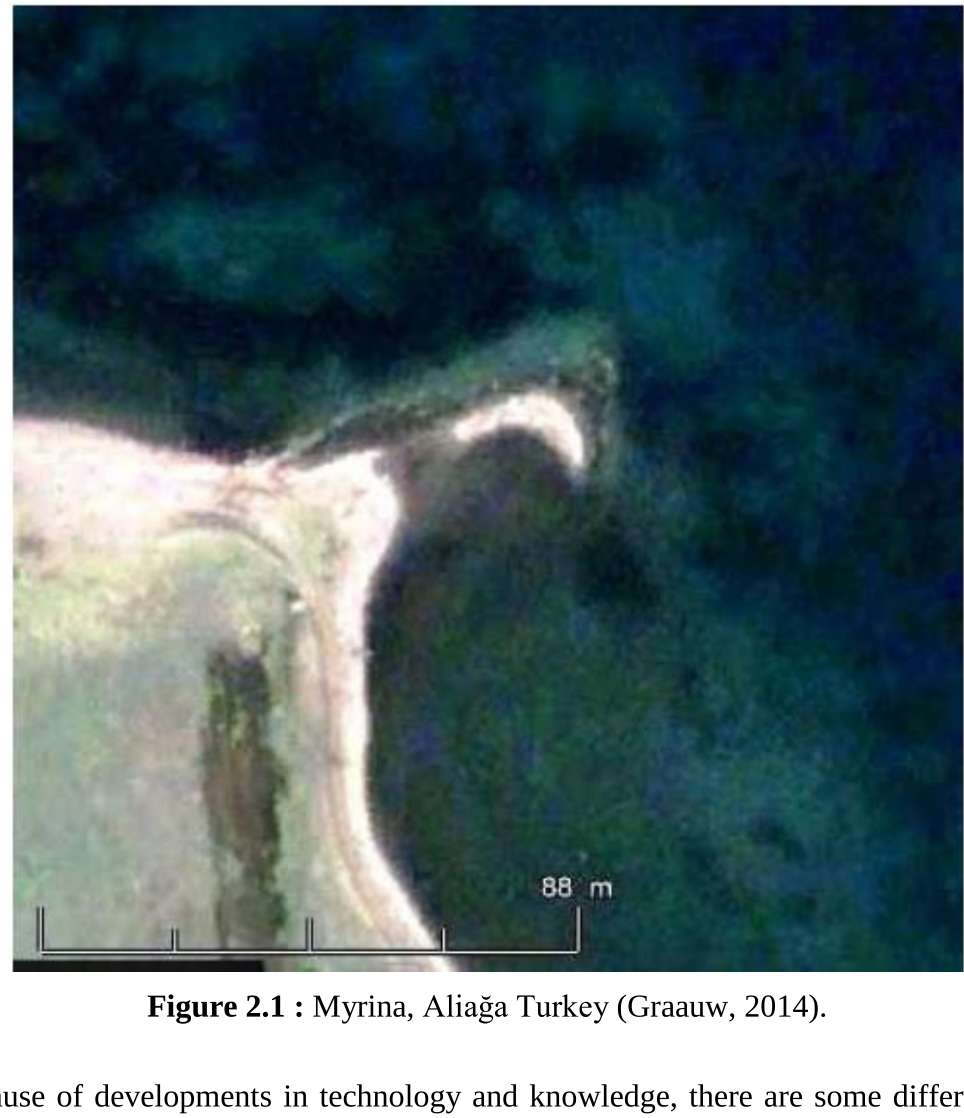

Figure 2.1 : Myrina, Aliağa Turkey (Graauw, 2014).

Because of developments in technology and knowledge, there are some differences between modern and ancient breakwaters. However, the result is that breakwaters are still in excellent shape nowadays and ancient times for sheltering harbours from storms. It can be understood simply that, relation between stone size and wave strength must be learned detail for stability of a structure. Size of stones and placement types are changed due to strength and direction of wave action. At the same time, relation between water depth, structure height and the stability position of the crest of rubble mound breakwaters subject to long-term wave attacks in breaking wave conditions. For ancient breakwaters, this means that:

• Ancient breakwaters could be found still in perfect condition: they were emerging and fulfilling modern design conditions

• Ancient breakwaters had been reshaped into an S-shape by 2000 years of storms:

• Ancient breakwaters will be lowered by wave actions to a level depending on the stone size. It is known that SWL have risen about 0.5 m since antiquity, so that breakwaters that were stable at that time in shallow water (a few meters water depth) may not be steady anymore because larger waves can reach them nowadays. (Graauw, 2014)

There are four main reasons of construction of breakwaters; to protect coasts, to prevent accumulation of solid in entry of channels and ports and to minimize dredging needs, to orientate flows in coast (Kabdaşlı, 1992).

Rubble Mound Breakwater is a coastal construction, which breaks and reflects waves and at the same time protects basin from waves which are situated behind breakwater. These breakwaters are constructed with accumulated huge stones (Günbak, 2012).

During natural processes, coastal areas can be affected negatively. Generally, there are huge deluges that overlap large areas along the coastline. At the same time, wave action usually erose seashore. For keeping coastal areas from unexpected natural processes, people designed coastal constructions. These constructions other features too. Because they preserve port basin, sheering channels at coves. There are different types of coastal structures and their function (Table 2.1). Some of them are presented below (CEM, 2006):

Sea dikes

As onshore constructions, sea dikes preserve low-lying areas from deluge. Construction materials of sea dikes are usually sand and clay. Sea dikes are constructed with a tender seaward slope for diminishing of the wave attack and for decreasing of erosion. There are different types of covering as armouring property. They are grass, asphalt, stones, or concrete slabs (CEM, 2006).

Table 2.1: Types and Functions of Coastal Structures (CEM, 2006)

Type of Structure	Objective	Principal Function
Sea dike	Prevent or alleviate flooding by the sea of low-lying land areas	Separation of shoreline from hinterland by a high impermeable structure
Seawall	Protect land and structures from flooding and overtopping	Reinforcement of some part of the beach profile
Revetment	Protect the shoreline against erosion	Reinforcement of some part of the beach profile
Bulkhead	Retain soil and prevent sliding of the land behind	Reinforcement of the soil bank
Groin	Prevent beach erosion	Reduction of alongshore transport of sediment
Detached breakwater	Prevent beach erosion	Reduction of wave heights in the lee of the structure and reduction of alongshore transport of sediment
Reef breakwater	Prevent beach erosion	Reduction of wave heights at the shore
Submerged sill	Prevent beach erosion	Retard offshore movement of sediment
Beach drain	Prevent beach erosion	Accumulation of beach material on the drained portion of beach
Beach nourishment and dune construction	Prevent beach erosion and protect against flooding	Artificial infill of beach and dune material to be eroded by waves and currents in lieu of natural supply
Breakwater	Shelter harbour basins, harbour entrances, and water intakes against waves and currents	Dissipation of wave energy and/or reflection of wave energy back into the sea

Floating breakwater	Shelter harbour basins and mooring areas against short-period waves	Reduction of wave heights by reflection and attenuation
Jetty	Stabilize navigation channels at river mouths and tidal inlets	Confine streams and tidal flow. Protect against storm water and crosscurrents
Training walls	Prevent unwanted sedimentation or erosion and protect moorings against currents	Direct natural or man-made current flow by forcing water movement along the structure
Storm surge barrier	Protect estuaries against storm surges	Separation of estuary from the sea by movable locks or gates
Pipeline outfall	Transport of fluids	Gravity-based stability
Pile structure	Provide deck space for traffic, pipelines, etc., and provide mooring facilities	Transfer of deck load forces to the seabed
Scour protection	Protect coastal structures against instability caused by seabed scour	Provide resistance to erosion caused by waves and current

Seawalls

Seawalls as sea dikes are onshore constructions and also preserving seashore or hinterland from deluge effects. Seawalls keep natural beaches, promenades, roads, and houses from flow of storms. That is why these structures are built parallel to the seashore. It can be assessed as a strengthening part of the coastal profile. Concrete walls, tied walls using steel or concrete piling, and stone-filled cribwork are used for construction of seawalls. Surface of these structures are constructed concrete slabs, concrete armour units, or stone rubble for strengthening. Seawalls either end or decrease erosion along the beach (CEM, 2006).

Revetments

Revetments are built for protection of seashore from erosion. Generally, armour part of revetments are constructed with materials, such as, stone, concrete, or asphalt at an angle of natural shoreline profiles. According Corps of Engineers, although there is no technical differencies between seawalls and revetments, but sometimes function of these structure can be changed regarding goals of project benefits (CEM, 2006).

Bulkheads

Bulkhead is constructed for avoid or stop sliding of the land. Secondary, bulkhead preserves seashore from deluge and controls wave action. Bulkheads are constructed as soil keeping structures and generally vertical wall mooring with tie rods. The most widespread implementation of bulkheads is anchored equipments in harbours and marinas for minimizing of wave action. Commonly, there is no differing between bulkheads and seawalls according various reference literatures (CEM, 2006).

Groins

Regularly, groins are built to arrange an enlargement of natural or artificially nourished beach for stopping erosion. As decrease of beach material hasten erosion, groins only become effective during alongshore transport occurs. Groins are perpendicular to the coastline. They are very narrow and straight. Series of groins or a groin system looks like a saw-tooth-shaped shoreline. In this system, groins are parallel to each other. This system also effects circulation and wave action along the shoreline (CEM, 2006).

Detached breakwaters

Detached breakwaters are short structures and main purpose of building structure is to reduce or to stop erosion. These structures are small and have no connection with shore. They are constructed parallel to the coastline in shallow water depths. Numerous detached breakwaters, which are placed along the shoreline, can ensure shield to coastline. As groins, a chain of detached breakwaters can be applied to manage beach material transport along the coastline. Due to controlling erosion level, detached breakwaters are prepared smaller and placed nearer to the shoreline (CEM, 2006).

Reef breakwaters

Reef breakwaters are submerged construction. They are parallel to seashore and can be long or short. Main feature is breaking of waves above the reef. As a result, these breakwaters decrease wave action. Reef breakwaters as rubble-mound structures consist of typical mass of stone or concrete armour blocks. Reef breakwaters can be narrow in shallow waters or can be wide crested in deep waters. Reef breakwaters can be dangerous for swimmers and boats (CEM, 2006).

Breakwaters

Breakwaters are constructed for decrease of wave action. There are two reasons for reduction of wave action. They are reflection and distributing of incoming wave energy after wave breaking. Breakwaters are built for making significant proper waters for secure mooring and loading operations, handling of ships, and protection of harbour facilities. Secondary breakwaters are constructed to develop current circulation at harbour entrances and to help manage sedimentation. Breakwaters have such features that protect seashore tsunami waves. These breakwaters are constructed parallel to coastline as detached breakwaters. The breakwaters are designed according to action of storm waves, orientation of currents and littoral flows and the manoeuvre possibilities of the vessels (CEM, 2006).

There are three elements, which are increase significantly the cost of breakwaters. They are water depth, wave climate severity and poor foundation. These elements seriously influence breakwaters in period of the design and placement of the breakwaters and the harbour layout.

Generally, there are two types of breakwater: sloping-front and vertical-front structures. Rubble-mound structures are included in sloping-front structures which rock or concrete armour blocks are used for construction of these structures. Sandfilled concrete caissons are example for vertical-front structures.

Floating breakwaters

Floating breakwaters are designed for calm wave climates with short-period waves. For example, box-shaped reinforced concrete pontoons are utilized to preserve marinas in protected zones. It can be observed floating docks attached to piles in marinas. There are four types of failure in floating structures (CEM, 2006):

- Failure of floating parts.
- Failure of floating part connectors.
- Failure of affix system or pile supports.
- Flooding and sinking.

Failure of breakwaters

One of the main subjects about breakwaters is element of ‘failure’. ‘Failure’ is estimated as collapse of structure totally or partially, however this estimation cannot be more accurate and acceptable. Generally, coastal structures are failed due to following reasons (CEM, 2006):

- Design failure occurs when its foundation or other construction elements cannot carried out according design criteria. Design failure can be also observed during unexpected performance of construction.
- Load exceedance failure happened when unexpected design load conditions were exceeded.
- Construction failure arises due to inaccurate or bad construction or construction materials.
- Deterioration failure is the result of structure worsening and reducing of project maintenance.

There is specific damage or failure for each type of breakwater.

2.1.1 Natural stone breakwater

The most regularly constructed breakwater is rubble-mound breakwaters. It has common shape as pile of stones. Nevertheless, huge stones play crucial role as frontage against rigid attacks of waves and sediments. Moreover, because of having rare features, these huge stones are very expensive. Finer material from quarry is used for core construction of breakwater. Armoured layer covers it but there is filter layer under armoured layer for protection finer material in core against washing. It can be called underlayer, too. Breakwater has armour layer, filter layer(s), and core and because of this, it is usually called multilayer structure (Figure 2.3). A toe berm supports the lower part of the armour layer. As armored blocks, concrete armour blocks are constructed in rigid wave zones. Concrete blocks are used in place where quarry stones cannot found (CEM, 2006):

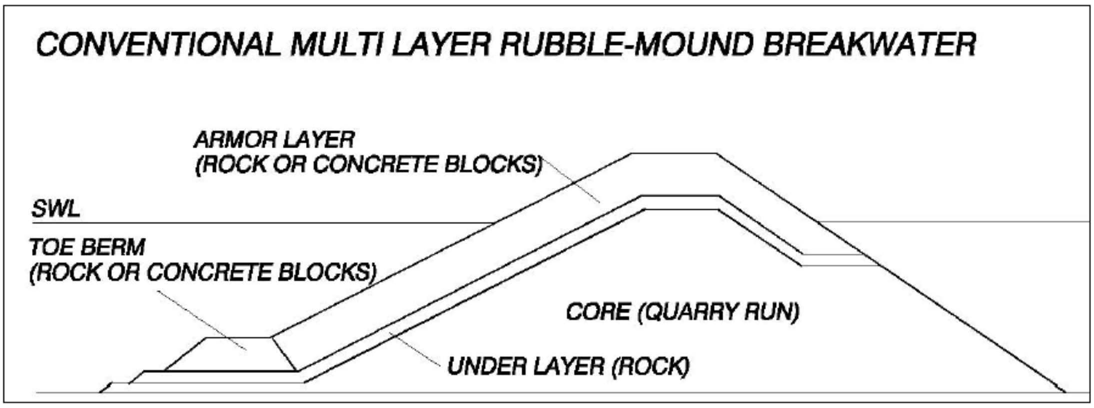

Figure 2.2: Multilayer rubble mound breakwater (CEM, 2006).

Hudson's Formula

There are some formulas, which are used for calculation during design stage of breakwater construction. For example, Van deer Meer, Hudson, Van Gent, Pilarczyk and etc. Hudson's Equation, also known as Hudson's Formula (3.1) (Kabdaşli, 1992) is an equation used by coastal engineers to calculate the minimum size of riprap (rock armour blocks) required to provide satisfactory stability characteristics for rubble structures such as breakwaters under attack from storm wave conditions:

$$W = \frac{\gamma_S H^3}{K_D\left(\frac{\gamma_S}{\gamma_W} - 1\right)\cot\alpha} \qquad \textbf{(2.1)}$$

And where; W is design weight of the riprap armour, γ_s is specific weight of the armour blocks, γ_w is specific weight of water, H is characteristic wave height ($H_{1/10}$), K_D is stability coefficient, α is slope angle

Design Phase of Breakwater

The main purpose of rubble mound breakwater is to keep coastal zone stability from rigid waves. Design and size determination is the key point for stable structures. For protection, rock and concrete units are used as armour unit. Because of design, breakwater performance can be assessed in periods of wave reflect, wave transmission and maximum run-up. As mentioned before, rock and concrete can be used for armour unit.

For building of breakwater, all environmental impacts must be evaluated comprehensively. Before construction phase, following factors are learned clearly and in detail. As a result, environmental feasibility of a certain construction is estimated (Sciortino, 2010). Before construction, there are some phases for designing of breakwater:

- Detail of hydrographical survey of the site
- Geotechnical investigation of the seabed
- Procedure of wave climatology
- A material needs assessment
- The cross-sectional design of the structure

For breakwater construction, environmental factors as wave heights, sudden changes in water depths, uncharted reefs, currents, tidal streams, seaweed and mobile beaches (sand drift) are crucial.

Bathymetric survey such as a hydrographical survey is necessary because right design decisions are made in project launch period.

Determination of the type of founding material and size is one of the main phases of breakwater construction. This phase is called geotechnical investigation and after this investigation the type of cross-section of the breakwater is determined. During this investigation, coastline features are also determined, for example: soft or hard rock, sand, clay, soft to very soft clay, silt or mud.

Behaviour and size of the breakwater usually depends on height of incident wave. Behaviour of waves is one of the nature's instable and complicated characteristic. Waves occur at periodic intervals. Because of strong winds, high and rigid waves are observed. Their size is changeable. Sometimes large ocean waves as 10 meters are detected. Generally, breakwaters are built from rocks or/and concrete or both of them. Calculation of the volume of material is necessary in order to build a rock breakwater. Sometimes construction material can be insufficient. In this case, required volume of material is carried by sea or by road to project site or location of the designed breakwater project can be changed to the nearest material accessible source.

In Figure 2.3, it is observed that each cross-section of structure sketch overlaid on a cross-section of the seabed and shown with a grid drawing with five cross-sections.

And it is also seen that the breakwater cross-section overlaid cross-section number 2 of the sea bed.

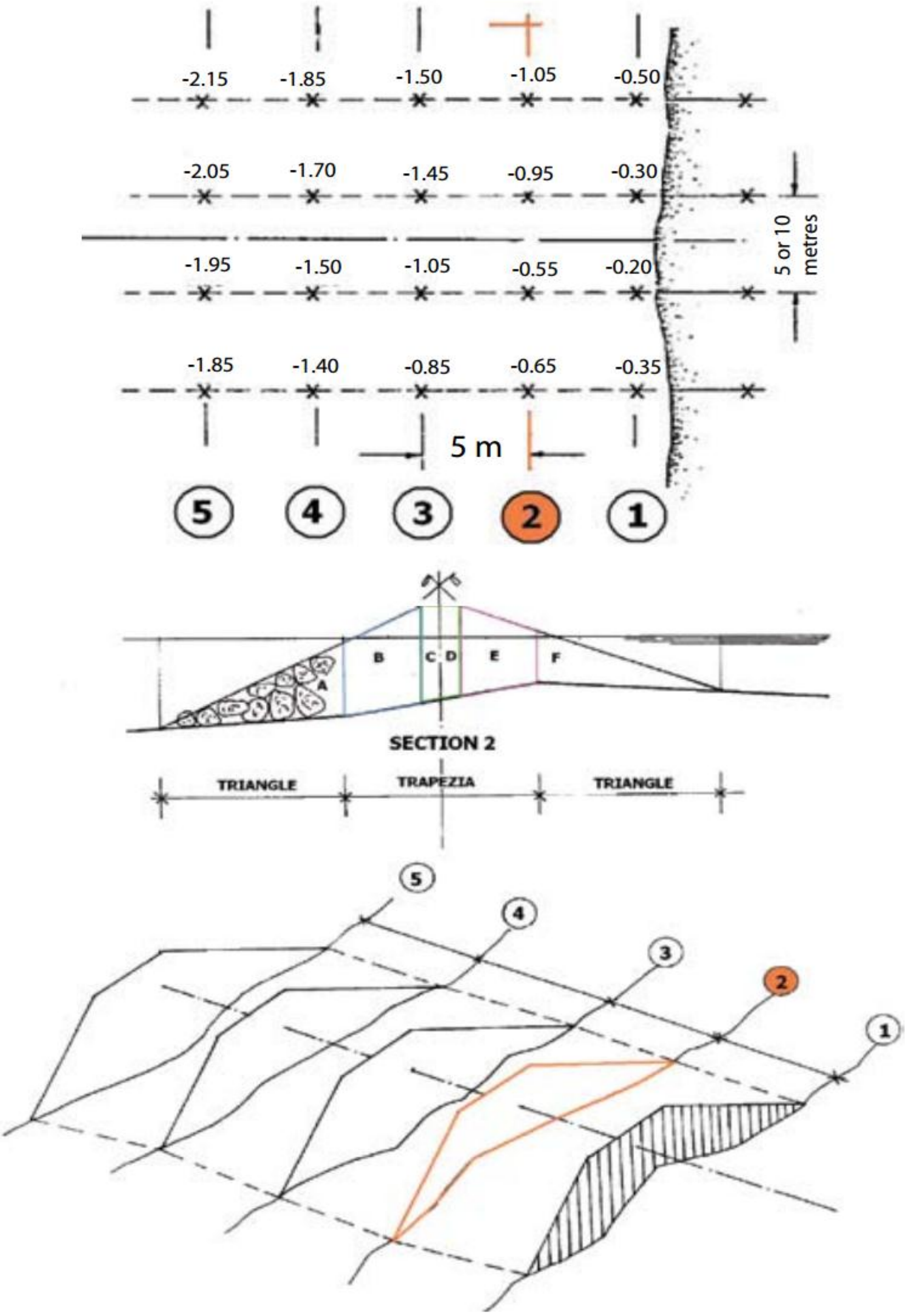

Figure 2.3: Calculation the volumes of rock in a breakwater. (Sciortino, 2010).

Triangles (A and F) and trapeze (B, C, D and E) are geometric subdivisions of each cross-section. In this way, area 2 can be understood as a sum of areas A + B + C + D + E + F. This calculation can be adapted to areas 1, 3, 4, 5, etc. The volume of required material is the sum of volume 1 + volume 2 + volume 3 + volume 4, etc..

For volume calculation of segment number 1, average of the sum of (area 1 + area 2) multiplied by the distance between sections 1 and 2. Otherwise, it can be calculated as (Sciortino, 2010).

$$1/2\ [\text{area } 1 + \text{area } 2] \times 5\ (\text{meters}) \qquad \textbf{(2.2)}$$

Cross-sectional design for the breakwater is complex estimation with all the previous data as water depths, type of foundation, height of waves, and availability of materials are to be taken into consideration. Generally, assessment of breakwater cross-sectional design is advised by experts to be performed before construction.

2.1.2 Tetrapod breakwater

Precast concrete amour units are used where rock is inaccessible. Nevertheless, generally the choice between rock or concrete could be effected by design which adapt to existing structures or natural characteristics. Tetrapod is the first 'engineered' precast concrete armour unit, designed by a French company in 1953. (Gavin and Colin, 1998)

A duly emplaced tetrapod is more durable than other alternative breakwater types against the rigid wave. Because of more protective feature, tetrapods are usually applied in the area of the most violent waves. (Cengiz, 2010)

At the same time, tetrapods are criticized because of being dangerous for swimmers and boaters. These structures also influence worthy to natural processes in coastal environment as hastening beach erosion. Another criticism is about ruining the traditional coastal scenery. But more people appreciate tetrapod as aesthetic structure for coastal zone (Url-3). Moreover, tetrapod has hydraulic (stability of armour components, strength of the structure as whole, reduced overlapping by waves, reduced wave reflection), structural (limitation of individual material weights, convenient artificial block fabrication, simpler block positioning) and financial (cutting of costs to a minimum) advantages (Danel and Greslou, 1957).

Other types of Armor Blocks

Armored units are devided following grouping in due to strength of structure:

Massive or blocky	(e.g., cubes incl. grooved types, parallelepiped block)
Bulky	(e.g., Accropode, Core Loc, Haro, Seabee)
Slender	(e.g., Tetrapod, Dolos)
Multi-hole cubes	(e.g., Shed, Cob)

It is presented examoles of sorts of concrete armor blocks in figure 2.4 (CEM, 2006):

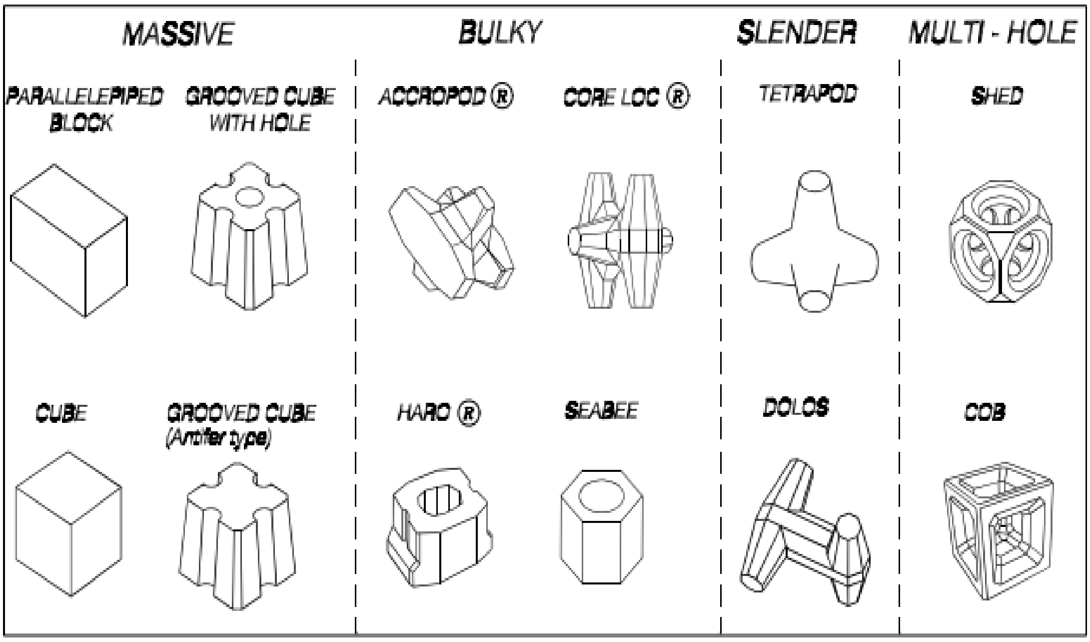

Figure 2.4 : Existing types of armour blocks (CEM, 2006).

2.2 Life cycle assessment

The notion of Life Cycle Assessment is formed from 70s of last century to nowadays. LCA was applied some independent initiatives in 1969-1970. First step came from Robert Hunt and William Fraklin. They are from Stanford University and University of Illinois. The projects in University of Illinois affected scientists in UK (1972). But in Germany LCA works organized in governmental level. This high level action was initiated by German Federal Ministry of Education and Science for enlarging problem of packaging waste. After US, UK and Germany, Sweden and Norway began scientific survey in this area (Baumann and Tillman, 2004). After so many investigations, scientists planned to change their surveys and analysis into practice. As a result, UNEP and Society of Environmental Toxicology and Chemistry (SETAC) union began the Life Cycle Initiative for putting life cycle understanding into practice in 2002. According to Malmö Declaration (2000), governments show their interests for life cycle economy because of this initiative (UNEP et. al., 2009).

The goal of the Life Cycle Initiative is to obtain sustainable development with the way of innovation and spread practical tools for the assessment of prospects and risks over their entire life of products and services.

Similar types of products generally pass same phases such that they are produced from raw materials, transported to the markets, purchased and utilized by consumers, and the last phase is disposal. At each phase in their life cycle, products can be evaluated in environmental, economic (cost) and social aspects. During decision making period, governments try to make a balance policy between using the right energy, resource efficiency and the lowest potential environmental impact. In this economy, consumers will evaluate this condition according to climate change, social consequences as for instance poor workers' rights, and costs.

Integration to modern consumption and production strategies and increasing permanent approach is the concept of life cycle thinking. As a result, managing the total life cycle of products and services towards more sustainable consumption and production form is an integrated model of Life Cycle Management (LCM). For putting Life Cycle Thinking into practice, Life Cycle Initiatives have three programmes (UNEP et. al., 2009):

- The Life Cycle Management programme (decision-making)
- The Life Cycle Inventory (data collection)
- The Life Cycle Impact Assessment (LCIA)

Factors (environmental, social, and economic factors) of sustainability are also included principles of LCA, too (Figure 2.5)

Figure 2.5: Factors of sustainability.

Definition Studies is the first action of Life Cycle Initiative, which is followed by putting life cycle thinking into practice. The goals of the Definition Studies are to classify the influences of the three programmes, and to guarantee that these effects are appropriate to the wishes and concerns of all stakeholders. During this process, special attention is needed to life cycle approaches in SMEs in developing countries where special requests and challenges can be formulated (UNEP et. al., 2009).

2.2.1 LCA Procedure

LCA has many similar and different definitions. Approximately all of them are based on the same fundamental notions. LCA covers the products from form of raw materials or from 'cradle' to other phases like production, use and disposal or to 'grave'. LCA has some reasons which make it acceptable; environmental sensitivity, public opinion and industry. LCA played a key solution role for finding more 'environmentally friendly' way of production. In other words, LCA was environmental assessment tool of products. LCA studies cover all product system. Strength and development of LCA take it to International Standardization Organization. Soon LCA has been accepted as ISO 14040 and 14043, which was declared in 1997. Resources use, human health and ecological consequences were considered in three main categories (Baumann and Tillman, 2004). There are four phases in LCA procedure (Figure 2.6).

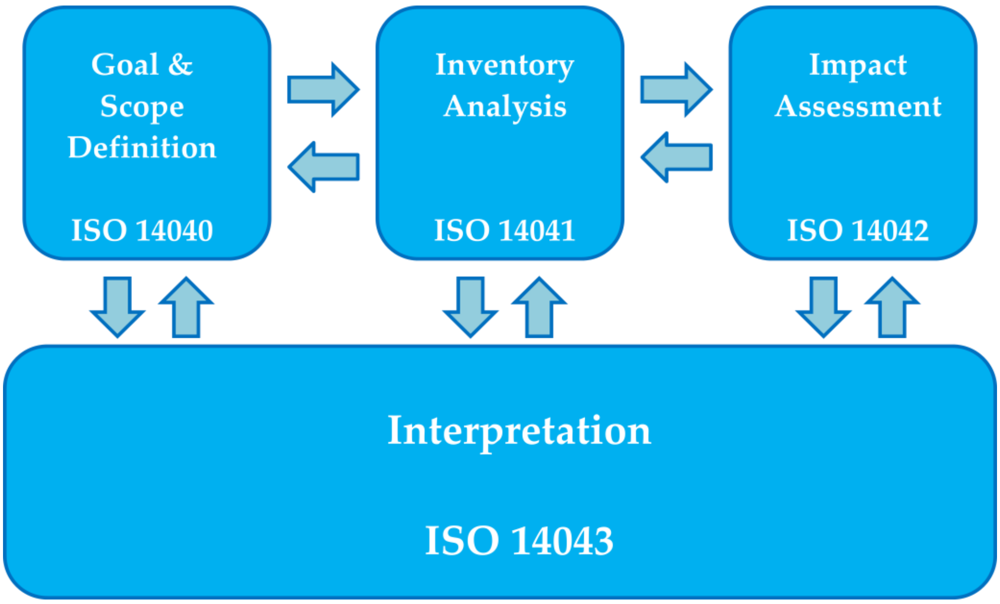

Figure 2.6: Phases of LCA.

2.2.1.1 Goal and scope definition

Determination of goal phase elucidate purpose of study or project comprehensively. A reason of applying of project is the main feature for this phase. At the same time, efficiency of project is very important due to benchmarking capability. Defining scope is also crucial. Functional Unit, System Boundary, Data Quality, Impact Categories and Options of Model take place in this step. Functional Unit is a joint unit which we can compare two or more projects/products. System boundaries include geographical, technical and time boundaries. However, in flow chart of production it is viewed its system boundaries: gate to grave, cradle to gate, gate-to-gate, and cradle to grave (Baumann and Tillman, 2004)

Due to being first phase, the goal definition phase is influential phase for all the other phases of the LCA. This phase orientates all features of scope definition, which is in relationship with LCI study and LCIA study. Results are estimated and interpreted. Interpretation is in relation with initial goal definition. Six features are decisive and important during the goal definition (European Commission , 2010):

- Intended application(s)

Initially, the intended application(s) of the LCA results shall be stated in an exact and definite technique during goal definition. More used LCA applications are presented below:

Identification of Key Environmental Performance Indicators (KEPI) of a product group for simplified LCA; weak point analysis of a specific product; detailed Ecodesign / Design-for-recycling; comparison of specific goods or services; policy development; improvement of specific, average unit process for use in specified types of LCA applications

- Method, assumptions, and impact limitations

Goal definition implies particular limitations of LCA results according to the applied methodology, assumptions made or limited impact-coverage (For example, carbon footprint). The definition and approval of these limitations requires a significant degree of proficiency and experience. Usually, the limitations can be regulate or develop during the work.

- Reasons for carrying out the study and decision-context

A reason for carrying out the LCI/LCA study is elucidated in goal definition phase. The decision-context is main feature of defining of suitable LCI modelling framework. At the same time, the decision-context defines main features of the scope definition, of inventory data collection and modelling, the calculation of impact assessment results, LCA results interpretation.

- Target audience

The goal definition defines the target audience of the study as with whom LCA results can be or should be shared. This communication format may be as methodological report or suitable form. Target audience can be government, municipalities, private sectors, and other stakeholders. At the same time, target audiences can be “internal” or “external” and “technical” or “non-technical” due to intention and requirements.

- Comparative studies to be disclosed to the public

Pure LCA study and giving publicity a comparative clear declaration is one of the main features during the goal definition.

- Commissioner of the study and other influential actors

The goal definition also defines who commissioned the LCI/LCA study (for example the Australian Agency for Protection of the Environment or the Australian Association of Paper Producers) (European Commission , 2010).

Scope definition phase is as important as goal definition and they are carried out parallel to each other. Functional unit, system boundaries, selection of LCIA impact categories, LCI data quality, and comparison techniques are included scope definition. There are two features of scope definition (European Commission , 2010):

- ✓ Consistency of methods, assumptions, and data

One of crucial necessity is to guarantee satisfactory consistency of methods and assumptions. It has relationship with all phases and characteristics of LCA work. This is also influence effectiveness of benchmarking.

- ✓ Reproducibility

Reproducibility is as important requirement as consistency for LCA application and this feature can be estimated as a qualitative assessment of LCA work. At the same time, appropriate reproducibility of LCA can take to the unambiguous results.

Functional Unit

In period of goal and scope definition, one of the main phases is to state functional unit. Functional unit has no relation with production and consumption volumes, it has relation with product function. As example, wood and concrete floor can be compared. Load bearing capacity of constructions is chosen for functional unit or with other word, it is stated as m^2 x year for flooring. Nevertheless, noise reduction and fire production may be evaluated as functional unit. Generally, functional unit requires being quantitative. In benchmarking during LCA studies, functional unit is referenced value. (Baumann and Tillman, 2004)

As quantity value, functional unit has two portions: the duration of use (in time) and the quantity of actual function presented. For example, an average lifetime of motorcycle is 8 years. Nevertheless, for the benchmarking with other motorcycles, the lifetime in terms of driven km are the more appropriate. (European Commission , 2010)

However, in qualitative approach functional unit opens different view. For example, although both of a parquet floor and wall-to-wall carpet are flooring techniques, but parquet floor is more aesthetical and carpet is preferable for noise reduction. Both flooring types can be compared according safety criteria (person x km for passenger transportation) or clean laundry (kg clean laundry for detergents). For example, for flooring aesthetically may be involved (Baumann and Tillman, 2004).

System boundaries

System boundaries are also determined in scope definition phase. Several types of dimensions indicate system boundaries (Baumann and Tillman, 2004):

- Boundaries in relation to natural systems

This boundary shows where life cycle begins and finish. In other word, it specifies ‘‘cradle’’ and ‘‘grave’’ of product. This boundary also can be understood as flow model of technical system or inventory model.

- Geographical boundaries

There are some reasons for creating of geographical boundaries as; various life cycle works can be occured various parts of world, applications about energy production, waste management and transportation changes for local area and warmth in approach to environmental issues are varied due to regional areas.

- Time boundaries
- Boundaries with in technical systems:
  - Boundaries related to production capital, personnel, etc. Cut of criteria
  - Boundaries relative with life cycle of other products

Apparent framework of LCA has to been formed as what is included and what is excluded. The most serious faults in practical life are done due to wrong system definition, which is too narrow, sub-processes are not taken into account that have more influence on output. Generally, systems are depicted in following types (Vogtländer, 2010).

- ‘the chain’ (from cradle to grave)
- ‘the cycle’ (C2C)
- ‘the tree’ (computer software)

2.2.1.2 Inventory analysis

Inventory analysis is second phase of LCA procedure. There are some works that have to do during this phase; data collection, refining system boundaries, calculation, validation of data relating data to the specific system, allocation.
Software programmes are required for calculation and structuring the inventory data. Importance of inventory data is defined all phases in flowchart of products or services and inventory table is designed for processes. (European Environment Agency, 1997)

Inventory analysis is the technical model part of LCA. All data collection, calculations are based on Inventory Analysis section. Following activities are included in inventory analysis (Baumann and Tillman, 2004):

- Creating of flow chart due to system boundary which is stated according goal and scope definitions
- Data collection of product system for all activities
- Assessment of environmental load as resource usage and emissions in connection with functional unit

Life cycle inventory cannot be estimated only as a cumulative aspect, but also it has iterative feature. Sometimes LCI effects goal and scope definitions, and requires revision of goal and scope definition.

Data collection is ‘‘blood stream’’ of LCA. Although it is very important, but there is some problems about accurate data collection. Numerical data is divided into inputs and outputs or with other word (Baumann and Tillman, 2004):

- ➢ Inputs of resources/raw materials and energy; as physical inputs (land use)
- ➢ Product;
- ➢ Emissions to air, water, land, and other environmental aspects (noise).

Definition of the system boundaries is also main stage of the inventory analysis. System boundaries are created according the scope of the LCA, and data collection in early phase. The definition of the system boundaries can affects the results of an LCI analysis considerably; the getting of methodological consistency has a great importance on this fundamental issue. There are three types of boundaries in LCA inventory (UNEP and SETAC Life Cycle Initiatives, 2005):

- Boundaries between the system and the environment;

The first type of system boundaries are openly presented in detail. They frame the environmental and economic processes that are involved or excluded. Because of more impact on the results of the study, boundaries have to be defined detailed and commented.

- Boundaries between the system under study and other related systems (or allocation);

The second type of system boundaries are more complex and are formed according allotment of the environmental load in a ‘multifunctional process’.

Many processes create numerous various products at the end of co-production, recycling or waste processing. Petroleum refining can be example for this process that named a ‘multi-functional process’. Special feature this boundary is utilization of excluded emissions and resource of such process for other functions as process provide. This allocation or distribution depends on the defined boundary if all products of a certain process are included in the analysis few of them. The allocation can be formulated according mass, commercial value, energy content, or similar product features.

- Boundaries between relevant and irrelevant processes (or cut-off):

The third type of system boundaries are formulated according the removal of processes from the LCI analysis, which is defined in boundaries. There are two reasons of process removing (or cut-off):

- If processes do not present an enormous cash flow or irrelevant environmental values are not analysed;
- Due to absence of (accessible) data, a process cannot be presented as numerical value.

Although, there are the variety of LCA methods and tools due to these three types of system boundaries, moreover, there is considerable variety of guidance documents. They can be in high quality that delivers detailed info, at the same time they can be restricted on international level. Individual groups, countries, prepare these methodologies. Furthermost guidance material has not accepted from regions and stakeholders, and because does not present condition reliance matters, as a result they cannot used in different circumstances and it makes some problems about development. The development of more steady guidance would help a lot to accomplish these weaknesses in LCA methodology (UNEP and SETAC Life Cycle Initiatives, 2005).

Developing of various national and international LCA projects are at different intensity in the world. At the same time practitioners in industry, governments, and universities, are woring on databases for carrying out more LCA projects more accurately. There are some databases and ongoing projects in table 2.1 (UNEP and SETAC Life Cycle Initiatives, 2005).

Table 2.2: Projects and database with relation towards LCI (UNEP and SETAC Life Cycle Initiatives, 2005)

Established LCI databases widely used in LCA practice	Actual national LCI database projects	Multinational LCI database projects	LCI databases that are made publicly available, but were developed within or for industry associations
GaBi, KCL-Eco, LCAit, SimaPro, SPINE, TEAM, Umberto, etc.	Australia, Canada, Germany, Italy, Japan, Switzerland, USA, etc.	Cost Action 530, eLCA, etc	APME database, etc.

2.2.1.3 Impact assessment

Impact Assessment is the third phase of LCA, and in this phase, Life Cycle Inventory (LCI) results are turned into environmental impacts by means of impact assessment methods. Generally, life cycle impact assessment tracks following steps (European Environment Agency, 1997):

- Category definition
- Classification
- Characterization
- Valuation/weighting

Category definition

Category definition is one of the main factors during LCIA phase. At the same time impact categories are discussed in goal and scope definition phase. According inventory collection, impact categories can be changed. System boundaries are also can be formed again. The goal of this step is to guide for choosing and determining the environmental categories. There are several environmental categories for life cycle impact assessment. Definitions of environmental categories are carried out for following principles (European Environment Agency, 1997):

• Completeness – related with environmental problems

• Practicality – prior categories

• Independence – detailed choice of impact categories

• Relation to the characterization step - suitable impact categories related to available characterization methods

Classification

The second step of the life cycle impact assessment classification of the inventory input and output data. The classification step goal is to provide inventory input and output data to categories. Classification is a qualitative value of relevant environmental processes according scientific analysis (European Environment Agency, 1997).

Characterization

The third step of life cycle impact assessment is characterization of the inventory data. After classification, characterization indicate loading of impact categories. Characterization is a quantitative pace of relevant environmental processes according scientific analysis. As a result, the possible value of each input and output to the environmental impacts are calculated. For calculation of impact categories, there is an agreement about equivalency factors, which is used (European Environment Agency, 1997).

Multiplying impact factors by classified results, represent Life Cycle Impact Assessment (LCIA). Impact categories are climate change, human toxic effects, ozone depletion, acidification, biodiversity, eutrophication (UNEP et. al., 2011). Impact categories evaluation is a connection between Life Cycle Inventory and Life Cycle Impact Assessment. Results about Life Cycle Inventory can be expressed in Life Cycle Impact Assessment. Cl is evaluated in AP characterization and HCl value is multiplied by AP factor (0,88) in order to get SO_2 Eq. (Table 2.3)

Table 2.3 : Calculation of impact categories.

LCI Emissions to air	Impact Categories (Midpoints)	Factors	LCIA (Damage categories or Endpoints)
SO_2 3 kg	Acidification Potential	3 kg SO_2 x 1	3 kg SO_2 Eq.
HCl 8kg	(AP)	8 kg HCl x 0.88	7.04 SO_2 Eq.

Valuation/Weighting

Except classification and characterization steps, there are several optional steps such as normalization, valuation or weighting. As it mentioned that characterization is quantitative step for impact categories e.g. global warming, stratospheric ozone depletion and ecotoxicological effects. Valuation or weighting are used for benchmarking of impact categories with each other. Although weighting is not estimated as, qualitative or quantitative step due to natural science but it has political or ethical importance (European Environment Agency, 1997).

Life cycle impact assessment has various performance methodologies. These methodologies are developed day by day. For sustaining of framework of these methodologies, scientific centres and institutes have important role. There are two leading methods for describing value of impact categories: CML and TRACI.

The U.S. Environmental Protection Agency (EPA) improves tool for the Reduction and Assessment of Chemical and other Environmental Impacts or TRACI. Generally this method is used in U.S. This method is damage-oriented method.

CML method is created and developed by Centre for Environmental Studies of the University of Leiden. Classification, characterization and normalization are included CML method (PE INTERNATIONAL, 2014).

Benchmarking of these methods are shown Table 2.4 according impact categories. (PE INTERNATIONAL, 2014)

Table 2.4 : Benchmarking of methodologies. (PE INTERNATIONAL, 2014)

CML	Unit	TRACI	Unit
Global Warming Potential (GWP 100 years)	kg CO2-Eq.	Global Warming Air	kg CO2-Eq.
Ozone Layer Depletion Potential (ODP, steady state)	kg R11-Eq.	Ozone Layer Air	kg CFC 11-Eq.
Acidification Potential (AP)	kg SO2-Eq.	Acidification Air	Mol H+ Eq.
Eutrophication Potential (EP)	kg Phosphate-Eq.	Eutrophication Air Eutrophication Water	kg N-Eq.
Photochem. Ozone Creation Potential (POCP)	kg Ethene-Eq	Smog Air	Kg NOx-Eq.
Human Toxicity Potential (HTP inf.)	Kg DCB-Eq.	Human Health Cancer Air	kg Benzene-Eq.
Terrestric Ecotoxicity Potential (TETP inf.)		Human Health Cancer Water	
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	Kg DCB-Eq.	Ecotoxicity Air Ecotoxicity Water	Kg 2,4-Dichlorophenoxyace
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)			
Abiotic Depletion Potential (ADP)	Kg Sb-Eq.	Human Health Criteria Air-Point Source	
		Human Health Non Cancer Air	Kg Toluene-Eq.
		Human Health Non Cancer Water	

Following impact categories are assigned according CML method:

Global Warming Potential (GWP)

In other word, short-wave radiation that comes from sun warms the surface of earth directly. But some part of the radiation is reflected as infrared radiation. Greenhouse gases absorb reflected part in the troposphere and are radiated again to all directions, and back to earth, too. This situation makes additional warming effect at the earth's surface. Furthermore, human activities increase the greenhouse effect (for example, carbon dioxide, methane and CFCs.). Carbon dioxide equivalents (CO_2-Eq.) are used for calculation of the global warming potential. A time range for the assessment is accepted 100 years period. (PE INTERNATIONAL, 2014)

Ozone Depletion Potential (ODP)

The disassociations of oxygen atoms, which are exposed to short-wave UV-light, create ozone in the stratosphere. The thickness of ozone layer is 15 - 50 km in the stratosphere. Because of mixing processes, 10 % of this ozone reaches the troposphere. The ozone layer is crucial for life on earth that ozone absorbs the short-wave UV-radiation and releases it in longer wavelengths and because of this small part of the UV-radiation influences the earth. Human activities (emission) deplete ozone. As a result, the hole in the ozone layer is observed according reports. The depleting effect on the ozone can be divided into two groups; the fluorine-chlorine-hydrocarbons (CFCs) and the nitrogen oxides (NOX). An evaluation of the ozone depletion potential should take into account for the long term, global and permanent effects. (PE INTERNATIONAL, 2014)

Acidification Potential (AP)

A transformation of air pollutants into acids influences to soils and waters as acidification. This condition makes decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H2SO4 und HNO3) make related contributions. Ecosystems are damaged direct and indirect by acidification. Not only forests but also buildings and building materials (metal, stone etc) also can be damaged. Sulphur dioxide equivalents (SO2-Eq.) are calculated as acidification potential. (PE INTERNATIONAL, 2014)

Eutrophication Potential (EP)

Enrichment of nutrients in a certain place is called eutrophication. Eutrophication can be observed in water basin or terrestrial area. Air pollutants, wastewater and fertilization in agriculture play important role for increasing of eutrophication. The quickly growth of algae in water, prevents sunlight reaching the lower depths and as a result, this makes less oxygen production according a decrease in photosynthesis and less. Less oxygen production increase fish dying diseases in water and degradation in plant. Harmful feature of eutrophication also influences groundwater and drinking water. Effects of eutrophication are different for region. The eutrophication potential is assessed in phosphate equivalents (PO4-Eq). (PE INTERNATIONAL, 2014)

Human and eco-toxicity (HTP)

The Human Toxicity Potential (HTP) assessment goals to evaluate the negative effect of, for example, a process on humans. At the same time this methodology is still in developing phase. The Eco-Toxicity potential target is to outline the damaging effects on an ecosystem. The Eco-Toxicity potential is divided into Terrestrial Eco-Toxicity Potential (TETP) and Aquatic Eco-Toxicity Potential (AETP). There are some parameters for estimation of toxicity. Harmful ingredients can extent to the atmosphere, into water basins or into the soil. Hence, potential contributors to important toxic loads are determined. The potential toxicities (human, aquatic and terrestrial ecosystems) are calculated according substance 1,4- Dichlorbenzol (C6H4Cl2). The unit is kg 1,4- Dichlorbenzol-Equiv. (kg DCB-Eq.) per kg emission. (PE INTERNATIONAL, 2014)

Abiotic Depletion Potential (ADP)

Affects on all natural resources (incl. fossil energy carriers) as metal containing ores, crude oil and mineral raw materials are calculated as the abiotic depletion potential. All raw materials from non-living resources that are non-renewable are included into abiotic resources. Reductions of the global amount of non-renewable raw materials are described in this impact assessment stage. Time range for non-renewable is 500 years according this impact category. This impact category covers not only evaluation of the availability of natural elements but also availability of fossil energy carriers. The reference substance is antimony as the characterisation factors. (PE INTERNATIONAL, 2014)

2.2.1.4 Interpretation

Interpretation is the last phase with the capability of identifying, checking, evaluating results obtained from LCI and LCIA. Interpretation is a phase of conclusions and recommendations. (UNEP et.al., 2011)

Interpretation is expressed jointly with goal and scope, LCI and LCIA phases. This step develops a reporting system. The final step of interpretation looks like traditional conclusions and recommendations part of scientific and technical assessment. (ACADEMY, 2008)

Interpretation phase consist of following stages (European Environment Agency, 1997):

• Identification of significant environmental issues

• Evaluation

• Conclusions and recommendations

Although policies and programs towards LCA are developed day by day, but interpretation stage is the least improved stage of ISO standard. Interpretation is in relation with the three other phases of the life cycle assessment. If the results of the inventory analysis or the impact assessment is not suitable according requirements of goal and scoping phase, the inventory analysis or impact assessment have to be developed or revised again. These processes have to be overcome as iterative application until the requirements in the goal and scoping phase are satisfied. In other word, the following steps chase this process. The process is repeated until 3 is carried out:

1. Identify the significant issues.

Description and arrangement of relative data are included identification step:

- Results from different phases
- Methodical choices
- Valuation methods used
- Role and responsibility of different stakeholder/parties

Significant environmental issues of the certain system can be e.g. CO_2, NO_x and SO_2 or they can be global warming, ozone depletion and human toxicological impacts according complication of LCA.

2. Evaluate

As second step, evaluating has three features, such as, at first to guide a qualitative control of the selected data or processes, secondly to conduct qualitative and quantitative investigation of inclusion of any replacement in the input data, and thirdly to dispute the identified changes due to goal and scope definition. If approaches systematically, this part of interpretation divided following sections:

- Completeness
- Sensitivity
- Consistency

The results of uncertainty analysis and data quality assessment can improve completeness, sensitivity and consistency check. Both of uncertainty analysis and data quality assessment are implemented throughout the application as they are relative to the individual data and calculations.

3. Conclusions, limitations and recommendations

Conclusion and recommendation is very openly and traditionally worked step of interpretation. This step is formulated according a scientific and technical assessment, and surveys. The goal of this step is to obtain conclusion and recommendation for the report of LCA application.

4. If so, report as final conclusions. If not, return to step one or 2.

The Interpretation phase has two crucial and fundamentally different goals (European Commission , 2010):

- In period of the iterative steps of the LCA, the interpretation phase conducts the effort on the way to developing the LCI model due to the requirement of study goal.
- The interpretation provides strong conclusions and recommendations, whether results of the iterative steps of the LCA are appropriate for LCI model, particularly during benchmarking of LCA applications.

All phases of life cycle assessment (goal and scope definition, inventory analysis, impact assessment and interpretation) are following each other and they have iterative relationship with each other (Figure 2.7):

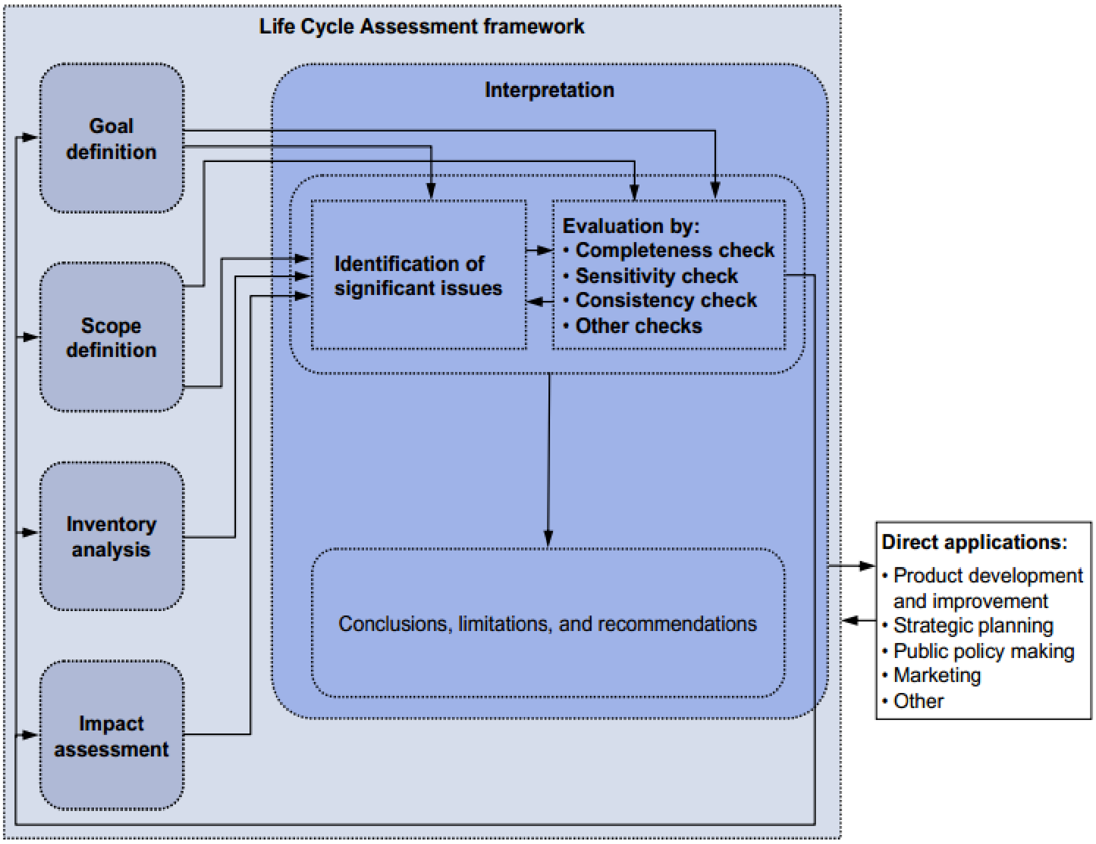

Figure 2.7: LCA phases as iterative model (European Commission , 2010)

2.2.2 Life cycle assessment tools

Amount of energy consumption and resource utilization are covered by LCA process. At the same time environmental discharges in period of life cycle, the calculation of the influence of these energy and material usage and the estimation and application of possibilities to accelerate environmental improvement are also include LCA process. Nowadays, LCA is evaluated as an instrument like environmental labelling, product environmental perfection, eco-design, and policymaking. The approval of LCA by international institutes, has hastened improvement of software tools and databases for performing LCA. More software tools and databases are licensed. These software and database could be for sale or free. LCA practitioners and general users can use these programs for academic or busness purposes. (Menke, Davis and Vigon, 1996)

After searching The 37 LCA software tools are defined (Table 2.3). They have different level of growth and utilization. Vendors are represented in second column Four of them are not yet fully developed (EcoSys, EDIP, LCAD, and SimaTool) and are shown as "Prototype" in the third column of Table 2.3. In last column, list countries are embodied that are data location of LCA tools. (Menke, Davis and Vigon, 1996)

Table 2.5: List of Life Cycle Assessment Softwares (Menke, Davis and Vigon,1996)

Name	Vendor	Version	Cost, $K	Data Location
1.Boustead	Boustead	2	24	Europe
2.CLEAN	EPRI	2	14	US
3.CUMPAN	Univ.of Hohenheim	Unknown	Unknown	Germany
4.EcoAssessor	PIRA	Unknown	Unknown	UK
5.EcoManager	Franklin Associates	1	10	Europe/US
6.ECONTROL	Oekoscience	Unknown	Unknown	Switzerland
7.EcoPack2000	Max Bolliger	2.2	5.8	Switzerland
8.EcoPro	EMPA	1	Unknown	Switzerland
9.EcoSys	Sandia/DOE	Prototype	Unknown	US
10.EDIP	Ins. For Prod. Devel.	Prototype	Unknown	Denmark
11.EMIS	Carbotech	Unknown	Unknown	Switzerland
12.EPS	IVL	1	Unknown	Sweden
13.GABI	IPTS	2	10	Germany
14.Heraklit	Fraunhofer Inst.	Unknown	Unknown	Germany
15.IDEA	IIASA	Unknown	Unknown	Europe
16.KCL-ECO	Finnish Paper Inst.	1	3.6	Finland
17.LCA1	P&G/ETH	1	Not Avail.	Europe
18.LCAD	Battelle/DOE	Prototype	<1	US
19.LCAiT	Chalmers Industriteknik	2.0	3.5	Sweden
20.LCASys	Philips/ORIGIN	Unknown	Unknown	Netherlands
21.LIMS	Chem Systems	1	25	US
22.LMS Eco-Inv. Tool	Christoph Machner	1	Unknown	Austria
23.Oeko-Base II	Peter Meier	Unknown	Unknown	Switzerland
24.PEMS	PIRA	3.1	9.1	Ave. European
25.PIA	BMI/TME	1.2	1.4	Europe
26.PIUSSOEC	PSI AG	Unknown	Unknown	Germany

OS				
27.PLA	Visionik ApS	Unknown	Unknown	Denmark
28.REGIS	Simum Gmbh	Unknown	Unknown	Switzerland
29.REPAQ	Franklin Associates	2	10	US
30.SimaPro	Pre’ Consulting	3.1	3	Netherlands
31.SimaTool	Leiden Univ.	Prototype	Unknown	Netherlands
32.Simbox	EAWAG	Unknown	Unknown	Switzerland
33.TEAM™	Ecobalance	1.15 & 2.0	10	Europe/US
34.TEMIS	Oko-Institute	2	Unknown	Europe
35.TetraSolver	TetraPak	Unknown	Unknown	Europe
36.Umberto	IFEU	Unknown	Unknown	Germany
37.Umcon	Particip Gmbh	Unknown	Unknown	Germany

In first period softwares are evaluated according six general categories. Determination of these categories is important for usage of softwares for suitable purposes. Selection of software can be changed due to user goals and computer requirements. For gained information about software, initial review categories are presented in table 2.4.

Table 2.6: Initial Review Categories (Menke, Davis and Vigon, 1996)

Software	Vendor	Features	Computing	Commercial Specification	Costumers Reviews
Name	Company name	Version	User support	Price and conditions	Number of users
Acronym	Address	System type	Operating system	Demo availability	Targeted type of users
	Contact	Data	Hardware requriments		Published reports/reviews
	Phone and fax	User interface			
		Calcultion methods			
		Outputs			

In general, during estimation of the selected LCA software tools, initial categories are taken into account, too. Center for Clean Products and Environment Canada define general list of specfication used to assess software tools. Six main categories of criteria were determined: computer requirements and interface; system definition; data and data management; flexibility; calculations and comparisons, and outputs and exports. (Menke, Davis and Vigon, 1996)

2.2.3 Life cycle management

Environmental Management Systems, Environmental Labelling and other environmental management tools are the results of formulation of environmental approach. One of the environmental tools is Life Cycle Management (LCM). All sorts of businesses to improve their products and thus the sustainability performance can use life cycle management as a business management approach. A technique can be used regularly by either large companies or small firms. This application can be used to aim, arrange, study and manage product-related information and activities towards permanent development along the life cycle.

Main goal of LCM is continuous improvement with the way of making life cycle thinking and sustainable product operation for businesses. These businesses do their bests to decrease environmental footprints and keep balance between environmental and socio-economic loads and developing economic and social values.

Management of sustainability performance of goods and services are included into framework of life cycle management (LCM). Other key points about LCM are short-term success and long-term value creation. That is why, during this application, policy making is usually crucial. Next stage can be changed into Mainstreaming LCM after results of certain policies and sustainable development. (UNEP and SETAP, 2009)

2.2.4 Social life cycle assessment (S-LCA)

Social aspects of products and their potential positive and negative impacts along the life cycle are main features of social life cycle assessment (S-LCA). With social aspects, S-LCA arranges site-specific data that can be quantitative or qualitative.

Decision about ‘‘product production or not’’ cannot be made by S-LCA. However, S-LCA may suggest “food for thought”.

Although S-LCA follows the ISO 14040 Framework, some features may vary in this methodology.

A methodology about improving life cycle inventory is offered by the UNEP Guidelines for Social Life Cycle Assessment of Products.

2.2.5 Life cycle costing

Method of life cycle costing (LCC) is the calculation of total cost of goods and services in period of its life cycle. There are more causes for using LCA. Generally, LCC is used for innovative and competitive purposes. The main users of this study are construction industry. Public and energy sectors use LCC either as a decision source or as a source of selection for different services. Environmental LCC is the economic version of LCA. The aim is to encompass important characteristics of the economic column of product-related sustainability. As LCA, environmental LCC also has system boundary and functional unit. LCC with an environmental and social assessment can represent all factors of sustainability. (UNEP and SETAP, 2009)

2.2.6 Streamlined LCA

After different survey of life-cycle assessment, applications and methodology made SETAC North America workgroup began investigations on Streamline LCA in April 1994. The key goal of the Streamlined LCA workgroup was to elucidate a process for an abrupt form of LCA. At the same time, measurement of amount of data took LCA methodology from “full” LCA approach to simplified “Streamlined LCA.” However, in prior times, this transition was not accepted completely and some people evaluated streamlined LCA. Generally, about goal and scope stating there are no differences between LCA methodologies. Moreover, these methodologies are streamlined in different levels. (SETAC, 1999)

The Society of Environmental Toxicology and Chemistry (SETAC) in North America and the U.S. Environmental Protection Agency (USEPA) financed projects to develop perspectives of framework of life-cycle inventory analysis and impact assessment. As SETAC in Europe, other international organizations began the same actions. As a result, framework of LCA and inventory methodology has begun developing (SETAC, 1999).

Spending either more time or more money were still main barriers for LCA application. This condition made some people investigate or find possibility of suitable methods that keeps main features of LCA. After introduction of Streamlined LCA, some practitioners emphasized that LCA could not be streamlined. Although there are some differences between full scale LCA and Streamlined LCA, as a methodology they are similar. Streamlined feature of this method is to reduce the duration. (SETAC, 1999)

Full Life Cycle Assessment is more complex and difficult. At the same time, it requires more time. However, using of Streamlined LCA is practical and manageable (ACADEMY, 2008). There are some advantages of Streamlined LCA:

- Restriction of scope
- Use of Qualitative information
- Removal of upstream and/or downstream elements
- Use of Specific impact category

Scope determination is an important phase of Streamlined LCA. Because system boundary and functional unit of products and/or services are defined during this phase. As in full LCA, same life cycle steps are also observed in Streamlined LCA:

- Raw materials
- Production
- Transport
- Operation
- End of Life

LCA studies are criticized because of long continuum, collection of more data. Streamlined LCA is simplified version of full LCA. (ACADEMY, 2008)

Another LCA-based benchmarking method is Fast Track LCA. Fast Track LCA has a different approach to goods and services. First thing in this period is to select a single indicator model. For example, damage based (carbon footprint), cost or cumulative energy demand. This method is 'to multiply input and output by eco-burden factors' which can be taken from Ecocosts 2007 LCA Databases. Fast Track LCA and 'full' LCA are varied type of calculation.

The main benefit of this method is that designer knows environmental values of the chosen materials because before followed from the tables without any computer calculation. (Vogtländer, 2010).

2.2.7 Importance of LCA

There are some causes to develop the understanding about LCA:

- Novel regulations and rules - In the European Union and Turkey for environmental marking
- Competitive advantage - To optimize industrial processes with a 'green way'. This has become a global trend and a competitive element.
- Requirement in public funded programs - LCA is an essential requirement of most of the publicly funded programs by the World Bank, the European Union (Horizon 2020) and Turkey. (Url-4)

Horizon 2020 as the largest EU Research and Innovation program has made a funding of 80 billion euros available for 7 years (2014 to 2020). This budget is attractive for private investors. This condition makes people produce innovative thoughts and inventions and takes these ideas from the lab to the market.

There are some sections of Horizon 2020 program. One of them is 'Security, Clean and Energy'. Energy Dispute makes stakeholders to follow a strategy towards more sustainable, viable and consistent energy system. Energy Efficiency, Low Carbon Technologies and Smart Cities and Communities are main priorities of "Secure, Clean and Efficient Energy" program. Life Cycle Assessment and economic modelling for use of energy storage technologies need progress and innovation. In general, energy storage has to develop in high level so that the difficulties with new storage concepts are decreased. Adaptation of new materials and growth for developed safety would be included in it. (Url-5)

Several implementations are carried out after estimation of LCA results. Some of them are given below (European Environment Agency, 1997):

• Interior manufacturing use in product development

• Interior strategic planning and policy decision

• Exterior manufacturing use for advertising reason

• Administrative policy making in the areas of eco-labelling and waste management prospects

2.2.8 Life cycle approach for coastal structures

As a valuable factor, Europe's ports play main role for steering the Commission's Communication on a European Ports Policy (COM/2007/0616). Then, Communication on an Integrated Maritime Policy (COM/2007/575) was implemented. To find solution of following problems are main goal of EU port authorities.

- ✓ Due to more ‘‘green’’ operations in port environments, it is required technological change.
- ✓ A decrease of greenhouse gases in the port environment;
- ✓ Arrange meeting between port stakeholders and growth of a dialogue on performance. Main purpose of this project is to grow LCA model parallel with EU environmental legislation regarding port development.

Although ports are environmentally affected areas for years, but it was not found any methodologies or guidelines to apply according UE environment legislation for developing of ports before 2012. The European Community launch new project "European Ports Life Cycle Assessment (LCA)" or LCA4PORTS for solution of certain problems. The goal of LCA4PORTS is to expand of a strategic point of vision on environmental management of European ports, according Community environment legislation to port development. The model of Life Cycle Assessment (LCA) and specific context of Anzio about application and experimentation are taken into account during application of this project. European Port Project, begun in November 2011 and will be completed in November 2015 for environmentally development of ports. The total budget of the project is € 1.091.650, with a Community donation of € 485.000. (Capo d'Anzio Spa and the Municipality of Anzio, 2011)

Environmental management of all processes and activities is the source of ‘port product’. However, key point in environmental management is life cycle of infrastructure. At the same time, application of this method builds an environmental label notion that might be useful for comparing ports in terms of the environmental sustainability aspects.

Coastal structures are usually influences in period of two phases: construction phase and operation phase. Construction of ports play crucial role for development of certain regions. However, equipment mounting and installations, storage of working materials influence environment, especially landscape, flora and fauna. Construction technologies and dredging activities bring environmental damage with themselves.

During port operation phase, ship traffic, fishing, passenger transport, loading & other vehicular actions contaminate port areas. In addition, results of these affect the ecosystem and biodiversity. There are some sources of pollution in port areas:

- Ships and other port vehicles
- Transportation and handling during operation phase
- Waste Production
- Dredging; environmental damage (modification of the seabed) and production of waste (toxic and hazardous)
- Other port activities; shipbuilding, logistic

Some actions in port areas cause environmental damages such as:

- Air pollution (emission of greenhouse gases)
- Sea pollution
- Soil and subsoil pollution
- Noise pollution
- Environmental deterioration and biodiversity loss

Whilst either difficulty or significance of these problems increases day by day, LCA application could be a useful choice in this stage. The results of an LCA clarify environmental impact categories and show level of environmental sustainability level in period of management of port services and activities. (Capo d'Anzio Spa and the Municipality of Anzio, 2011)

During this Project, two stages are suggested (Capo d'Anzio Spa and the Municipality of Anzio, 2011):

1. In first stage, process of a port infrastructure as a single process is developed. All phases joined to each other. End of environmental protection of a phase is the beginning point of the next phase. Applications of all phases are according to "Environmental Policy", that was announced before starting of the stage.
2. In other stage, an "original" form is proposed, LCA methodology is applied during construction and operation phase. It is determined sustainable development and environmental performance of the port service as an entire.

Generally, Life Cycle Management and Port Management are in close relationship with each other. Life Cycle Management pays attention on functionality, operational viability, quality and cost condition over the lifetime of a structure. The flow of costs is classified under three substances:

1. Infrastructure; dredging, engineering and offsite facilities
2. Terminal costs including building costs and replacement costs
3. Life cycle costs; regulatory and environmental charges

Life cycle of port is formulated on a sustainable basis both financially and environmentally by balancing investment. Environmental damage, design sustainability, maintenance and expenses are inevitable issues of Life Cycle of Ports. Port productivity is important, but problems have to be also evaluated throughout environmental point of view. (Charlier, 2013)

After literature survey, two types of LCA appear for place of application: LCA’s for construction phase and LCA’s for operation (industry) phase.

There are some works on mitigation of environmental impacts of container terminal operations as a cargo handling equipment (CHE) industry. LCA methodology is used as a tool of comparison and the target is zero emission technology. Diesel rubber-tired gantry (RTG) crane and utility tractor rig (UTR) are compared with an electric RTG and UTR.

Working on development of CHE, industry provides companies to use environmentally more efficient technologies. Due to CHE policy, it is observed reduction of emission and stepping towards ‘zero emission’. ‘Zero emission’ principle of the RTG and UTR passed through LCA methodology framework for getting sustainability. For a result of LCA, electrification of CHE is more environmentally suitable than diesel version of CHE. It is revealed that mitigation possibilities of environmental impacts on ports can be accomplished with LCA application (Vujicic et.al, 2013).

Another LCA approach could be observed in waste management of ports. One of the environmental problems of seaports is engine bilge water. It is a mixed form of water and oil products. Waste management and treatment methods have more importance for international and EU community. In this situation with the LCA methodologies, it is aimed to develop oily and engine bilge water treatment and assessment of environmental protection is important.

Reason of LCA application is to determine environmental impacts of ship-generated waste LCA is an assessment of water and energy input, chemically contaminated sludge and transport emission occurred in the course of transportation of products and fluxes of waste.

After application of LCA model, people got qualitative and quantitative information in different levels. During this period, information is defined explicitly and comprehensively:

- to assess the control of waste arrangement, gathering, and utilization
- to effectively handle stock and energy amounts for each stage of a technological process
- to classify and estimate the sources of environmental pollution (ambient air, water, waste)
- to anticipate the priority spheres of waste management optimization

Finally, as a result of the environmental assessment, produced waste is offered to be converted into energy and to be addressed back to a technological process, thereby closing the life cycle (Dvarioniene et.al, 2013).

GWP, AP, Human Toxication, Ozone Depletion are some of result indicators of LCA. Sometimes GWP could be main and/or only indicator for environmental evaluation of structures. UK and European regulations do their bests to quantify carbon emission of constructions. Carbon accounting is becoming crucial requirement for construction phase. Coastal structures are also evaluated in this model/case. One of the rare papers in this area is ‘Quantifying the carbon footprint of coastal construction – a new tool HRCAT. Carbon accounting tool can also assess environmental impacts of breakwater constructions. Generally, in coastal constructions carbon emissions are divided into following categories:

- Production of materials for use in construction
- Transportation of materials to breakwater site
- Construction of breakwater

In this study, distance from quarry to construction site is about 500 km for rock carrying. However, for caissons, concrete is produced near the construction site and sand for ballasting is obtained from marine borrowed area where dredging equipment work. Trucks would be fully loaded while they carry rocks from quarry to construction site and they would be empty while return to quarry. The distance used for carrying materials from quarry played key role on assessment of carbon emission. Evaluations of breakwaters are accomplished for CO_2 in table 2.7. (Broekens, 2011)

Table 2.7: Assessment of EC for each material (Broekens, 2011)

Material	Rubble Mound Breakwater		Caisson Breakwater	
	Quantity (tonne)	EC (million $kgCO_2$)	Quantity (tonne)	EC (million $kgCO_2$)
Rock	3,650,000	18.3	510,000	2.6
Concrete (armour units)	550,000	44.0		
Concrete (caissons)			342,000	91.8
Sand			1,300,000	2.6
Total		62.3		91.0

The advantage of LCA is not only to assess environmental impacts but also is being instrument of comparison between products and/or services. Trude Maas (2011) has compared four construction materials with each other regarding CO_2 emission and Life Cycle Analyse. These materials are concrete, steel, wood and fibre reinforced polymer (FRP) for designed quay wall. If quay wall is compared in term of costs, wood design is twice expensive than concrete and steel. But FRP design is the most expensive design which is 7-10 times higher than other designs. Cost valuations are done for 1.0 m quay wall.

For CO_2 – emission CO_2, CH_4, N_2O, HFC's, PFC's and SF_6 are taken into account. Except greenhouse gases, other impact categories have been calculated with the way of Life Cycle Analysis (LCA). There are ozone, energy, abiotic/biotic depletion potential, human toxicity potential fresh and salty water, terrestrial, aquatic eco-toxicity potential, photochemical oxidant creation potential, acidification, and eutrophication potential. Functional unit for comparison is 1 m quay wall. Lifetime of certain structure is 50 years.

Impacts during material production phase, transportation phase, construction phase and use phase are taken into account except reuse, recycling and incineration phases. For calculation of carbon footprint, two databases are used: Ecoinvent 2.0 and IVAM LCA Data 4. For carbon footprint calculation wood is material with lowest value for design. However, FRP has more CO_2 – emission than other materials (Table 2.8). Durability and lowest carbon footprint features made wood suitable material for quay wall design. (Mass, 2011)

Table 2.8: CO_2 emissions for each construction materials (Mass, 2011)

Material	kg	Global warming (GWP 100)	Total kg equivalents
Concrete diaphragm wall	93 600	10 858	25 803.9 (with reinforcement steel and bentonite)
Steel combi wall	6 032	10 012	21 412.5 (with sheet piles and anodes)
Wooden wall	50 050	10 711	13 361.7 (with steel and bentonite)
FRP sandwich panel	17 269	51 808	236 334 (with vinylester resin, glass fiber, PU foam and bentonite)

Life Cycle Assessment of natural stone and tetrapod breakwaters have more significance throughout LCA4PORTS program (2011, November – 2015, November).

There are some similarities and differences between this thesis and other articles which were mentioned before. As similarities, following items can be mentioned:

- Definition and minimizing of environmental impacts are one of the main points of all LCA applications.
- In articles, lowest harm product/services and more suitable way are selected throughout comparison by means of LCA application
- LCA application increases sustainable development

At the same time, there are some differences between this paper and other articles:

- Firstly, in this paper two LCA of two analogous breakwaters are compared.
- In this paper, different LCA methodology is observed which is named "Streamlined LCA" or "simplified LCA"
- The first LCA application is in regional area about construction of breakwaters.

During flow of this thesis, sustainability is a key feature as a relationship between coastal sciences and environmental sciences (Figure 2.8). An integration of Coastal and Environmental Studies through the view of sustainability is hypothesized.

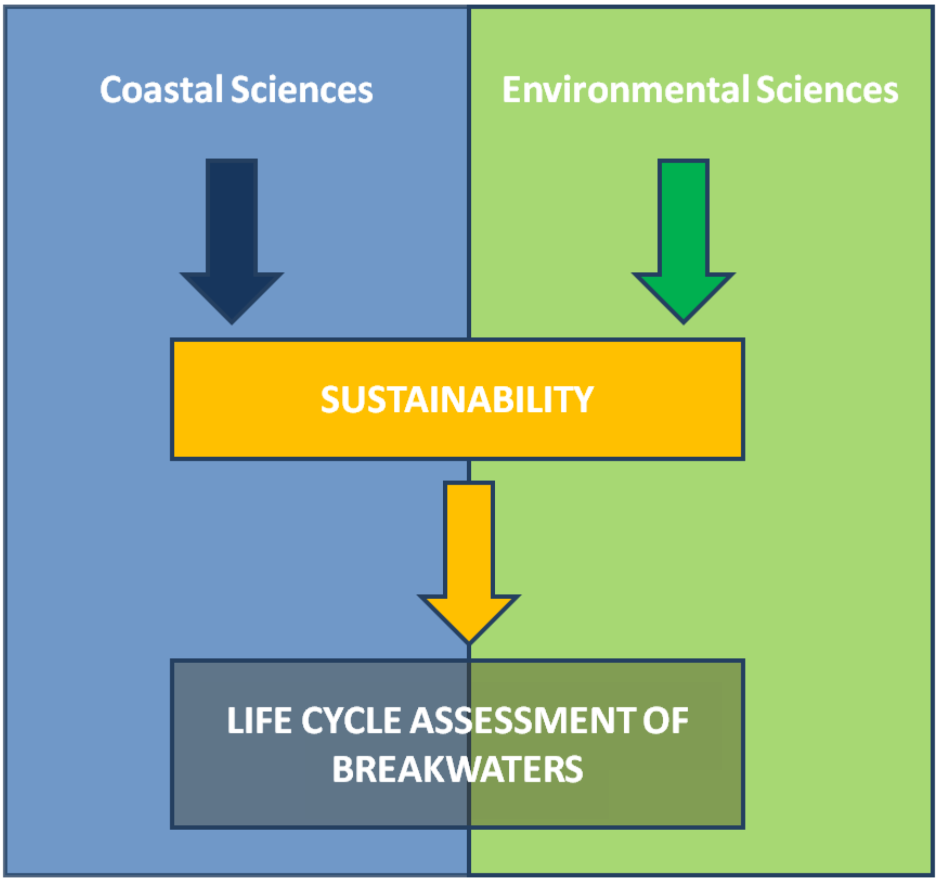

Figure 2.8: Life cycle assessment of breakwaters.

3. DESIGN OF NATURAL STONE AND TETRAPOD BREAKWATERS

Three sides of Turkey are surrounded by seawater. This provides more possibilities about construction of marine structures. Marine structures have importance on development of tourism, international trade, fishery and other economic opportunities. At the same time, these opportunities have some environmental impacts. Worse impacts on coastline area, on flora and fauna increase continuously. These environmental pollutions require preferable solution. One of these approaches is Life Cycle Assessment (LCA). LCA of coastal structure covers all works starting from the beginning of construction, using and deconstruction.

For evaluation of LCA of breakwaters, two breakwaters are selected, firstly. These are natural stone breakwater and tetrapod breakwater. Natural stone breakwater is built in Aliaga peninsula according to Port Project. This harbour will be international customs gate for international container vessels. Some data about calculations of breakwater belongs to Port Project Report (Es-Fermak, 2013).

At the same time, tetrapod breakwater was designed for the same properties (wave height, etc.) used for natural stone breakwater. Design in the same characterization is the main feature for benchmarking with the same functionality. After this step, assessment of environmental impacts will open obvious view about difference/similarity of these breakwaters. During design phase of coastal structures, more calculations, modules and formulas are applied for detailed description of design. As a result, distinguished scientists do their best to find the nearest solutions with their models.

3.1 Trunk Section stability

For designing of breakwater, determination of trunk section stability is important. In Table 3.1, breaking wave can be understood as depth-limited wave breaking because of armoured slope and also non-breaking wave can be understood as no depth-limited wave breaking because of armoured slope. D (damage percentage) is expressed in order to SPM 1984. Removal volume of active armoured units presented as damage percentage. $\cot \alpha$ is value for placement of axis of stone for slope of structure (CEM, 2006).

Table 3.1: K_D values by SPM 1984, $H=H_{1/10}$. (SPM, 1984)

Stone Shape	Placement	Breaking wave	Nonbreaking wave (D^4=0-5%)	$\cot \alpha$
Armoured Block	Random	2	4	1.5-3
Tetrapod	Random	7	8	1.5-3

3.2 Construction Stages of Natural Stone and/or Tetrapod Breakwaters

For construction of breakwater, some issues must be taken into account. Before construction, experts work on design of structure. Labour force, healthy, safety, environment management plans, risk analyses, quality control and assurance techniques and forms, etc. are also important. In addition, this construction is carried out with developing technology and machinery. As machinery and equipment, barges, cranes, tugboats and trucks will be used for realization of this project. All processes are carried out according work schedule.

In this study distance between quarry and breakwater construction site is 17 km (Figure 2.1).

Figure 3.1: Places and distances used for LCA study.

There are some kinds of rock-breaking equipment for making suitable stones for all parts (core etc.) of breakwater. Rockfill material is washed either in quarry or in construction site. Although in quarry, tap water is used, seawater is used for washing in construction site. During construction Works, GPS measurement is important for determination of coordinates. Compressive strength of the rocks will be tested according to BS EN 1926. All works and applications are performed within the scope of 'Port Project Report' (Es-Fermak, 2013)

The following machineries, equipment and tools shall be used during construction phase:

- Hydraulic Crawler Crane – 160t, 110 ft boom length – 1pc
- Excavator – Sumitomo S500 (50t) – 2pc
- Excavator – Sumitomo S500 with Extended Boom –1pc
- Split Barge – with 420 m^3 capacity
- Split Barge – with 900 m^3 capacity
- Flat Barge – 25mx90m
- Loader – Liu Gong, 18t, 1pc
- Excavation Truck – of any brand and capacity – at sufficient quantity
- Mooring Boat – 1pc
- Tug Boat – 1pc

The marine works engineer will calculate the truck quantity, and simultaneously estimate location of taking filling material from quarry, weather conditions, daily construction site efficiency, daily personnel and machinery quantities and effectiveness at the filling stage.

As emphasized before, in design phase approximately all quantities are calculated. Quantities of rocks are indicated in the Table 3.2.

Table 3.2: List of Works During Natural Stone Breakwater Construction. (Es-Fermak, 2013)

No	Step of Work	Unit	Approximate Quantity
1	Ground improvement under breakwater using 1-4 t material acquired from the quarry	ton	198.061
2	Core rockfill manufacture using the 0-0,4 t material acquired from the quarry	ton	2 637.879
3	Rockfill armouring manufacture using 0,4-2 t material acquired from the quarry	ton	501.072
4	Rockfill armouring manufacture using 2-4 t material acquired from the quarry	ton	183.370
5	Rockfill armouring manufacture using 6-8 t material acquired from the quarry	ton	21.849

1. Construction of Ground Improvement Rockfill with 1-4 t Material

For removing silty-clay, rockfill will be carried out using 1-4 t material. During construction of soil improvement, barge, 50 t excavator and 210 t crane will be used. Continuous bathymetric measurements will be applied. No other work will be done until finishing of soil improvement works. 1-4 materials will be loaded on the barge from the loading ramp. Tugboat will stay with the barge until the material placement work is finished.

2. Construction of Core Rockfill with 0-400 kg Material

0-400 kg rockfill material will be used for core of breakwater. This material will be placed over the soil improvement material by barges.

3. Construction of Protection of Core Rockfill with 0,4-2t Material

0,4-2 t material will be used for protection of core rockfill section. During this phase, barge, 2010 t crane, excavator and tug-boat play an active role. Rockfill protection layer will start in the areas where 0-400 kg core rockfill reaches the 12.00 elevation.

4. Construction of the Toe Rockfill with 2-4t Material

Toe Rockfill Works may begin after construction of core rockfill. Toe Rockfill construction will begin from sea with the help of barge, crane and tugboat.

5. Construction of the Rockfill Protection Layer (Outermost) with 6-8 t Material

6-8 t material will be used for armoured section of natural stone breakwater. But in Tetrapod Breakwater Construction, 5 t tetrapods are used instead of 6-8 t stones. These huge armoured blocks will be placed by 25mx90m barge and 210 t crane. The depth of toe is -12 m. Construction of breakwater is described in Figure 3.2:

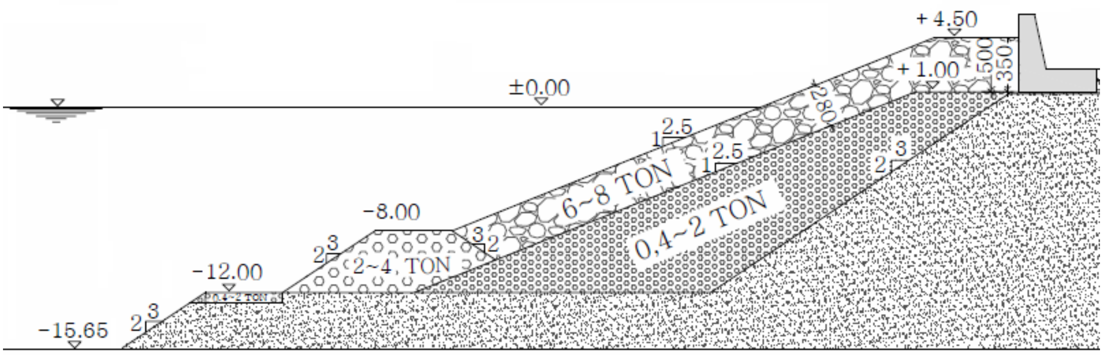

Figure 3.2 : Construction of breakwater

Labour force is one of the requirements for construction. Because technical and administrative personnel are main part of management of field works. Personnel at the following qualification and quantity shall be seen in construction site:

Marine Works Department Supervisor – Civil Engineer – 1 engineer

Site Engineer – Civil Engineer – 2 engineers

Navigation Skipper – 1 captain

Divers – 2 divers

Foreman – 2 foremen

Bathymetry Measuring Team Leader – Topographical Engineer – 1 engineer

Bathymetry Measuring Team – 3 teams

Construction Machine Operators and Marine Equipment Personnel

Shore Personnel – 2 people

Flaggers and Markers – 5 people

Oilers – 3 oilers

All calculation and assessment of parameters were done in Port Project. But only parameters of armoured part are required. The length of breakwater is 530 m.

3.3 Design Weight of Armoured Block

For comparison of breakwaters, streamlined LCA will be applied. According to this methodology, part of armour layer is an area for benchmarking (Figure 2.3).That is why; it is needed to calculate weight of armoured block and tetrapod.

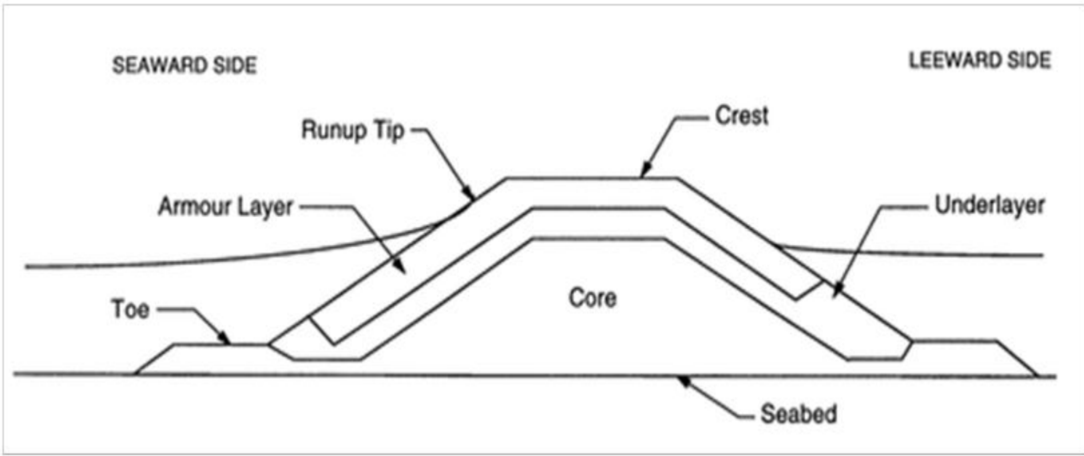

Figure 3.3 : Cross-section of typical rubble mound breakwater. (URL-6)

Before LCA of breakwaters, all data and parameters about coast and sea (wave parameters, sea flow condition etc.) are collected (Table 3.3). Because breakwaters are designed according these features. According calculation, spectral significant wave height (H_s) is 3.7. But (cot (αrep)) representative slope is 2,5. (Yüksel Proje, 2012)

Table 3.3: Parameters for calculation weight of rock (Yüksel Proje, 2012).

y$_s$ (t/m^3)	**y$_w$** (t/m^3)	**H$_s$**(m)	**K$_D$**	**Cotα**
2,65	1,025	3,7	4	2,5

$H_{1/10}$ The height of the highest 10% of waves (Ainsworth, 2006). When considering that $H_{1/10}=1.27H_s$ for Rayleigh distributed wave heights (non-limited waves) it is seen that the recommendations of *Shore Protection Manual* (1984) introduce a considerable safety factor compared to the practice based on *Shore Protection Manual* (1977) (CEM, 2006).

$$W = \frac{2.65 \times (1.27 \times 3.7)^3}{4 \times (\frac{2.65}{1.025} - 1)^3 \times 2.5} = 6.88\ (7\ ton\ )$$

After evaluation, rock weight is 7 tons. The volume of a tetrapod is 2,64 m^3. After calculation of weight of stone for armour layer, quantity of stone is needed to evaluate. Moreover, how many tonnes of stones are required according functional unit. Porosity for quarry stone (rough/random) is 37 % (CEM, 2006).

3.4 Design Weight of Tetrapod

After designed in 1950s, tetrapods are used widely, over the world (Figure 2.4). In this thesis tetrapod is thought as an alternative choice. Approximately all parameters used for armoured blocks are required for design of tetrapod. These different breakwaters have to do same job. In this phase Hudson formula is used again. But specific weight of the tetrapod (y_t) and stability coefficient (K_D) are changed:

Table 3.4: Parameters for calculation weight of tetrapod (Yüksel Proje, 2012)

$\mathbf{y_t}$ (t/m^3)	$\mathbf{y_w}$ (t/m^3)	$\mathbf{H_s}$(m)	$\mathbf{K_D}$	**Cotα**
2,4	1,025	3,7	8	2,5

$$W = \frac{2.4 \times (1.27 \times 3.7)^3}{4 \times (\frac{2.4}{1.025} - 1)^3 \times 2.5} = 5\ ton$$

After evaluation, tetrapod weight is 5 tons. The volume of a tetrapod is 2,08 m^3. The production of tetrapods will be near to coastal area. Concrete is carried from Concrete Plant. Distance from Concrete Plant to Fabrication yard is 3 km (Figure 2.1). One of the main phases in tetrapod construction is iron mold making. There are some methods for making iron mold.

Figure 3.4 : Tetrapods breakwater, Japan (URL-7)

Action of vibration table is required during pouring of concrete into the tetrapod formed mold. After tetrapod is detached from mold, pre-cast has to be cured for 14 days. Porosity for tetrapod is 50 % (CEM, 2006).

There two methods for replacement of a tetrapod (Çelikoğlu, 2014). In the first placement method, three feet of tetrapod are placed over the slope, other foot is directed upwards. In upper layer, tetrapods are inverted model of first layer (Figure 3.5, left). In the second method, first layer tetrapod are placed as first method. But upper layer is placed without inverted (Figure 3.5, right).

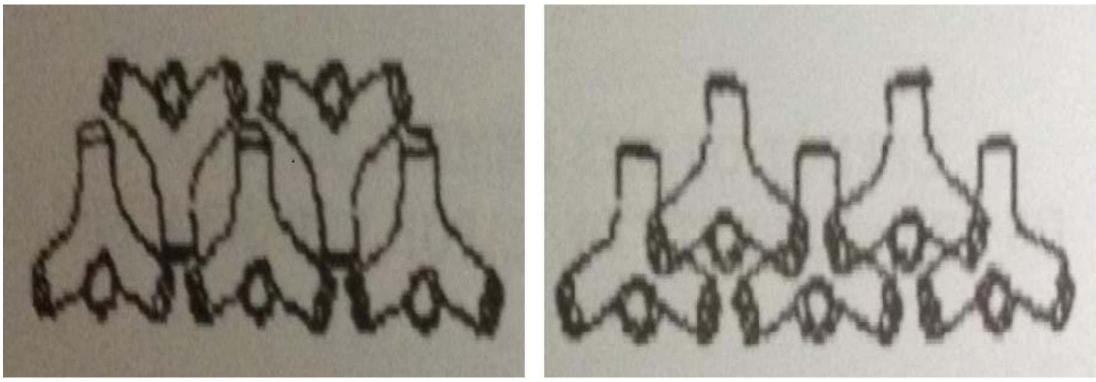

Figure 3.5 : Tetrapod placement Methods (Çelikoğlu, 2014).

First method will be used in designed tetrapod breakwater (Figure 3.6).

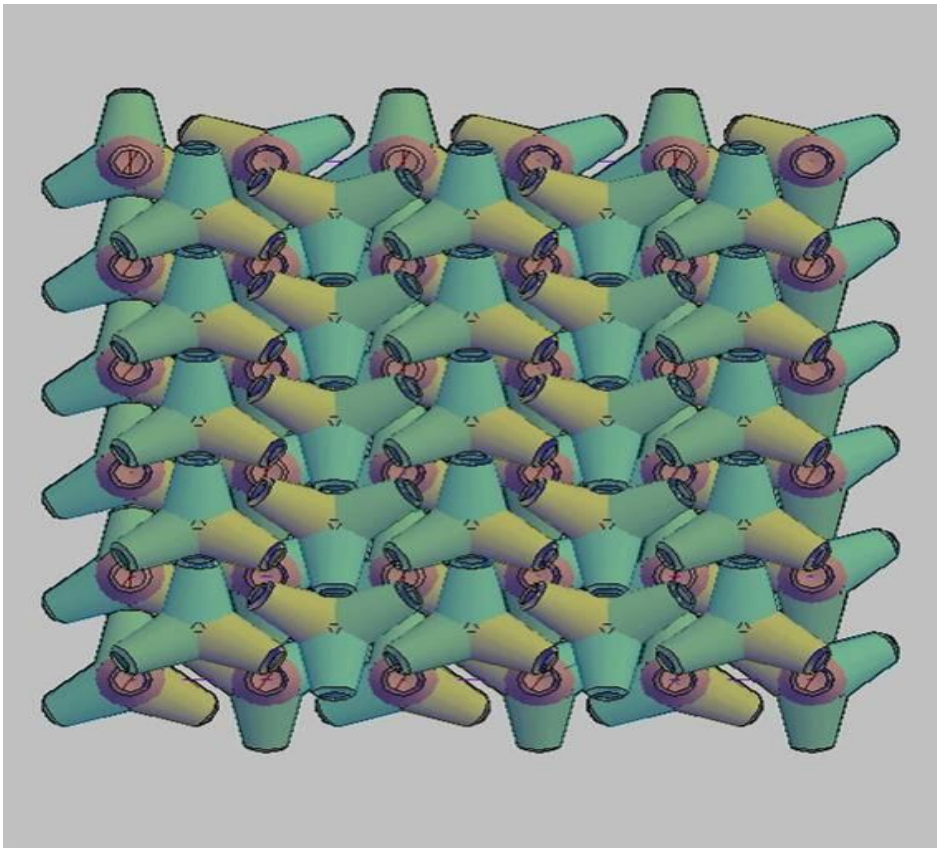

Figure 3.6 : Tetrapod placement. (Cengiz, 2010)

4. LIFE CYCLE ASSESSMENT OF NATURAL STONE AND TETRAPOD BREAKWATERS

4.1 Goal and Scope Definition

The main goal of LCA of breakwaters is to define anticipated environmental impacts and to elucidate differences/similarities between them. Which of breakwaters is environmentally preferable choice for protection of port? (Bauman and Tillman, 2004). First LCA of breakwaters will be evaluated separately then these two results will be compared. LCAs of breakwaters are going to be conducted in the order below:

- Describing construction processes of breakwaters according LCA procedure.
- LCA Calculations of breakwaters with the way of software programme
- Estimation and comparison of LCA results.

The scenarios are covered from raw materials extraction till the end of construction. Use and disposal phases are not included in applied LCA**.** In other words, scenarios will be evaluated in 'from cradle to gate' perspective.

4.1.1 Target audience

- Company (who designed port) – In these days, one of the environmental target of constructed harbor is being 'green'. Name of 'green port' has extraordinary prestige. These ports are approved by certified organizations. In design phase, this assessment is formulated for require of 'internal' audience.

- Local people – Generally LCA report is presented for recommendation of people who lived port construction area. As 'external' assessment, public commentaries are also important.

- Researchers (LCA about ports) – There are few LCA studies about coastal structures. LCA report about breakwaters can be beneficial for researchers.

4.1.2 Method

The ISO 14000 family has inner standards assessment of environmental impacts for organizations. One of them is ISO 14040-14044 standard that gives some policies about decrease of environmental impacts on products and services. This standard is called life cycle assessment (Url-8)

LCA family consists of different types of LCAs, such as; the classical ('full', 'rigorous') LCA and the 'Fast Track' LCA. Although they look similar to each other fundamentally, they have some differences on application of methodology. On other hand, each method has application of compliance for local condition. Streamlined LCA is one of them. Evaluation mechanism of Streamlined LCA is based on 'differences' between products or services.

Streamlined in original concept, is a reducing system boundaries cleverly, while being in frame of formal LCA requirements. Streamlined LCA Calculation is made through differences of products in this application and avoids same systems of both products (Vogtländer, 2010).

In this thesis, streamlined LCA method is also used. Difference between two breakwaters is construction of armoured part construction. Because other construction phases are nearly same (Figure 4.1).

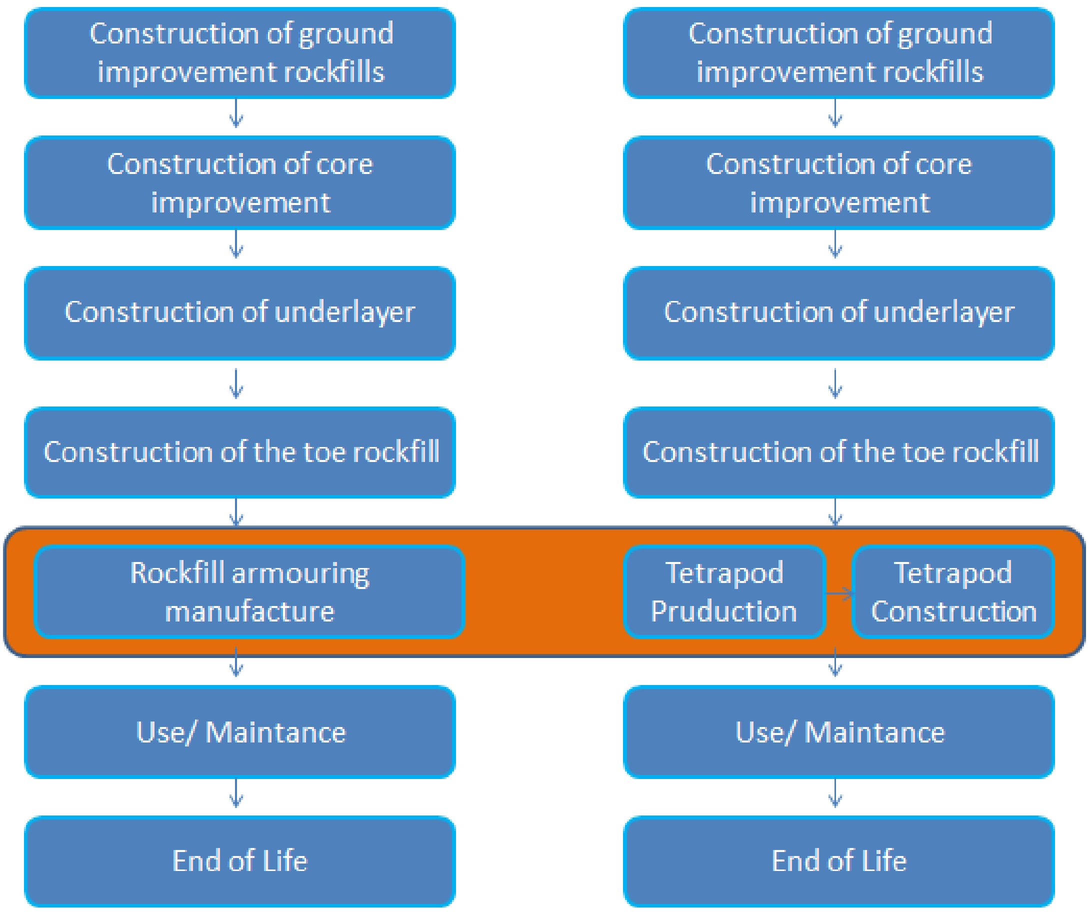

Figure 4.1 : Identification of difference between two breakwaters construction.

Cross section of breakwaters is shown in Figure 4.2. At the same time, restricted area is determined on cross section according to the scope of streamlined LCA. All LCA calculations are applied after determination of restricted area.

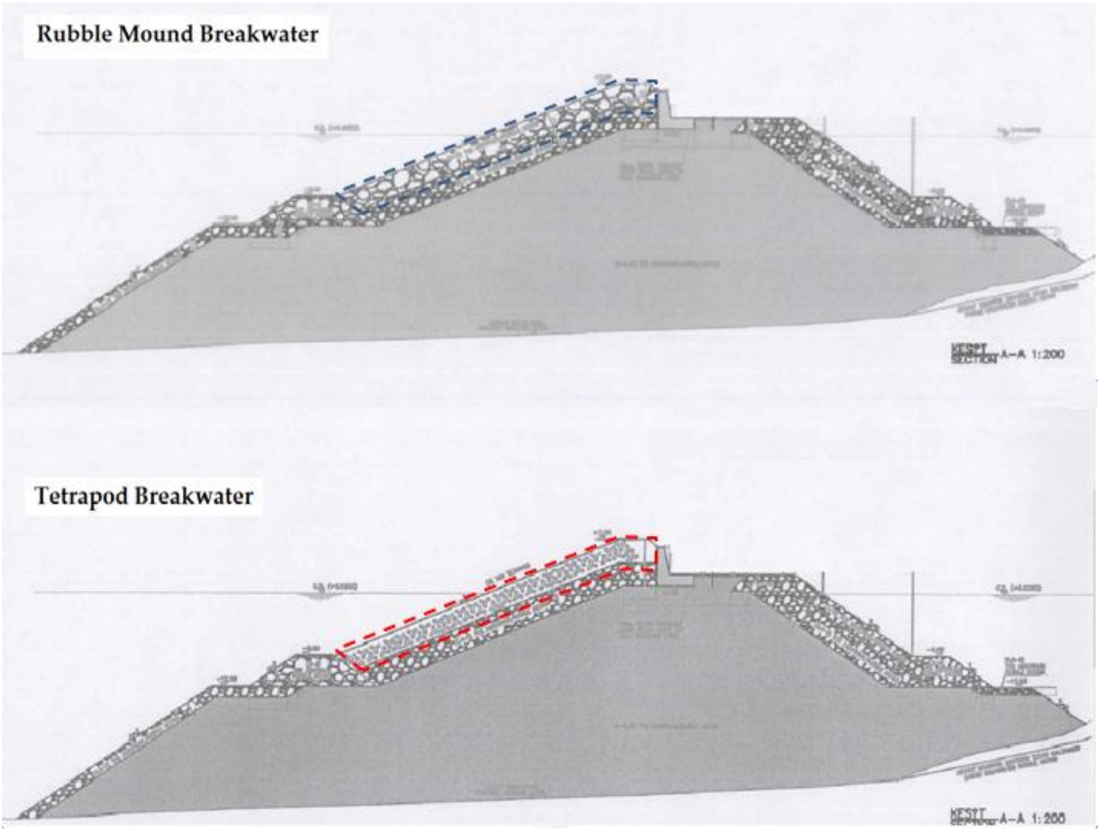

Figure 4.2: Streamlined LCA: a restricted scope of study.

4.1.3 System boundaries

Geographical Boundaries: Breakwaters are situated in Aliağa peninsula area.
Time Boundaries: Lifetime of breakwaters'constructions are considered construction period or approximately as 2 years.

4.1.4 Functional unit

Functional Unit is important for benchmarking of products. Although there are not enough similar studies, but functional unit is 1 meter in more of them. Before, it is mentioned comparison of materials for counstruction of quay wall by Trude Mass. However, in this study, functional unit for rubble mound and tetrapod breakwater is 10 m of breakwater. Because these breakwaters are very huge structures and they have porosity quota between armour units.
After weight calculation of armour units for each structure, number of rocks and number of tetrapods are different because of size for usage. That is why number of

armoured blocks is calculated separately. Porosity for rocks is 37 (percent). Calculation for rock;

Weight of rock is 7 tonne, height of rock is 1,4 meter. Height of two layer armoured part of armoured part is (2h):

$$2 \times 1{,}4 = 2{,}8$$

Length of Slope of armoured part is 20 meter. Volume of rocks in 200 m^2 surface area, which is in two layers:

$$37/100 \times 200 \times 2{,}8 = 207{,}2 \ m^3$$

Number of rocks (for two layers):

$$207{,}2 / 2{,}64 = 78$$

Number of rocks (for one layer):

$$78 / 2 = 39$$

Weight of rocks for using 10 meters breakwater (armoured part):

$$207{,}2 \ m^3 \times 2{,}65 \ t/m^3 = 549 \text{ tonne}$$

549 t rocks are needed for construction of 10 meter breakwater.

Porosity for tetrapod (rough/random) is 50 (percent). Calculation for tetrapod is done as below:

Weight of tetrapod is 5 tonne, and height of two layer is 2,6 (Levent, 2010) .Length of slope of armoured part is 20 meter. Volume of tetrapods in 200 m^2 surface area, which is two layer is:

$$50/100 \times 200 \times 2{,}6 = 260 \ m^3$$

Number of rocks (for two layers):

$$260 \text{ m}^3 / 2 \text{ m}^3 = 130$$

Number of rocks (for one layer):

$$130 / 2 = 65$$

Weight of rocks for using 10 meters breakwater (armoured part):

$$130 \text{ x } 5 = 650 \text{ tonnes}$$

650 t tetrapod is needed for construction of 10 meter breakwater .

4.1.5 Software and database

There are some programs for application LCA, such as; GaBi, SimaPro, OpenLCA etc. GaBi (Ganzheitlichen Bilanzierung (German for holistic balancing)) Software Product with databases is one of the more used programmes. Educational version of GaBi 6 is used in this thesis (Figure 4.3).

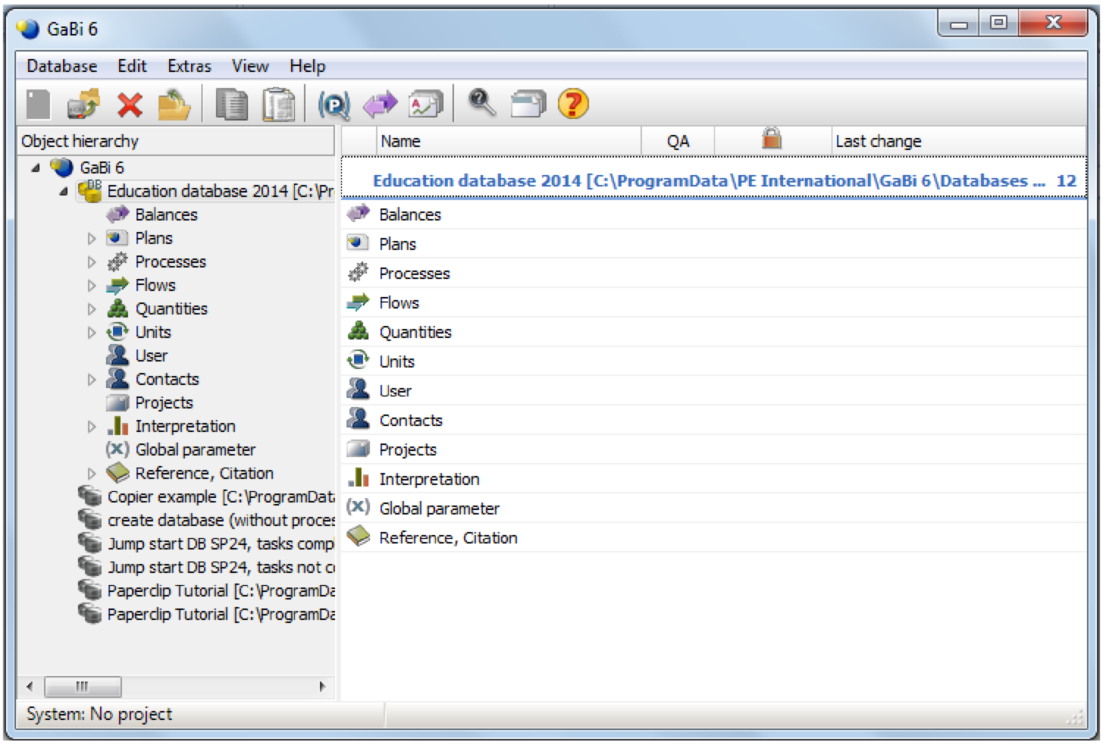

Figure 4.3 : Screenshot of GaBi 6 (Educational version).

4.2 Inventory analysis

4.2.1 Life cycle of natural stone breakwater

For getting right result after LCA application, all processes during this breakwater construction have to been understood clearly. Due to streamlined LCA, armour part of natural stone breakwater will be analysed comprehensively. Rocks are carried by trucks from quarry, which is 17 km far from the breakwater construction site. During construction phase, rocks are placed by 210 tonne cranes. At the same time during LCA application, definition of boundary is important. Boundaries could be different; cradle to grave, gate to gate, cradle to gate and etc. During LCA of natural stone breakwater, boundary of scope of study covers from cradle to gate (Figure 4.4).

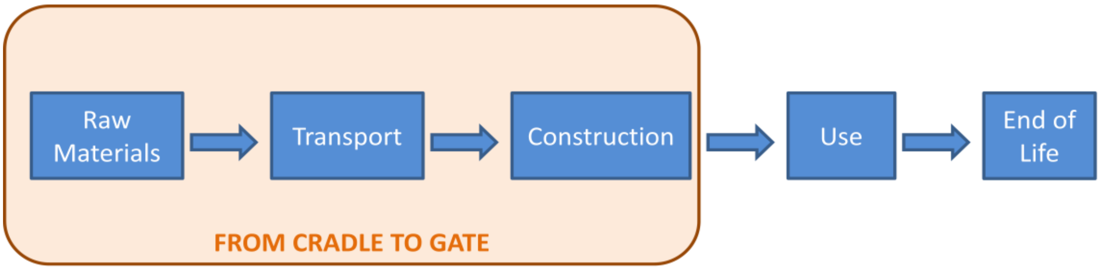

Figure 4.4 : Flow chart of natural stone breakwater.

All processes in period from cradle to gate are given separately and detailed in Table 4.1. Rock extraction from quarry, rock washing, transportation, rock washing for twice and rock placements are included these processes.

4.2.1.1 Rock Production (Crushed Stone)

Quarrying of limestone blocks with blasting agent and its crushing are included. Energy is also one of the inputs of this process. PE international is owner of the dataset.

For breakwater construction, 6-8 tonne blocks will be used. Rocks are carried to 'building site' after block production.

4.2.1.2 Rock Washing

In quarry before transportation, blocks are washed. This process is important. Because after washing, some effects as dust cannot affect surroundings. Data about water pumping is chosen according to technical specification of 1/2HP Industrial Centrifugal Clear Water Pump.

4.2.1.3 Transportation

After production of blocks, the next step is transportation. All relevant and known transport processes as ship transport, rail, truck and pipeline transport can be included during LCA application.

Truck is used for breakwater construction. Calculation of truck power, cost and emission is altered for vehicle, utilisation ratio, distance and for driving in urban or/and suburban. Generally transportation processes' inputs are diesel (or other energy source) and cargo. Outputs are cargo and combustion emissions (ammonia, benzene, carbon dioxide, carbon monoxide, methane, sulphur dioxide). PE international is owner of the dataset.

For construction of breakwater, 28 tonne trucks carry concrete to construction site after production. Distances between concrete plant and construction site is 3 km.

4.2.1.4 Rock Washing

Carried blocks to construction site are washed again twice. During this process, blocks are cleaned from harmful effect, which can be influenced during transportation. At the same time, it increases quality of work. Data about water pumping is chosen according to technical specification of 1/2HP Industrial Centrifugal Clear Water Pump.

4.2.1.5 Natural stone construction (placement)

Excavator will be used for tetrapod placement process. Inputs of this process are diesel and tetrapod. Outputs of this process are combustion emissions due to engine operation, comprising regulated emissions (NOx, CO, hydrocarbons and particles), fuel dependent emissions (CO_2, SO_2, benzene, toluene and xylene) and others such as CH_4 and N_2O. PE international is owner of dataset.

One tetrapod is placed for 8 minutes. In other way cycle for minute is 0,125. Processes are also presented in Table 4.1.

Table 4.1: Processes of natural stone breakwaters construction.

Process	Input	Value	Output	Value
Rock Production from Quarry	Rock (mountain)	1kg	Rock (rubble)	1 kg
	Energy (diesel)	0,0084 MJ		
Rock Washing	Rock	1 kg	Rock(washed)	1 kg
	Water	0,08 kg	Waste water	0,08 kg
	Energy (pumping – electricity)	3 x 10^{-6} MJ	Emission	
Transportation	Rock	1 kg	Rock (washed)	1 kg
	Energy (diesel)	241 x 10^{-5} kg	Emission	
Rock Washing (sea water)	Rock	1 kg	Rock (washed)	1 kg
	Water (sea water)	0,08 kg	Waste water	0,08 kg
	Energy (pumping – electricity)	3 x 10^{-6} MJ	Emission	
Rock/Block Placement	Block	1 kg	Block (breakwater)	1 kg
	Energy (diesel)	0,029 MJ	Emission	

Schematic view of natural stone breakwater can be formed according processes which are mentioned above (Figure 4.5). Generally, rocks are output of all processes.

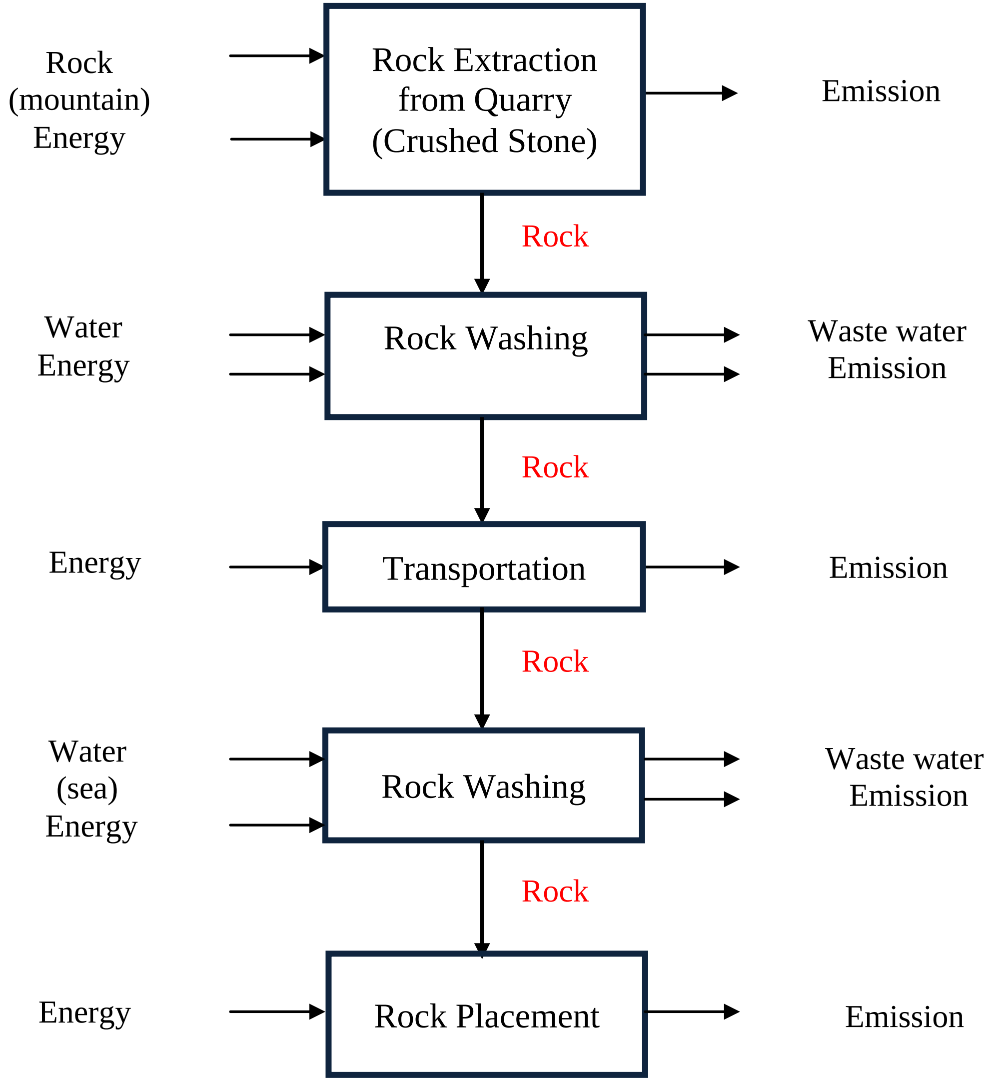

Figure 4.5 : Schematic view of natural stone breakwater construction.

4.2.2 Life cycle of tetrapod

At first step, concrete is carried from concrete plant. For tetrapod production, it is required concrete and tetrapod formed mold. The Life Cycle of Tetrapod Breakwater is described in Figure 4.6. Boundary is from cradle to gate (site).

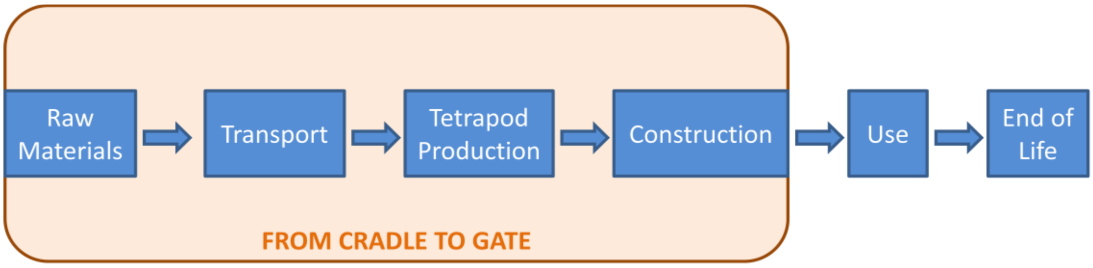

Figure 4.6 : Flow chart of tetrapod breakwater.

4.2.2.1 Ready-mix concrete

Mixture of cement, water, sand, gravel and other aggregates are used for production of concrete. Because of using for different structures and purposes, concrete's features can be changed. As aggregates, electricity is also important for concrete production.

During this phase, energy source is chosen for lowest emission, suitable transportation, efficiency standards, production and processing techniques.

For tetrapod production, ready-mix concrete is carried from concrete plan, which is near to construction site. PE internatıonal is owner of the dataset.

4.2.2.2 Transportation

Truck is used for breakwater construction. Calculation of truck power, cost and emission is altered for vehicle, utilisation ratio, distance and for driving in urban or/and suburban. Generally transportation processes 'inputs are diesel (or other energy source) and cargo. But outputs are cargo and combustion emissions (ammonia, benzene, carbon dioxide, carbon monoxide, methane, sulphur dioxide). PE internatıonal is owner of the dataset.

For construction of breakwater, concrete is carried by 28 tonne trucks to construction site after production. Distances between concrete plant and construction site is 3 km.

4.2.2.3 Tetrapod Production

Tetrapod Production Process inputs are concrete, tetrapod cast, energy for pumping and energy for vibration. But before tetrapod production, tetrapod cast manufacture is needed and according this process there are some sub-processes as cast part production and electrode production.

During steel cast part production steel scrap and alloy components are melted in an electric furnace then moulded in sand moulds. For this process, two types of energy are used: Electricity, Thermal energy. PE is international owner of dataset. Ready casting part requires welding. In Electrode Production process (IPCC, 2006), electrodes are produced for tetrapod cast welding. Steel (73%), mixed flux (25%), binder (2%) are needed for electrode production (EUREKA 2004). After welding, some emissions and steel scrap are observed. A calculation of amount of electrode and using energy for welding is according to Ecocosts2012-V2-LCA and EI-V3-Idemat 2014 (Vogtländer, 2010). Data about concrete pumping is taken from technical specification of BSS 1490-CP concrete pumping lorry. Other data about vibration belongs to Guofeng vibration table.

4.2.2.4 Tetrapod Curing

After tetrapod production, pre-cast have to been cured. Cured process will be continued for 14 days. Data about water pumping is according to technical specification of 1/2HP Industrial Centrifugal Clear Water Pump. For tetrapod curing 1 m^3 water is used for 1 m^3 Tetrapod.

4.2.2.5 Tetrapod Placement

Excavator will be used for tetrapod placement process. Inputs of this process are diesel and tetrapod. Outputs of this process are combustion emissions due to engine operation, comprising regulated emissions (NOx, CO, Hydrocarbons and Particles), fuel dependent emissions (CO2, SO2, benzene, toluene and xylene) and others such as CH4 and N2O. PE international is owner of the dataset.

One tetrapod is placed for 5 minutes. In other way cycle for minute is 0,2. Tetrapods are placed with the 210 tonne cranes. For right results all processes has to be learned clearly. Inputs and outputs of processes are presented in Table 4.2. These processes are expressed comprehensively and detailed as schematic view in Figure 4.7

Table 4.2 : Processes of tetrapod breakwater construction.

Process	Input	Amount	Output	Amount
Ready-mix Concrete	Cement	0,170 kg	Concrete	1 kg
	Sand	0,332 kg		
	Gravel	0,498 kg		
	Water	0,0625 kg	Emission to water	
	Energy (elec.)	0,0014 MJ		
Transportation	Concrete	1 kg	Rock(washed)	1 kg
	Energy (diesel)	241 x 10-5 kg	Emission	
Steel Cast Part Production	Steel scrap	1,05 kg	Steel casting part	1 kg
	Energy (electricity)	9,82 MJ		
	Energy (electricity)	6,85 MJ	Emission	
Electrode Production	Steel wire rod	0,73kg	Electrode	1 kg
	Binder	0,02 kg	CO_2	
	Flux	0,25 kg		
	Electricity	0,0756 MJ	Emission	
Tetrapod Cast Manufacture (Welding)	Steel casting part	1kg	Tetrapod Cast	1 kg
	Electrodes	0,00129 kg	Scrap	0,0002 kg
	Energy(welding-electricity)	0,0528 MJ	Emission	
Tetrapod Production	Concrete	1kg		
	Tetrapod cast	0,00154 kg		
	Energy (Concrete pumping-diesel)	0,0195 MJ		
	Energy (vibration -electricity)	0,0003 MJ	Emission	
Tetrapod Curing	Tetrapod	1 kg	Tetrapod (cured)	1 kg
	Water	0,1344 kg	Emission to water	
	Energy (pumping –electricity)	4,6x10-6 MJ	Emission	
Tetrapod Placement	Tetrapod	1kg	Tetrapod (breakwater)	1 kg
	Energy (diesel)	0,01816 MJ	Emission	

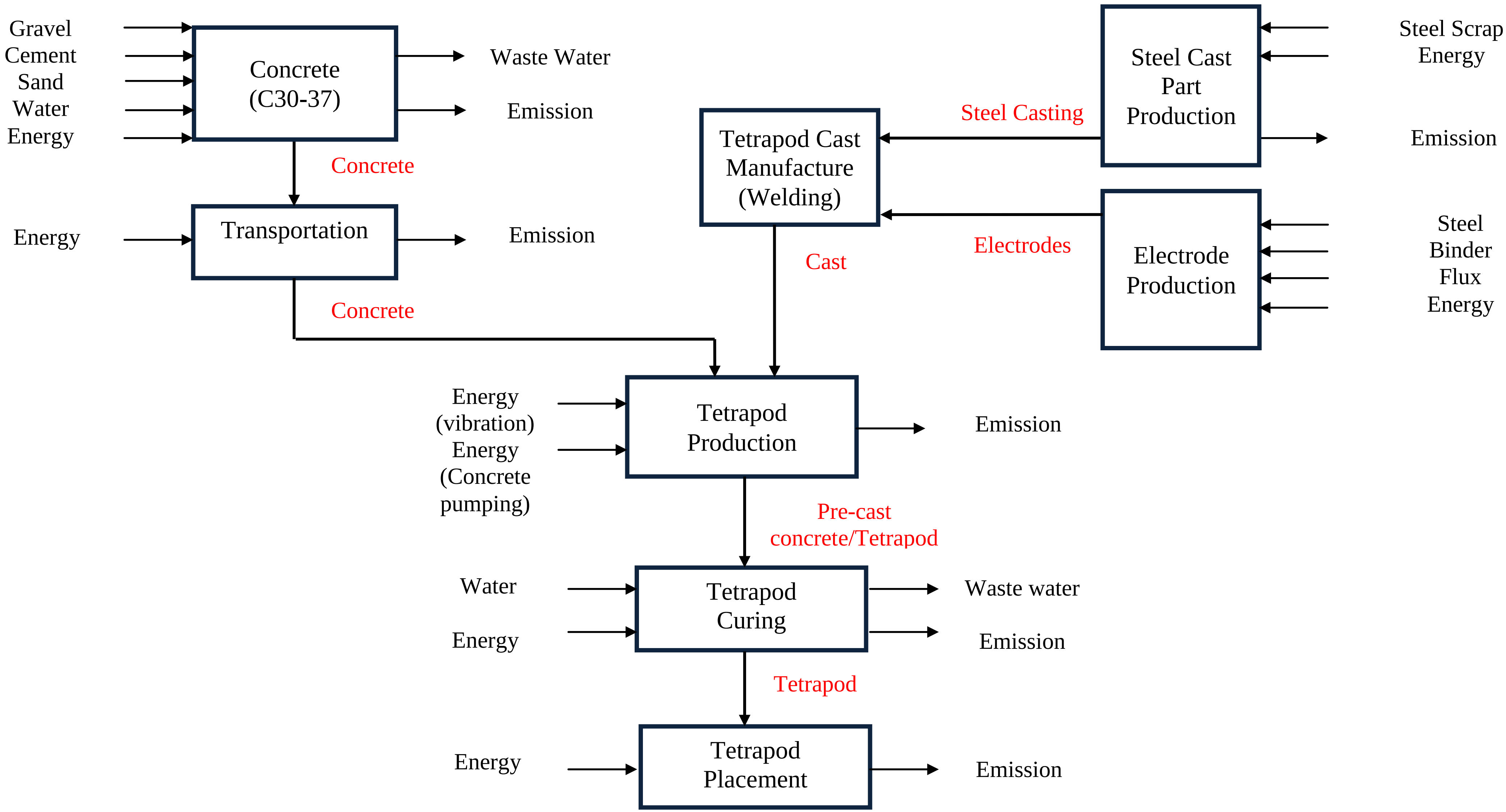

Figure 4.7 : Schematic view of tetrapod breakwater construction.

5. RESULTS AND DISCUSSIONS

In this section, results of LCA application are presented with the way of diagrams. As a result, comparison between breakwaters will be stated according impact categories. First scenario is natural stone breakwater construction; second scenario is tetrapod breakwater construction.

All results are presented according functional unit. Functional unit for natural stone breakwater and tetrapod breakwater is 10 m of breakwater. Impact categories are given according CML method.

Some comparative tables will present similarities/differences between results of this thesis and results of several researches which are applied before.

5.1 Global Warming Potential (GWP)

After Life Cycle Application, some results can be observed. One of these results is Global Warming Potential (Figure 5.1).

In Figure 5.1, some results of processes are defined. In scenario about natural stone breakwater, distance is 17 km, but in second scenario about tetrapod breakwater, distance is 3 km. That is why, GWP value in transportation process in first scenario is more than second scenario.

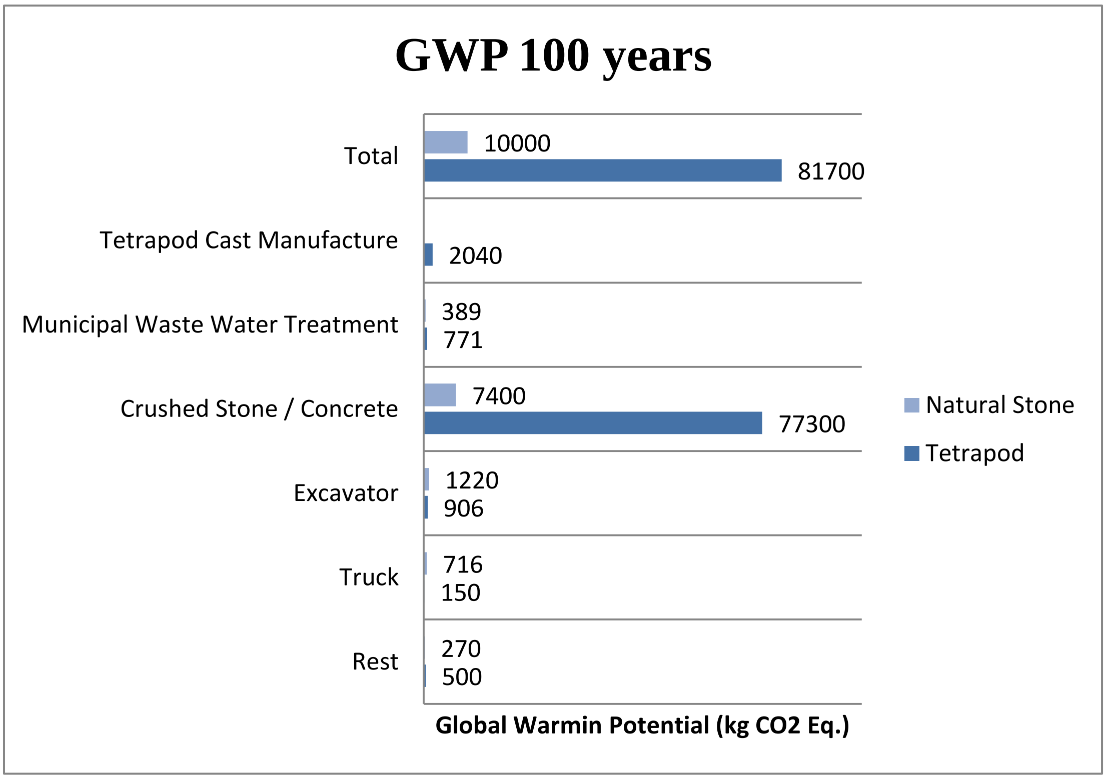

Figure 5.1 : Global warming potential results.

In placement process, placement of tetrapod takes less time than placement of natural stone. Time spending is important factor. Diesel usage is changes for time spending. But in municipal waste water treatment prosess, influence of second scenario is increased. Tetrapod cast manufacture process is special process in second scenario and has more environmental influences. At the same time, concrete production has more environmental impacts that define the result. According total results, GWP value of tetrapod breakwater (81700 kg CO_2- eq.) is more than GWP value of natural stone breakwater (10000 kg CO_2- eq.).

5.2 Acidification Potential (AP)

In Figure 5.2, AP values of placement and transportation in first scenario are more than second scenario. But municipal water treatment process and concrete production process in second scenario has more effects. Tetrapod cast manufacture process is a unique process which has no alternative in first scenario, also effects environment. According all results, AP value of tetrapod breakwater (135 kg SO_2- eq.) is more than AP value of natural stone breakwater (23,8 kg SO_2- eq.) (Figure 5.2).

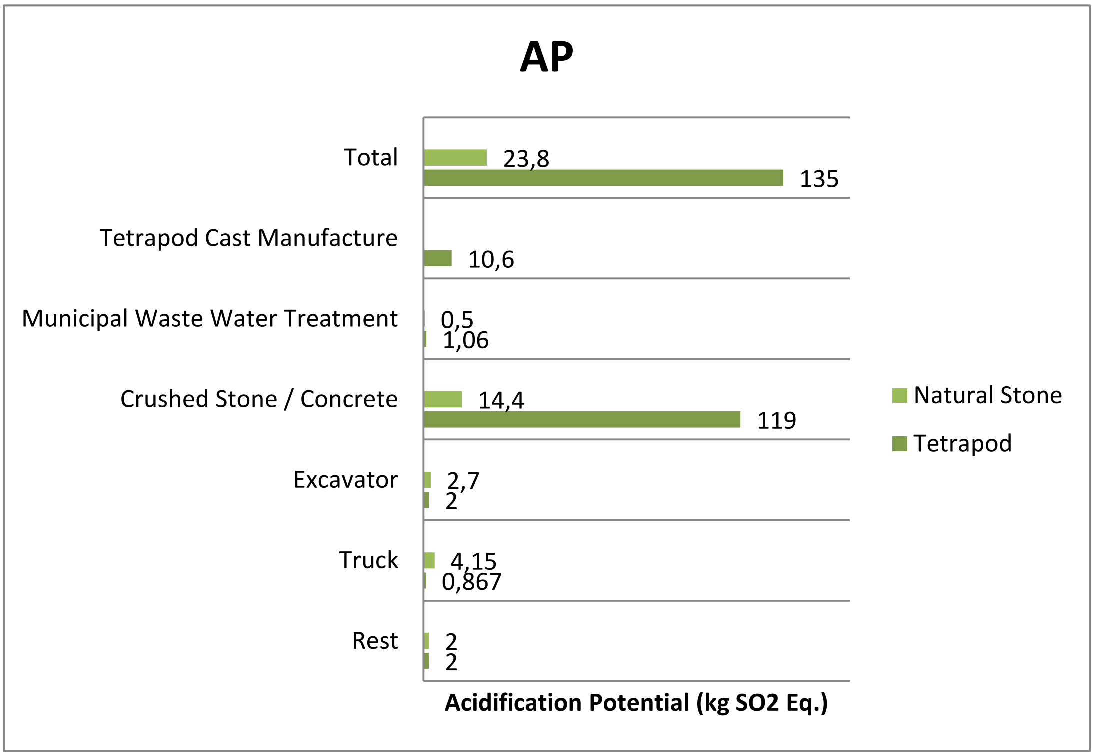

Figure 5.2 : Acidification potential results.

5.3 Eutrophication Potential (EP)

In Figure 5.3, it is observed that EP value of truck process and Placement process is more in construction natural stone breakwater than construction of tetrapod construction. EP effects during municipal waste water process approximately are same. But more effective process which affects results is concrete production process. An effect of this process is eight times more than stone production process. According results EP value of tetrapod breakwater (19,2 kg PO_4- eq.) is more than EP value of natural stone breakwater (5,49 kg PO_4- eq.) (Figure 5.3).

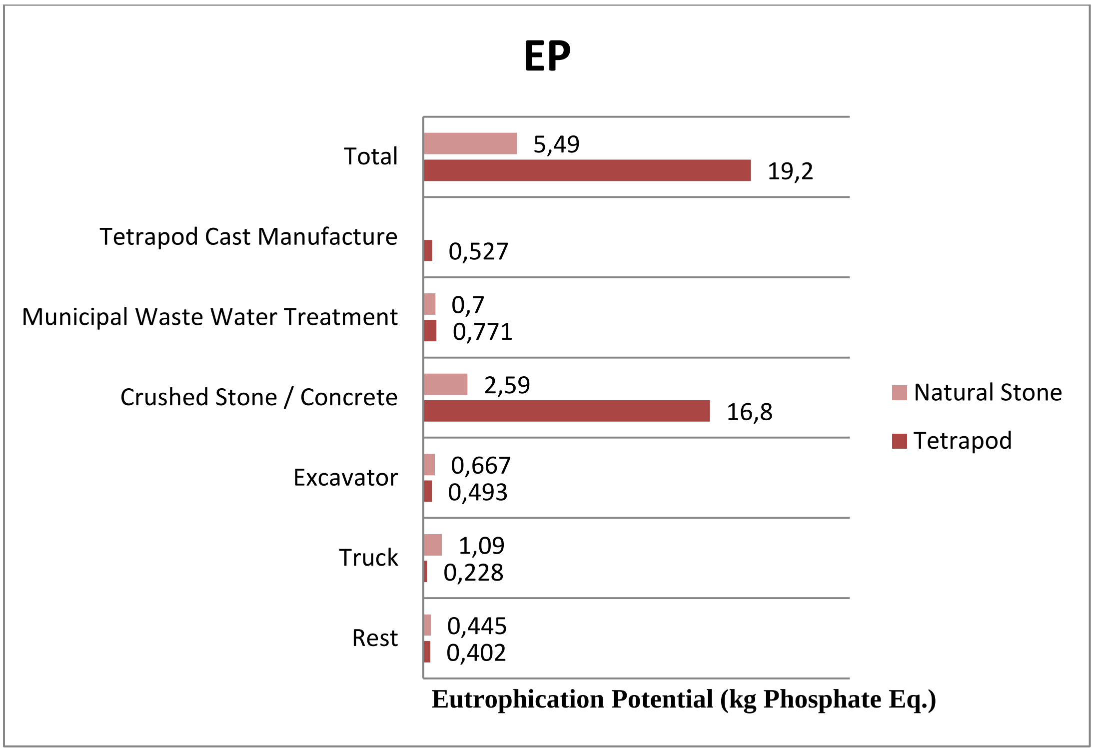

Figure 5.3 : Eutrophication potential results.

5.4 Ozone Depletion Potential (ODP)

In Figure 5.4, it is determined that ODP values three processes (tetrapod manufacture, wastewater treatment and concrete production) have more effects in second scenario. However, the most effective result in natural stone breakwater is natural stone production. According all results, ODP value of tetrapod breakwater (1,88E-6 kg R11-Eq.) is more than ODP value of natural stone breakwater (6,06E-7 kg C_2H_4-Eq.) (Figure 5.4).

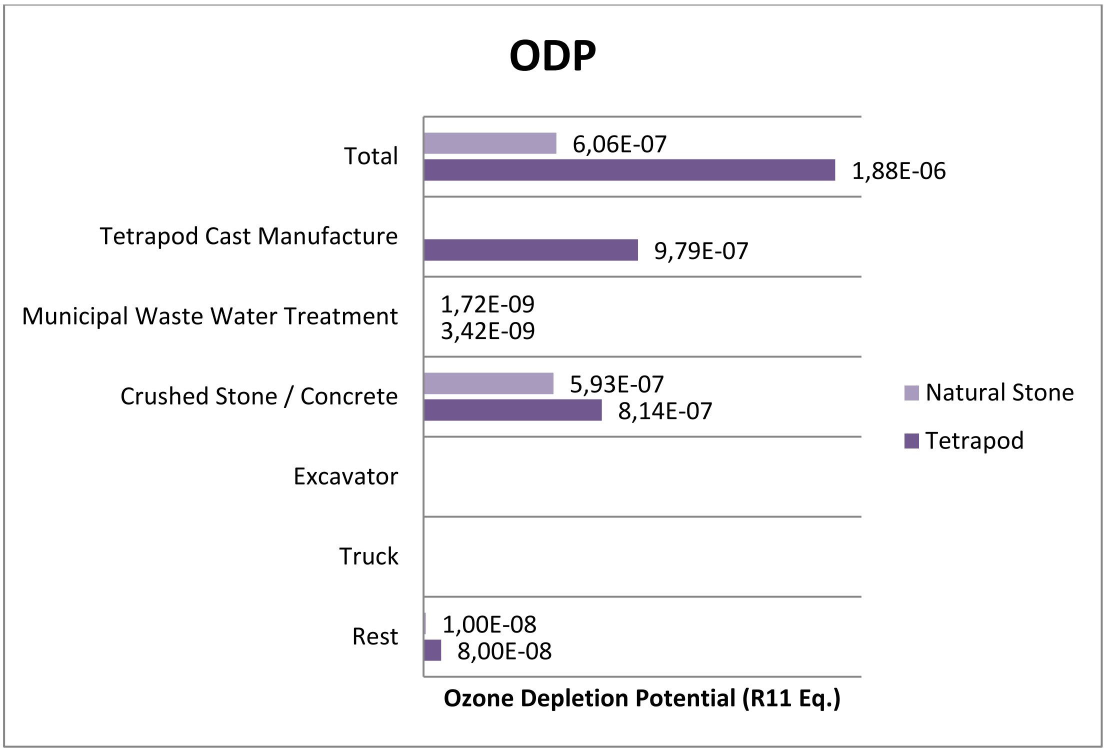

Figure 5.4 : Ozone depletion potential results.

5.5 Human and eco-toxicity (HTP)

In Figure 5.5, it is defined that as other impact categories, more effective source of HTP is concrete production process. There is no serious distinction during

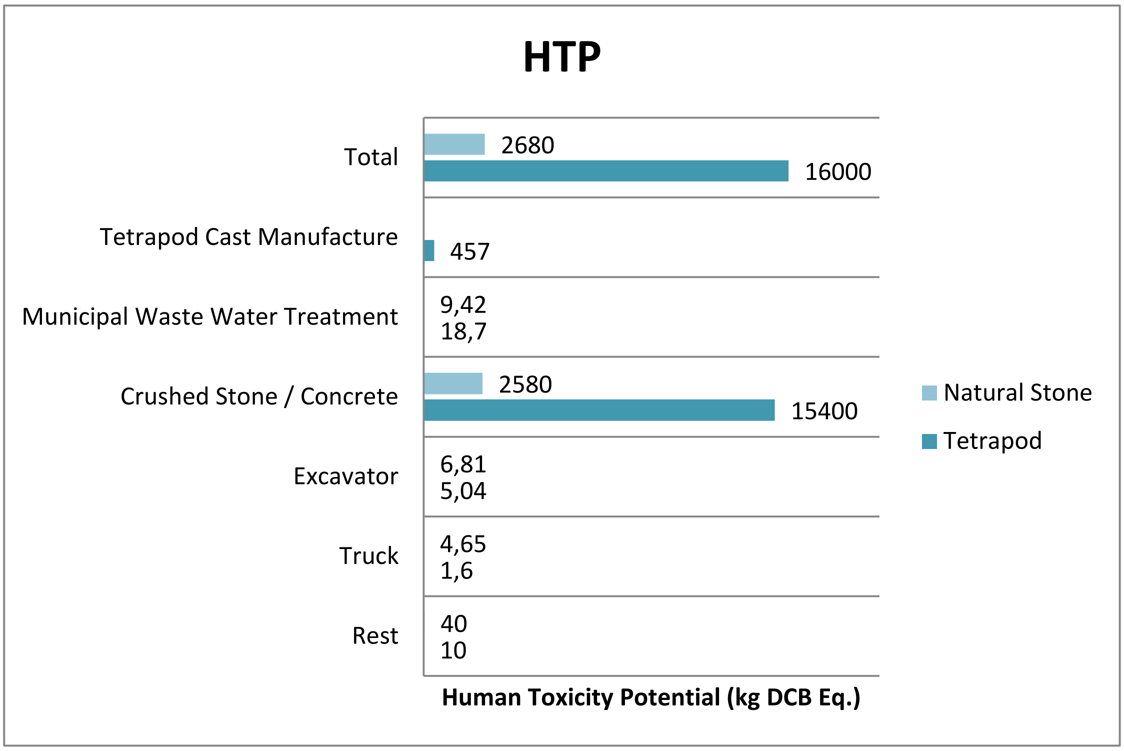

Figure 5.5 : Human toxicity potential results.

placement processes. It is not observed more difference municipal waste water treatment process, too. As other result of impact categories, HTP assessment of tetrapod cast manufacture has no alternative value in natural stone breakwater construction. According all results, HTP value of tetrapod breakwater (1,6E004 kg DCB-Eq.) is more than HTP value of natural stone breakwater (2,68E003 kg DCB-Eq.) (Figure 5.5).

5.6 Abiotic Depletion Potential (ADP)

There are more differencies between results of first scenario and second scenario. In second scenario concrete production, municipal waste water treatment and tetrapod manufacture prosesses have more effects. According all results, ADP value of tetrapod breakwater (2,74E005 MJ) is more than ADP value of natural stone breakwater (1,1E005 MJ) (Figure 4.7).

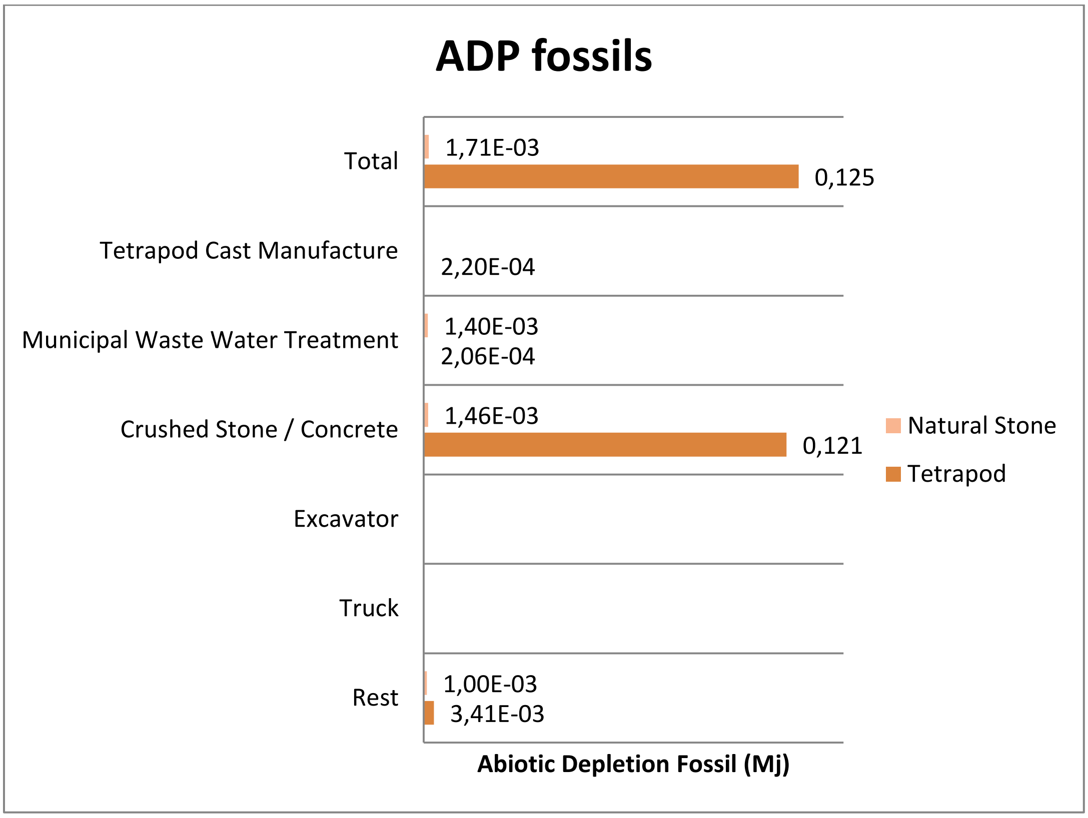

Figure 5.6 : Abiotic depletion fossil results.

5.7 Energy Consumption

There are also differences between natural stone breakwater and tetrapod breakwater about energy of gross calorific value and net calorific value.

Table 5.1: Energy Use.

Breakwaters	Energy (gross calorific value)	Energy (net calorific value)
Rubble Mound Breakwater	237 000 MJ	228 000 MJ
Tetrapod Breakwater	504 000 MJ	481 000 MJ

5.8 Benchmarking with other researches

Although there are a few investigations about calculation of carbon footprint of coastal structures, it is found some results of other researches for comparison. One of them is ‘Quantifying the carbon footprint of coastal construction – a new tool HRCAT’(Broekens, 2011). In this research rubble mound breakwater with concrete armour units is compared with caissons. Second one is ‘Comparison of quay wall designs in concrete, steel, wood and composites with regard to the CO2-emission and the Life Cycle Analysis’ (Maas, 2011). In this research, construction materials as concrete, steel, wood and fibre-reinforced polymer (FRP) are compared with each other regarding CO_2 emission and Life Cycle Analyse. According HRCAT calculations, 550 tonne of concrete unit of rubble mound breakwater is 44 million kg CO_2. Trude Maas calculates 10858 kg CO_2 for 93600 kg diaphragm wall (concrete). In this thesis, GWP of 650 tonne tetrapod is 77000 kg CO_2. For benchmarking, concrete units of rubble mound breakwater (Broekens, 2011) and diaphragm wall (concrete) (Maas, 2011) for designed quay wall are compared with tetrapod (concrete). The comparison is carried out for 500 tonne concrete. According results, there are some similarities between results of concrete structures. It can be seen 40000 kg CO_2 in rubble mound breakwater, 58002 kg CO_2 in diaphragm wall and 59461 kg CO_2 in tetrapod breakwater for 500 tonne concrete.

6. CONCLUSION

Environmental performances of breakwaters (two scenarios) are determined in the last chapter. Environmental effects are evaluated according to methodology of Life Cycle Assessment. Results of evaluation cover a scope ranging from ‘raw material phase’ until the end of construction. LCA application is taken into account in following phases:

a. Construction of breakwaters, and all construction processes are formalized according to LCA procedure

b. Evaluations of scenarios are carried out according to Gabi 6 (Educational version). Determinations of impact categories have importance in this phase.

c. Recommendation and interpretation for results are conducted: Comparison between two scenarios.

In this chapter, results are discussed and interpreted. Some different values are obtained according to results. Results can be divided into three types of sources; material utilization, energy consumption and emissions. According to results of impact categories (GWP, AP, EP, ODP, and ADP), concrete production has more influence than natural stone production. At the same time, more energy consumption during tetrapod breakwater construction is observed. One of the main differences in tetrapod breakwater construction is tetrapod production. More energy resources are used for tetrapod cast manufacture and electrode production in the course of tetrapod production stage. It is defined that construction of tetrapod breakwater has more environmental impacts than construction of natural stone breakwater in certain area.

REFERENCES

ACADEMY (Airbus Corporate answer to Disseminate Environmental Management System). (2008). *Streamlined Life Cycle Assessment.*

Ainsworth, T. (2006). *When Do Ocean Waves Become 'Significant'? A Closer Look at Wave Forecasts.* 05 14, 2015 tarihinde National Oceanic and Atmospheric Admistration's Center of Exellence in Marine Technology: http://www.vos.noaa.gov/MWL/apr_06/waves.shtml adresinden alındı

Baumann, H., & Tillman, A. M. (2004). *The Hitch Hiker's Guide to LCA.*

Broekens, R., Escarameia, M., Cantelmo, C., & Woolhouse, G. (2011). Quantifying the carbon footprint of coastal construction – a new tool HRCAT. *ICE Coastal Management Conference.* Belfast.

Capo d'Anzio Spa, the Municipality of Anzio. (2011). *GUIDELINES FOR THE LCA APPROACH FOR PORTS.*

Cengiz, L. (2010). *Tetrapod Raporu.*

Charlier, H. R. (2013). Life cycle of ports. *International Journal of Environmental* .

Çelikoğlu, Y., Çevik, E., & Yüksel, Y. (2014). Tetrapod Dalgakıranlarda Yerleştirme Yönteminin Stabiliteye Etkisi. *8. KIYI MÜHENDİSLİĞİ SEMPOZYUMU.*

Daniel, P., & Greslou, L. (1962). *COASTAL ENGINEERING.*

Dvarioniene, J., Zobelaite-Noreikiene, G., J., K., & Stasiskiene, Z. (2013). Application of the Life-Cycle Assessment Method for Pollution Prevention in Klaipe˙da Sea Port, Lithuania. *Journal of Coastal Research* .
Es-Fermak. (2013). *Petkim Container Terminal Project.*

EUREKA SYSTEMS AND ELECTRODES PVT.LTD. (2004). *BRIEF PROJECT PROFILE ON WELDING ELECTRODE MANUFACTURİNG.*

European Commission . (2010). *International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance.* Luxembourg: Publications Office of the European Union.

European Environment Agency. (1997). *Life-cycle assessment (LCA) – a guide to approaches, experiences and information sources.*

Gavin, N. P., & Colin, D. C. (1998). Design and construction of rubble mound. *IPENZ transaction .*

Graauw, d. A. (2014). *Ancient Ports and Harbours.*

Günbak, A. R. (2012). Taş Dolgu Dalgakıranlar.

Kabdaşlı, S. (1992). *Kıyı Mühendisliği.*

Kabdaşlı, S., Maktav, D., & Sunar, F. (1997). Kıyı Mühendisliğinde Ölçüm Teknikleri ve uzaktan Algılama Teknolojisi Gereksinimi.

Labrujere, A., & Verhagen, H. (2010). *ANALYSIS OF THE CARBON FOOTPRINT OF COASTAL PROTECTION SYSTEMS.*

Maas, T. (2011). *Comparison of quay wall designs in concrete, steel, wood and composites with regard to the CO2-emission and the Life Cycle Analysis.*

Mass, T., Van Heel, D. D., De Gijt, J., & Saif, M. (2011). Comparison of quay wall designs in concrete, steel, wood and composites with regard to the CO2-emission and the Life Cycle Analysis. *The third International Conference of EACEF (European Asian Civil Engineering Forum).*

Menke, D. M., & Davis Gary A. and Vigon, B. W. (1996). *EVALUATION OF LIFE-CYCLE ASSESSMENT TOOLS.*

PE INTERNATIONAL. (2014). *Introduction to LCA and modelling using GaBi.*

Sciortino, J. A. (2010). Fishing harbour planning,constructıon and management.

Society of Environmental Toxicology and Chemistry (SETAC) and SETAC Foundation for Environmental Education. (1999). *Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup.*

The Intergovernmental Panel on Climate Change (IPCC). (2006). METAL INDUSTRY EMISSIONS . *IPPC Guidelines for National Greenhouse Gas Inventories.* içinde

U. S. Army Corps of Engineers (USACE). (2006). *Coastal Engineering Manual (CEM).*

U.S. Army Corps of Engineers (USACE). (1984). *Shore Protection Manual (SPM).*

UNEP and SETAC Life Cycle Initiatives. (2005). *Life Cycle Approaches, The road from analysis to practice.* Paris: UNEP and SETAC Lİfe Cycle Initiatives.

UNEP, SETAC, Life Cycle Initiative. (2011). *Towards a Life Cycle Sustainability Assessment.*

UNEP, SETAC, Life Cycle Initiative, CIRAIG, FAQDD and the Belgium Federal Public Planning Service Sustainable Development. (2009). *Guidelines for Social Life Cycle Assessment of Products.*

UNEP, SETAP. (2009). *Life Cycle Management: How business uses it to decrease footprint, create opportunities and make value chains more sustainable.*

Vogtländer, J. (2010). *A practical guide to LCA for students, designers and business managers.*

Vogtländer, J. (2010). *A quick reference guide to LCA Data and eco-based materials selection.*

Vujicic, A., Zrnic, N., & Jerman, B. (2013). Ports Sustainability: A life cycle assessment of Zero Emission Cargo Handling Equipment. *Journal ot Mechanicai Engineering .*

Yüksel Proje. (2012). *Petkim Harbour Breakwater and others Coastal Structures Design Report.*

Url-1
< http://www.cesam.ua.pt/index.php?menu=182&language=eng&tabela=geral>, date retrieved 14.05.2015

Url-2 < http://ec.europa.eu/ourcoast/download.cfm?fileID=1629 > date retrieved 27.06.2015

Url-3 < http://www.unesco.org/csi/act/russia/legalpro5.htm>, date retrieved 30.04.2015

Url-4 < http://concretebasics.org/articles/tetrapods/ > date retrieved 30.04.2015

Url-5 < http://www.pe-international.com/academy/workshops-seminars/gabi-lca-intensive-training/ , date retrieved 30.04.2015

Url-6 < https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020> date retrieved 30.04.2015

Url-7 < http://universitywimadisonbreakwater.weebly.com/objective-and-background.html> date retrieved 30.04.2015

Url-8 < http://www.vcharkarn.com/varticle/500253 > date retrieved 14.05.2015

Url-9 < http://www.iso.org/iso/theiso14000family_2009.pdf > date retrieved 14.05.2015

CURRICULUM VITAE

PHOT
O

Name Surname:	Vasif VALIYEV
Place and Date of Birth:	Azerbaijan, 11.03.1986
E-Mail:	vasif.valiyev@yahoo.com
EDUCATION:	
B.Sc.:	Baku State University (Environmental Protection and Efficiently Use of Natural Resources)
M.Sc. (If exists):	

PROFESSIONAL EXPERIENCE AND REWARDS:

Environmetal Expert at Petkim Container Terminal Project