A LIFE CYCLE SUSTAINABILITY ASSESSMENT METHODOLOGY FOR THERMAL INSULATION MATERIALS

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ABSTRACT

A LIFE CYCLE SUSTAINABILITY ASSESSMENT METHODOLOGY FOR THERMAL INSULATION MATERIALS

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The study aims to develop a comparative holistic life cycle sustainability assessment method for building materials and test this method on thermal insulation material selection phase of a pilot renovation project.

Life Cycle Assessment (LCA) and its more recent adaptation Life Cycle Sustainability Assessment (LCSA) methods have been utilized to compare the sustainability of thermal insulation material options for a pilot sheathing application. "Three pillars of sustainability" approach has been designated to form a foundation to LCSA system and Environmental Life Cycle Assessment (E-LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) methods have been used together. Among them, S-LCA methodology has the greatest need for development and adaptation. For this reason, the study aims to build a S-LCA method, test it on the case of insulation material selection and interpret the results along with LCA and LCC results. Results and discussions involve both the performed case study and the suggested assessment method. The case renovation scenario was created with respect to “Energy Performance in Buildings Directive” and TS-825” documents and building data was managed in the Building Information Modeling (BIM) environment.

Lack of developed LCSA standards has been the most important motivation for this study as well as the greatest challenge of it. Especially, scarcity of the local database made it difficult to obtain reliable results. Nevertheless, the case study revealed a convenient comparison table to interpret that glass wool can be an alternative sustainable sheathing material compared to rock wool and more socially sustainable compared to XPS in local conditions. Consequently, the method that has been presented in this study has a potential to serve as a model for future LCSA standards.

Keywords: Sustainability, Life Cycle Assessment, Energy Efficiency, Renovation, Thermal Insulation

ÖZ

ISI YALITIMI MALZEMELERİ İÇİN BİR YAŞAM DÖNGÜSÜ SÜRDÜRÜLEBİLİRLİĞİ DEĞERLENDİRME YÖNTEMİ

İlhan, Burak
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Bu çalışma, yapı malzemeleri için bütüncül bir karşılaştırmalı yaşam döngüsü sürdürülebilirlik değerlendirmesi yöntemi geliştirmeyi ve bu yöntemi pilot bir tadilat projesinin ısı yalıtım malzemesi seçme safhasında test etmeyi amaçlamaktadır.

Yaşam Döngüsü Değerlendirmesi (YDD) ve onun daha yakın tarihli uyarlaması olan Yaşam Döngüsü Sürdürülebilirlik Değerlendirmesi (YDSD) yöntemleri, bir örnek mantolama uygulamasında kullanılacak olan ısı yalıtım malzemesi seçeneklerinin sürdürülebilirliklerini karşılaştırmak için kullanılmıştır. YDSD sistemine temel oluşturması için, “sürdürülebilirliğin üç sac ayağı” yaklaşımı belirlenmiş olup, Ekolojik Yaşam Döngüsü Değerlendirmesi (E-YDD), Yaşam Döngüsü Maliyeti (YDM) ve Sosyal Yaşam Döngüsü Değerlendirmesi (S-YDD) yöntemleri birlikte kullanılmıştır. Bu yöntemler arasında, S-YDD yöntemi gelişime ve adaptasyona en çok ihtiyacı olan yöntemdir. Bu nedenle, bu çalışma S-YDD için bir yöntem geliştirme, bu yöntemi yalıtım malzemeleri bazında test etme ve sonuçları E-YDD ve YDM yöntemleriyle birlikte değerlendirmeyi amaçlamaktadır. Sonuç ve öneriler bölümünde hem uygulanan çalışmanın sonuçlarına hem de önerilen yöntem hakkında değerlendirmelere değinilmiştir.

Örnek tadilat senaryosu, "Binalarda Enerji Performansı Yönetmeliği" ve "TS 825" belgelerine göre oluşturulmuş olup, bina ile ilgili veriler Yapı Bilgi Modelleme (YBM) ortamında yönetilmiştir.

YDSD standartlarının gelişmemiş oluşu, bu çalışma için hem en önemli motivasyon, hem de en büyük zorluk olmuştur. Özellikle yerel veritabanının yetersiz oluşu, güvenilir sonuçlar almayı zorlaştırmıştır. Mamafih, örnek çalışma, cam yününün yerel şartlarda taş yününe göre daha sürdürülebilir, XPS'e göre de daha sosyal anlamda sürdürülebilir bir alternatif mantolama malzemesi olabileceği yorumlamasının yapılmasını sağlayan elverişli bir karşılaştırma tablosu ortaya çıkarmıştır. Sonuç olarak, bu çalışmada sunulan yöntem, gelecekteki muhtemel YDSD standartları için bir örnek teşkil edebilecek potansiyel taşımaktadır.

Anahtar kelimeler: Sürdürülebilirlik, Yaşam Döngüsü Değerlendirmesi, Enerji Verimliliği, Tadilat, Isı Yalıtımı

To my parents

Oğuz Okan İlhan and Elif Esin İlhan

for their endless support and understanding

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Symbol	Definition	Unit
Cw	Category weight	-
H_V	Ventilation heat loss	W/K
Iw	Impact category weight	-
In	Total indicator number	-
LPT	Local poverty threshold	₺
MWW	Minimum wage of full time workers	₺
OAFR	Occupational accident occurrence rate	-
ODFR	Occupational disease occurrence rate	-
Ow	Overall weight	-
P	Probability	-
R	Thermal resistance coefficient	$m^2.k/W$
RV	Risk value	-
Sf	Female salary	₺
Sg	Supplier grade	-
Sm	Male salary	₺
Sw	Supplier weight	kg
TL	Turkish Lira	₺
U	Heat loss coefficient	$W/m^2.k$
V_h	Total ventilated volume	m^3
WT	Working time	hour
YPH	Total yearly person*hour	-
W	Heat	W
WT	Working time	hour
#CW	Number of workers with a contract	-
#MW	Number of minor workers	-
#NLW	Number of non-local workers	-
#OA	Occupational accident number in a year	-
#OD	Occupational disease number in a year	-

#TW	Total number of workers	-

LIST OF ABBREVIATIONS

AP	Acidification potential
BA	Benefit analysis
BIM	Building information model
CEI	Core environmental indicators
CESCR	Committee on Economic Social and Cultural Rights
D	Exterior door
DEI	Decoupling environmental indicators
E-LCA	Environmental life cycle assessment
EP	Eutrophication potential
EPD	Environmental product declaration
EU	European Union
F	Windows (Fenestration)
GHG	Greenhouse gas emission
GmbH	Gesellschaft mit beschränkter Haftung
GRI	Global Reporting Initiative
GWP	Global warming potential
HIB	Higher is better
IDO	Indicators derived from accounting
IEA	International Energy Agency
ILO	International Labor Organization
IP	Impact potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
İK	İş Kanunu
İSGK	İş Sağlığı ve Güvenliği Kanunu
İSGRDY	İş Sağlığı ve Güvenliği Risk Değerlendirmesi Yönetmeliği
KEI	Key environmental indicators

LCA	Life cycle assessment
LCC	Life cycle costing
LCSA	Life cycle sustainability assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LIB	Lower is better
MSHA	Mine Safety and Health Administration
NA	Not applicable
NF	Normalization factor
NOx	Nitrogen oxides
NZEB	Nearly zero energy building
ODP	Ozone depletion potential
ODS	Ozone depleting substances
OECD	Organization for Economic Co-operation and Development
OHSAS	Occupational Health Safety and Assessment Series
P	Foundation pad
PED	Primary energy demand
PRI	Performance related incentives
PROSA	Product Sustainability Assessment
PSR	Pressure-state-response
R	Roof
REPA	Resource and Environmental Profile Analysis
R&D	Research and Development
SETAC	Society of Environmental Toxicology and Chemistry
SFP	Smog formation potential
SGK	Sosyal Güvenlik Kurumu
S-LCA	Social life cycle assessment
TIV	Total impact value
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNHROHC	United Nations Human Rights Office of the High Commision

US EPA	United States Environmental Protection Agency
VOC	Volatile organic compound
W	Weighting factor
WB	Exterior brick walls
WC	Exterior concrete walls
XPS	Extruded polystyrene

Subscripts and superscripts

max: Maximum

min: Minimum

n: Normalized

s: Standardized

th: Ordinal indicator

w: Weekly

wt: Weight / weighted

CHAPTER 1

INTRODUCTION

This chapter aims to present the argument and objectives of the study along with a summary of the methodology that is used to conduct the study. This chapter also aims to inform the reader about the motivations to conduct this study. The chapter is concluded with a disposition of the general structure with brief summaries of the subjects covered in each chapter.

1.1. Argument

According to US Energy Information Administration, (2016) the global energy consumption will rise 28% until 2040 with respect to 2015. On the other hand, due to rapid depletion of non-renewable energy sources, a serious global energy crisis is sighted on the horizon (Williams & Alhajji, 2003). Building sector accounts for 20.1% of global energy consumption. Energy use in homes has a larger share when compared to commercial energy usage (US EIA, 2016). Therefore, industrialized countries work on reducing their primary energy demand of their building stock with strategies like insulating buildings, recycling materials and using energy efficient appliances (WWF, Ecofys, OMA, 2011).

In order to increase energy efficiency in building stock of European Union, (EU) Energy Performance of Buildings Directive (EPBD) was published in 2010 with ambitious goals that include reaching nearly zero energy building (NZEB) standards by 2018 and constructing every new building according to NZEB standards starting from 2021. Similarly, in Turkey, Energy Performance in Buildings Directive (Binalarda Enerji Performansı Yönetmeliği, 2008) has been prepared by Turkish Ministry of Environment and Urbanization. The directive includes methodology definitions for energy measurement and classification of current building stock, definition of minimum energy efficiency standards, authorization for inspections, system to create and update current building stock inventory and encouragement in usage of cogeneration and renewable energy systems to meet building energy demand. Unfortunately, the scope of energy efficient measures is mostly limited with building envelope insulation applications in Turkey with an aim to achieve maximum energy demand that is defined in TS-825 standards (2009). However, there is a general belief that energy efficiency measures should consider sustainability parameters like carbon emission, indoor air quality and occupant comfort (Brunsgaard *et al.*, 2013).

It is obvious that each decision that is taken to improve energy efficiency of buildings reveals new impacts on society, environment and economy and eventually on sustainable development of the country. Monitoring all these impacts of buildings on sustainable development is a challenging subject. In environmental sustainability domain, life cycle assessment (LCA) method is being performed on buildings as a benchmarking and decision-making tool to measure environmental impacts of a product, service or activity primarily.

Upon reviewing related studies, it was realized that although recent LCA studies mostly define sustainability as a holistic approach, they only focus on environmental impacts. Nonetheless, the sustainability assessment framework is not complete unless other aspects are included in the assessment as well. LCA as an environmental assessment method may have emerged from urgent global crises on energy and environment but it has the potential to become a holistic sustainability assessment tool as well. For this reason, a new concept called life cycle sustainability assessment (LCSA) was created. It covers environmental impacts that are defined in LCA methods, cost implications that are defined in life cycle costing (LCC) methods and social consequences that are defined in social life cycle assessment (S-LCA) methods (Figure 1.1) (UNEP/SETAC Life Cycle Initiative, 2011). The main motivation behind this study is the detected gap in the literature about socio-economic aspects of building sustainability assessment.

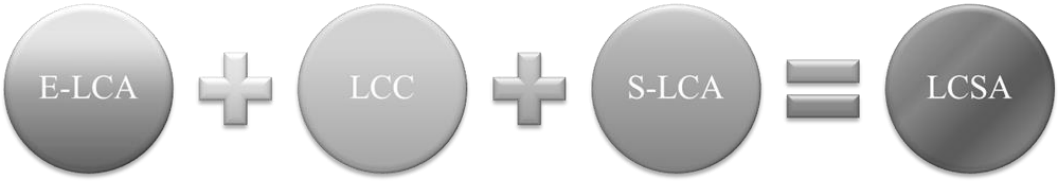

Figure 1.1 Life cycle sustainability assessment framework

LCC method depends completely on measurable quantitative data. LCA method is developed to assess all environmental impacts by converting them to measurable quantitative data as well. Also, complex indicators for LCA studies are simplified to certain equivalent values. On the other hand, S-LCA mostly depends on qualitative or semi-qualitative parameters which are required to be translated into numeric values to assess in the framework of LCA. Although S-LCA is not as developed as LCA in maturity, holistic sustainability assessment studies are increasing in number and global directives are expected to be created for them like LCA guidelines and directives which are ISO 14040 and ISO 14044. Nevertheless, each S-LCA study that is conducted puts a building block on the future fully developed S-LCA methodology. It is particularly essential to conduct a holistic study that covers all three assessments to understand the linkages and intersections among them. Such researches have potential to build the basis for an integrated approach and during these studies, potential overlaps must be identified (UNEP/SETAC Life Cycle Initiative, 2009).

1.2. Aim and Objectives

The aim of this study is to develop a comparative holistic life cycle sustainability assessment method for the building industry and test this method on a selected case scenario. To reach this goal, study objectives are listed below:

- Analyzing discrete social sustainability assessment studies in the literature to define stakeholder, impact category and indicator inventories that are required to develop a social life cycle assessment methodology.
- Selecting a pilot renovation scenario to validate the method on its thermal insulation material selection step since directives in Europe and Turkey mostly cover energy efficient renovation measures and thermal insulation of buildings is the keystone of such renovation projects.
- Performing LCA, S-LCA and LCC studies for the comparison of different insulation material scenarios.
- Combining all assessment results in a holistic life cycle sustainability assessment to detect hot spots and suggest improvements to render selected materials more sustainable.
- Recommending further development in the assessment method due to experiences gained in this study.

1.3. Procedure

The study was conducted in five steps:

Firstly, an assessment framework has been developed depending on former studies and guidelines in the literature for S-LCA, LCC and LCA. Literature findings showed the gaps in the literatures and directed the flow of the study to these areas. Conventional frameworks, holistic LCSA attempts and LCSA guidelines in the literature were studied to build a LCSA framework. Also, analyzed studies provided a database that has been utilized to develop a scoring system for the suggested S-LCA framework.

Secondly, a pilot building and three insulation materials were selected. According to gathered data, three exterior sheathing scenarios with selected insulation materials were created in Building Information Model (BIM) environment. Using the BIM data, a conventional LCA study was conducted to compare environmental impacts of design scenario by using Tally software which is a Revit plug-in. Afterwards, a S-LCA study method was developed by using literature and conventional LCA method as a basis. According to developed S-LCA method, required data was gathered via interviews, surveys and desktop screening. Lastly, a LCC study was conducted to compare economic feasibility of each renovation scenario with respect to property owners as the decision-making body. Assessment phases were concluded by processing results of each assessment study to obtain a single score result that can be used in overall life cycle sustainability assessment. Processing of the results was done via normalization and weighting.

Thirdly, results of three assessment studies were gathered to compare and interpret them by giving references to detected hot spots in the assessment studies. Interpretation was concluded by suggesting possible enhancements within the life cycle of the insulation materials to render them more sustainable.

Finally, the overall life cycle sustainability assessment experience was evaluated and further improvements were suggested.

1.4. Disposition

The study is composed of five chapters:

The first chapter reveals the argument and motivation behind this study as well as the aim, objectives, framework and simplified structure of the study.

The second chapter is a literature review about the study subjects. Literature review is conducted to understand main terms of the study which are sustainability and life cycle assessment.

The third chapter explains materials and methods that are used for this study. It is composed of three life cycle assessment studies on a case scenario.

The fourth chapter concludes the assessment studies and combines obtained results in the same medium for interpretation of the results as well as assessment methods.

The fifth chapter concludes and summarizes the study.

CHAPTER 2

LITERATURE REVIEW

Literature review was conducted to understand main terms of the study which are sustainable architecture and life cycle assessment (LCA). Sustainable architecture section focuses on general sustainable architecture terminology as well as holistic and limited sustainability definitions. The scope narrows down to product level on LCA section and this section was used mostly to create the framework of the study. Aim of this section is to analyze sustainability concept and LCA methodology individually to be able to understand whether LCA is a proper tool to assess sustainability. Possible developments for the methodology and gaps in the literature were searched.

2.1. Sustainable Architecture

The largest scope of sustainability concept was defined in built environment domain for this study. However, universality of sustainability definition fades out as we narrow the scope down to architecture. For this reason, some recent studies were analyzed in terms of their sustainable architecture understanding. While doing so, these definitions were also analyzed in terms of their scope and sub topics since this study attempts to define a scope for sustainability assessment.

It was stated by U.S. Energy Information Agency (2016) that by 2025, global energy consumption will increase by 33% in developed countries and by 91% in developing countries. The International Energy Agency on the other hand, stated that between 2003 and 2030, annual growth rate of energy consumption would be 1% in OECD countries and 3% in non-OECD countries (Najjar *et al.*, 2017). According to the estimations of the United Nations Environment Program, buildings consume approximately 40% of the global energy, 25% of the global water, 40% of the global resources and they emit 1/3 of the global greenhouse gas (Asdrubali et al., 2015; Woodhead Publishing Limited, 2014).

Building sector, - along with other industries – have realized the significance of the environmental impacts that are caused by its activities in 1990s. Since then, many changes were motivated by public policies and growing market demand on environmentally labeled projects covering building design, construction and operation phases (Haapio & Viitaniemi, 2008). Sustainable development in buildings aims to meet necessary standards and functions with minimum negative impact on environment by also encouraging development in social and economic conditions in global, national and local levels (Häkkinen & Belloni, 2011). Broad sustainability definition is reduced to a firm framework by sustainability measurement tools. Although these tools have been accused for reducing sustainability approach to environmental terms, they developed parameters to cover other aspects of sustainability including long term economic development, human health, local human rights, *etc.* in time. Development of the term in maturity, set more clear boundaries between similar terms which are green building and high-performance building (Berardi, 2013). On the other hand, finding long-term solutions to render human existence and well-being continuous on the planet is considered to be more important and challenging than finding a proper terminology (Kim & Rigdon, 1998). Nevertheless, various sustainable development approaches (criterion-based and holistic) were analyzed to be able to define a scope for this research. Examples of criterion-based approach mostly focus on environmental and economic parameters where holistic approach includes social and cultural parameters as well.

2.1.1. Environmental Sustainability Approach

Sustainable architecture has been attributed to the building's environmental impacts and resource consumption throughout its lifecycle including its construction, use, operation and demolition phases by some authors. According to Ragheb *et al.* (2016), sustainable architecture should minimize resource consumption, waste production, pollution and harmful emission throughout the building's lifecycle. To minimize negative impacts of buildings on the environment, it is essential to use natural resources and efficient materials, supply them locally and design the space according to energy use (Mahmoud, 2016; Eiraji & Akbari, 2011). In other words, sustainable architecture is possible in a self-sufficient and self-maintained settlement where inhabitants can survive without contributions of the larger natural environment or ecologic system (Karabag & Fellahi, 2017). On the other hand, according to Mohammadi and Pazhouhanfar (2017), sustainable architecture is simply enhancement of Vitrivius principles (firmitas, utilitas, venustas) all together by paying respect to the spirit of the location (genius loci). In other words, sustainable architecture should be based on local needs, use local materials and reflect local traditions (Saeig *et al.*, 2018).

Sustainable architecture can be a term that was born a few decades ago but sustainable architecture practice is as old as architecture itself (Yılmaz, 2006). Some architects and researchers claim that vernacular architecture has been creating sustainable examples of architecture whereas architecture of modern societies created unimaginative buildings by using inflexible and toxic materials that lead people to social isolation (Vellinga, 2005). Vernacular buildings are known with their passive energy efficiency strategies according to their region and they culturally connect their habitants to the environment. They take surrounding environment, climate and available resources in a holistic way (Mahmoud, 2016). Somehow vernacular buildings contradict with a global definition of sustainable buildings materials and construction techniques. The design, form and orientation of vernacular buildings are also shaped by social parameters like living style, traditions and socioeconomic conditions of the region (Karabag & Fellahi, 2017). Vernacular architecture is mostly shaped with respect to local characteristics, materials and resources. It is somehow sustainable in its own context and time without being aware of it (Mohammadi and Pazhouhanfar, 2017).

Although vernacular buildings were obliged to rely on passive strategies for a comfortable indoor environment, these sustainability strategies became a secondary design parameter in modern age because of modern air conditioning technologies (Eiraji & Akbari, 2011). According to the Physical Institute in Maldegem, building facades are responsible for 40% of heat loss in winter an over-heating in summer which renders active air conditioning systems essential in today's world (Barozzi *et al.,* 2016). However, there are some reasons behind the rise of sustainable architecture subject in literature in the last decades. Uysal and Sogut (2017) explain these driving factors in a cause and effect order as rising energy costs, facility lifecycle costs, financial pressures, resource conservation, worldwide awareness and eventually, environmental mandates. Sustainable architecture is a critical balancing subject between increasing energy consumption in buildings and increasing world population that require more accommodation which are two major global problems of today's world (Karabag and Fellahi, 2017). Since sustainability concept focuses on limited energy and resources and negative effects on environment, it wouldn't be illegitimate to say that sustainability parameters have gained importance in literature due to economic and environmental reasons mainly (Holstov *et al.,* 2015).

To answer the rising awareness in the world, every nation started to create its own sustainable building parameters as well as global standards and these standards are constantly updated according to changing technologies and needs. U.S. Green Building Council developed LEED (Leadership in Energy and Environmental Design) certification which is divided to 5 main categories: sustainable site design, water conservation and quality, energy and environment, indoor environmental quality and conservation of materials and resources (Ragheb *et al.,* 2016). Most of these parameters have also direct relation with BIM (Building Information Modeling) methodology (Saieg *et al.,* 2018). Similar certification programs were developed in United Kingdom, (BREEAM) in Australia, (GreenStar) CASBEE in Japan, HQE in Japan and internationally (Green Building Challenge) as well (Sydney University of Technology, 2014; Bissoli-Dalvi et al., 2016). It is important that building which have been construction with respect to these standards should also be operated according to these standards (Ragheb *et al.,* 2016). Minimizing energy consumption during operation phase is also essential for renovated existing buildings (Maywald & Riesser, 2016). It is obvious that these standards are also results of recent economic and environmental crises. For that reason, they were mainly focused on these subjects.

2.1.2. Holistic Sustainability Approach

One of the most frequently cited sources about building sustainability is Agenda 21 which was published after United Nations Earth Summit in 1992 to be used in sustainable public policy formulation (Bunz *et al.*, 2006). Chapter 7 specifically deals with human settlements and it aims to develop policies about affordable settlement, settlement management, water use, transportation, planning, energy systems and human resource development (United Nations, 1992). The chapter has laid the foundations of socio-economical sustainability in built environment.

Some authors tend to base their sustainability understanding on three pillars approach which are environmental, economic and social sustainability in built environment (Maywald & Riesser, 2016; Shao, 2013; Benkari, 2013). Environmentally, sustainable architecture reduces pollution, natural resource and energy usage and prevent environmental degradation; economically, it reduces the money spent on energy and resources during construction and operation of the building and socially, it is aesthetically appealing and cause minimum strain on the local infrastructure (Ragheb *et al.,* 2016). Aesthetics of sustainable architecture which has been underlined in this definition is generally neglected in the literature according to Fadeai *et al.* (2015). According to Yılmaz (2006), sustainable architecture has a physical and spiritual meaning. Physical definition is related with building's physical endurance, minimum maintenance requirement, energy and cost saving whereas spiritual definition depends on subjective values like fostering man's spirit and soul and aesthetics. Douglass (2008) claims that to define a framework for sustainable aesthetics, it must be an applicable method or a practical philosophy. Also, it must be an organizing concept generator and it should represent a universal approach.

Karabag and Fellahi (2017) relates environmental aspect of sustainability with lifecycle assessment, social aspect with "humane design" that focuses on the interactions between humans and nature and economic aspect with reduction, reuse and recycle of natural resources. They have developed sustainable design principles with respect to their case study by further sub-categorizing these main subjects (Figure 2.1).

Sustainable Methods		
Economy of Resources	Energy Conservation	Energy-Conscious Urban Planning
		Energy-Conscious Site Planning
		Passive Heating and Cooling
		Insulation
		Day Lighting
		Choose Materials with Low Embodied Energy
	Water Conservation	Reduce Consumption
	Material Conservation	Use Materials that can be Recycled
		Size Building and Systems Properly

Life Cycle Design	Pre-building Phase	Use Materials Made From Renewable Resources
		Use Materials Harvested or Extracted Without Causing Ecological Damage
		Use Materials with Long Life and Low Maintenance
	Building Phase	Minimize Site Impact
Humane Design	Preservation of Natural Conditions	Respect for Topographical Conditions
	Urban Design Site Planning	Promote Mixed-use Development
	Design For Humane Comfort	Provide Thermal, Visual, and Acoustic Comfort
		Provide Visual Connection to Exterior
		Provide Operable Windows
		Provide Fresh Clean Air
		Accommodate Persons with Different Physical Abilities

Figure 2.1 Sustainable design principles (Karabag & Fellahi, 2017)

International Council for Research and Innovation in Building and Construction (CIB, 1999) defines sustainability by extending traditional competitive factors which are cost, quality and time to social equity and cultural issues, economic constraints and environmental quality. Häkkinen & Belloni (2011) also use this structure and list environmental aspect as climate change, deterioration of ecosystem and depletion of resources; social impacts as health, satisfaction and equity; economic impacts as economic value and productivity.

Three pillars sustainability approach is also mentioned in architecture education to some extend but principles are not studied in detail. In United Arab Emirates, percentage of credit hours on economic and social aspects of sustainability is less than 5% most of the educational programs (Benkari, 2013). In UK and USA, architecture education is applied in 5 core subjects (design, professional studies, building technology, humanities and electives) and sustainability issues are covered within building technology subject as environmental and ecological design parameters, green technologies, sustainable constructions and building materials (Keumala *et al.*, 2015). Universal definition of sustainability indicators and parameters in other dimensions (social and economic) of sustainable architecture would promote a holistic sustainability education in universities. An attempt to define a compilation of sustainable design parameters in architecture has been described by Ahmad *et al.* (2016) on Figure 2.2.

<table>
<tr><th>D</th><th colspan="4">ENVIRONMENTAL</th><th colspan="2">ECONOMIC</th><th colspan="2">SOCIAL</th></tr>
<tr><td>I</td><td>Climate Change</td><td>Emissions</td><td>Water efficiency</td><td>Depletion of Resources</td><td>LCC values</td><td>Affordability, Manageability & Adaptability</td><td>User comfort and safety</td><td>Functional, Aesthetic & Innovative design approach</td></tr>
<tr><td rowspan="7">P</td><td rowspan="7">Global warming potential</td><td>Acidification potential</td><td>Rain water use</td><td>Land use</td><td>Capital Cost</td><td rowspan="3">Adaptability & flexibility of building</td><td>Indoor environmental quality</td><td>Usability, functionality & aesthetic aspects</td></tr>
<tr><td>Inert waste to disposal</td><td rowspan="6">Potable water use</td><td rowspan="2">Depletion of material resource</td><td rowspan="6">Life Cycle Cost</td><td>Health and well being</td><td rowspan="2">Innovation & design process</td></tr>
<tr><td>Hazardous waste to disposal</td><td>Safety</td></tr>
<tr><td>Eutrophication potential</td><td rowspan="4">Depletion potential of fossil fuels</td><td rowspan="2">Affordability and economic performance</td><td>Open space availability</td><td rowspan="4">Architectural considerations, integration of cultural heritage & compatibility with local heritage values</td></tr>
<tr><td>Smog potential</td><td>No. of facility users</td></tr>
<tr><td rowspan="2">Ozone Depletion potential</td><td rowspan="2">Manageability aspects of building</td><td>Community amenities provision</td></tr>
<tr><td>Accessibility</td></tr>
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Figure 2.2 Sustainable design principles (Ahmad *et al.*, 2016)

2.1.3. Sustainable Architecture and Life Cycle Approach

To be able to create an organized method with complex indicators of sustainability, some authors analyzed sustainability parameters within the life cycle of a building and categorized them by phases. These phases are programming (pre-design) phase, design phase, construction phase, operation phase and demolition (Bunz *et al.*, 2006; Public Technology Inc., 1996). This lifecycle assessment concept was originated from product based LCA. Product based LCA is an important tool to determine a building's sustainability. The tool is analyzed in detail on the following pages. LCA is mostly performed in environmental domain but it can be applied to other dimensions of sustainability as well. However, parameters of assessment studies for other dimensions of sustainability are not definite yet. In their case study, Maywald and Riesser (2016) have given attention on acoustic and thermal comfort measures as social parameters as well as environmental parameters like energy efficiency and economic parameters like heating bills. Bilge and her colleagues (2016) developed a sustainable value creation method that depends on three sustainable architecture measures with specific lifecycle scopes for project management, equipment and products (Figure 2.3). Lifecycle analysis is an essential tool to determine a building's environmental sustainability and lifecycle assessment comparison of different design options with different materials can be easily performed in BIM medium today. BIM can assist project stakeholders to compare energy efficiency and environmental impact results of various design alternatives easily (Saieg *et al.*, 2018).

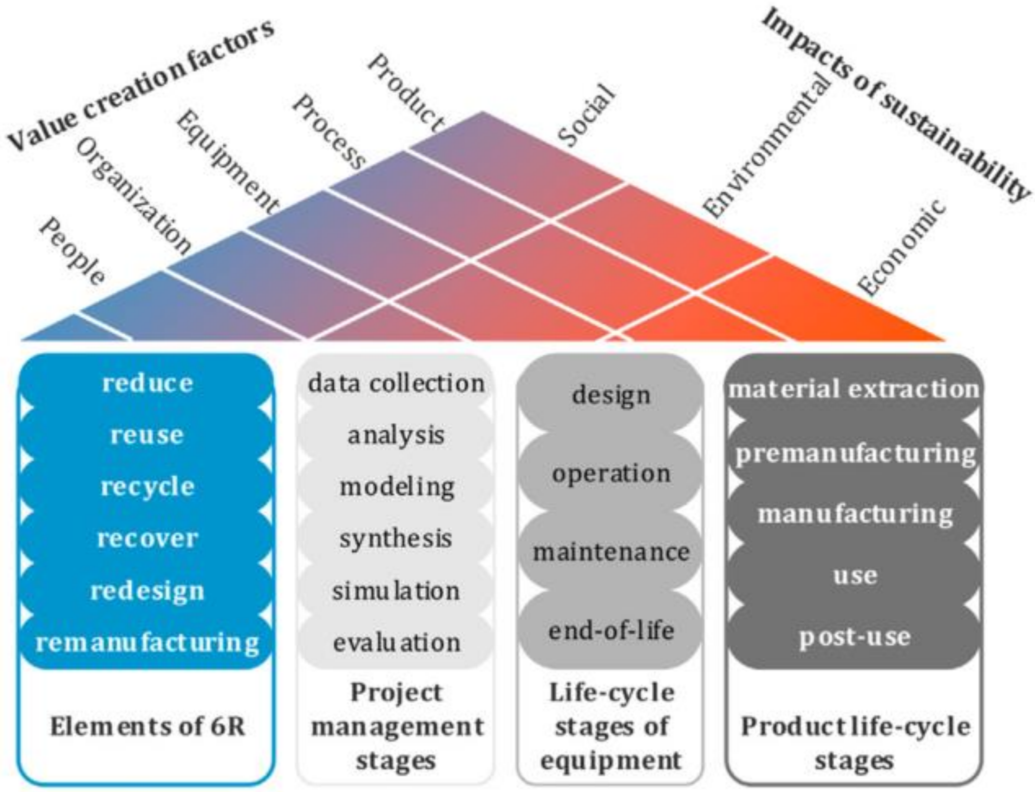


Figure 2.3. A conceptual framework for mapping and integrating product life-cycle for sustainable value creation (Bilge *et al.*, 2016)

2.2. Life Cycle Assessment

Life cycle assessment (LCA) is a methodology to evaluate the potential impacts throughout the product's life. It is also referred as "life cycle analysis", "life cycle approach", cradle to grave analysis" or "ecobalance" (Jensen *et al.*, 1997). Origins and areas of usage for these terminologies are further explained in following parts. From an environmental point of view, it is a measure of all the environmental impacts throughout the defined scope of the study including design, material extraction, manufacture, use and disposal or recycle (Case, 2011). Although full life cycle assessment covers the whole lifespan of a product from raw material extraction to product disposal, or in other words, cradle-to-grave; the scope of the assessment can be narrowed down (Çamur, 2010). For example, cradle-to-gate assessment covers only a partial product life-cycle from resource extraction to the factory gate (until the pre-installment phase). If the end-of-life phase is a recycling process instead of disposal, this closed loop assessment is called cradle-to-cradle (McDonough, Braungart, 2002) (Figure 2.4). Apart from these, other scopes can be defined for specific studies like gate-to-gate or production-only.

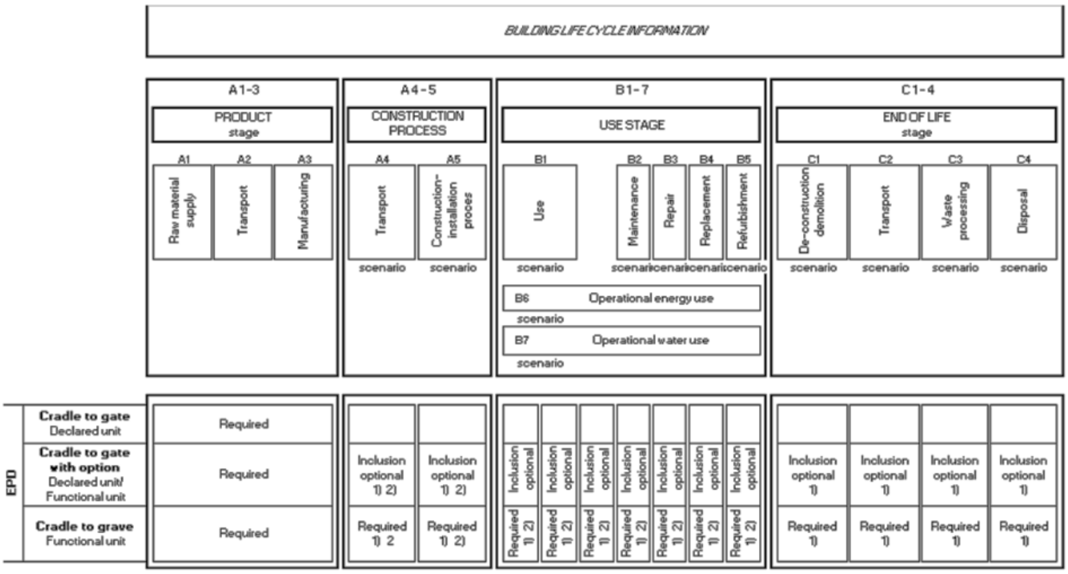


Figure 2.4 Scope definitions of LCA (BS EN 15804:2012)

As it is mentioned in LCA guide lining work of International Wool Textile Organization (IWTO, 2016) for wool textiles, LCA methodology is still under development but current essential guidelines for LCA studies are:

- ISO 14040:2006 Environmental management - Life Cycle Assessment - Principles and Framework
- ISO 14044:2006 Environmental management - Life Cycle Assessment - Requirements and Guidelines
- ISO/TS 14067:2013 Carbon footprint of products – Requirements and guidelines for quantification and communication

- ISO 14046:2014 Environmental management - Water footprint - Principles, requirements and guidelines.
- PAS 2395:2014 Specification for the assessment of greenhouse gas (GHG) emissions from the whole life cycle of textile products.
- LEAP (2015a) Greenhouse gas emissions and fossil energy demand from small ruminant supply chains: Guidelines for quantification.

Both private sectors and public bodies may require LCA studies before decision making since they allow environmental comparison between both existing products and future products (Singh *et al.,* 2013). Buchart-Korol (2011) claims that significance of LCA methodology is its holistic approach to evaluate environmental, social and economic performance of materials, technologies and products from all stages of manufacture, product use and end-of-life.

2.2.1. Brief History of Life Cycle Assessment

History of LCA dates back to 1960's. The main motivation behind the studies is based on reduction of energy resources and raw materials that are used in production of a material as well as to projection of future resource supplies and uses. Harold Smith's report on calculations of cumulative energy requirements for the production of chemical intermediates and products at the World Energy Conference in 1963 was one of the first publications of its kind (Curran, 2006). On the other hand, first study of LCA is funded by Coca-Cola in 1969 on beverage containers to compare cans and bottles. The study mainly covered consumption of raw materials, energy efficiency and waste disposal to some extent (Jensen *et al.*, 1997). The methodology was eradiated as it is used in this first study in early years dated from the late sixties and early seventies.

In early 1970s, the process known as quantifying resource and environmental releases of products became known as Resource and Environmental Profile Analysis (REPA) in USA and Ecobalance in Europe. With boosting effect of the oil crisis in early 1970s, approximately 15 REPAs performed between 1970 and 1975 (Curran, 2006). After solid waste recycle became an important worldwide issue in 1988, waste disposal and recycle became an essential phase of LCA methodology (Çamur, 2010).

LCA was an important tool of product promotion for companies that are done by third party researchers in late 80s and 90s. After LCA studies became so common and off the point in 1991, 11 State Attorneys General in USA recommended against using LCA for advertisement until LCA became standardized in 1997 with International Standards Organization (ISO) 14000 series (Curran, 2006). In UN Earth Summit in 1992, life-cycle assessment methodologies stood out as one of the most promising new tools for a wide range of environmental management tasks (Jensen *et al.*, 1997).

In 2002, the United Nations Environment Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC) launched Life Cycle Initiative together as an international partnership to put LCA to practice and develop inventory and indicators by using its three programs namely; Life Cycle Management, Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). As the LCA methodology started to consolidate, its development has slowed down (Curran, 2006).

As a brief evaluation of LCA history, it is obvious that LCA methodology grows mature and more detailed over years. The early studies in 1960's were mainly focused on energy and resource amounts until energy crisis was at the door in 1970s. In 1980s, waste disposal and recycle added as a response to raising awareness. The organic development of LCA methodology can be tracked up to ISO standards are set in 1997. Until then LCA methodology is naturally shaped by social awareness on worldwide issues and maturation of sustainability understanding.

2.2.2. Life Cycle Assessment Methodology

LCA is a method that evaluates all environmental impacts associated with a product, process or technology associated with its whole life cycle (Buchart-Korol, 2011). International standardization of LCA has been possible with ISO 14040 series (2006). The standards encouraged many performers of LCA and increased conducted LCA studies globally. While these standards were mainly defining basic principles and framework of the studies, ISO 14044 (2006) standards gave a more detailed information on requirements and guidelines (Lehtinen *et al.*, 2011).

General lifecycle methodology is commonly composed of four interrelated phases depending on ISO 14040 directive (Figure 2.5):

1) Definition of the goal for and scope of the LCA
2) Compiling an inventory of relevant inputs and outputs of the product system & inventory analysis
3) Evaluation of the potential environmental impacts - impact analysis
4) Interpretation, i.e. improvement analysis considering the results of 2 and 3 (International Council of Marine Industry Associations, 2007)

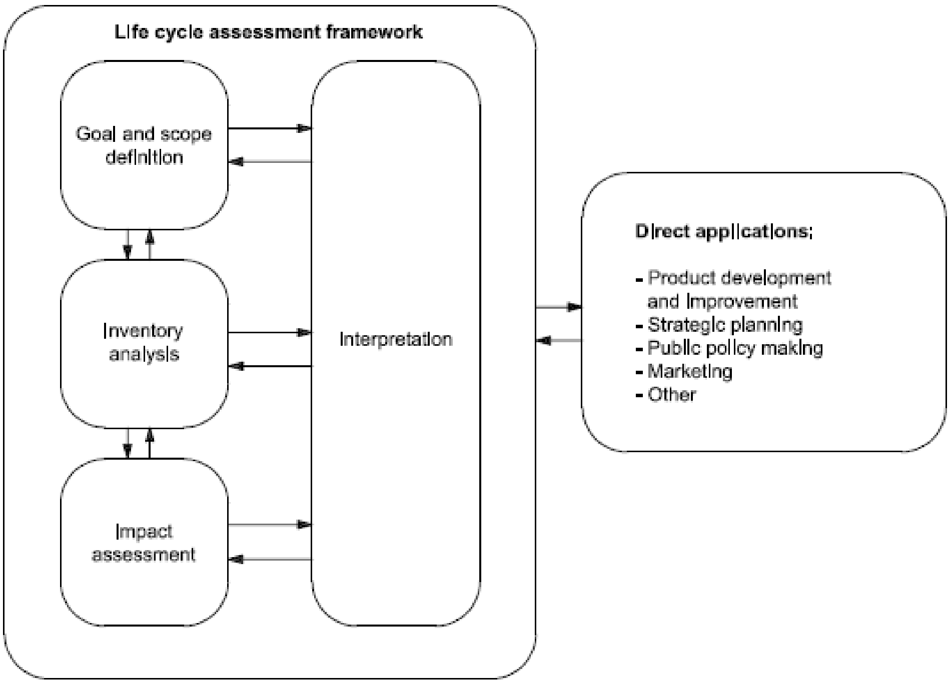


Figure 2.5 Stages of LCA (ISO 14040: 2006)

Goal and Scope Definition

This step is a fundamental phase of any LCA study. In this step, purpose of the study is defined and framework and key parameters to evaluate are specified (Australian Renewable Energy Agency, 2016).

Life Cycle Inventory Assessment

The second phase deals with collecting required data to meet the objectives of the LCA study. System inputs and outputs are determined. Existing databases and performed measurements are specified (Lehtinen *et al*., 2011).

Life Cycle Impact Assessment

Impact assessment phase requires definition of list of certain environmental impacts. It aims evaluating and measuring the potential environmental impacts of a product, technology or process throughout its life cycle. Inputs and outputs of inventory elements are correlated with environmental impacts (Margni, nd.). This phase requires two important steps called; classification and characterization. Classification is performed to create life cycle impact category. Characterization on the other hand, is performed to assign inventory elements to impact categories. Generally, performers use pre-defined databases for this step (Lehtinen *et al*., 2011).

Interpretation of Results

On the last step of LCA, results of second and third steps are summarized and discussed to conclude the study with understandable, qualitative inferences. The goals and objectives that are set on the first phase are questioned (Lehtinen *et al*., 2011).

2.2.3. Life Cycle Assessment in Construction Industry

As a developing country, construction industry has an important role in Turkey's development. According to Kaymaz (2015), some key indicators and their values are given in Figure 2.6. At the end of 2014, worth of construction sector represented a share of GDP between 4.6% and 5.9% according to calculation method. However, when construction sector's impact on other sectors of the economy is considered, the share rises to 30% with 10% of the working population is employed within the sector in large scope (Oxford Business Group, 2017). With these stats, Turkey has held the second place for nine years straight (from 2007 to 2016) in Engineering News-Record's (ENR) The largest 250 international contractors of the World list in terms of the number of contracting companies building the largest volume of projects across the world outside their home countries with 42 construction companies active in the world out of top 250 (Çoban *et al.,* 2015; Kaymaz, 2015). Consequently, construction industry is an important factor that should be evaluated both in environmental life cycle assessments with its high share in economy and social life cycle assessment with its high rate of employees both nationally and globally.

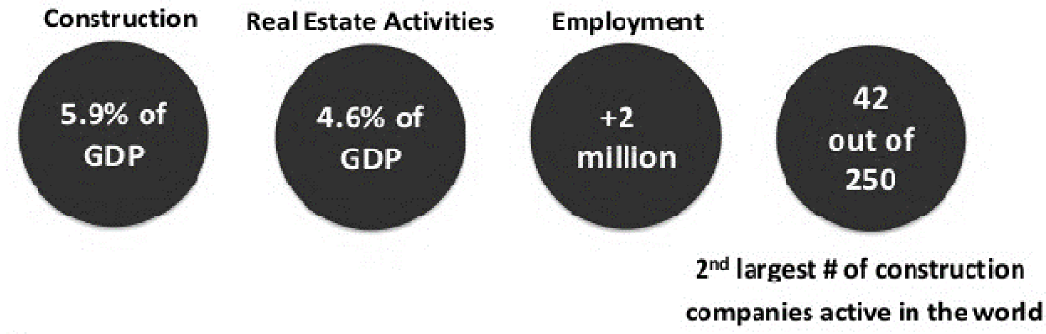


Figure 2.6 Key Indicators in Turkish Construction Industry (Kaymaz, 2015)

As sustainability indicators including environmental, social and economic aspects are developing all over the world, these indicators draw attention to construction sector expectedly which is one of the biggest industries in both developing and developed countries that is responsible for most of the energy and resource consumption, solid waste generation, global greenhouse emission, pollution and environmental damage in those countries (Ortiz *et al.,* 2009).

According to Means and Guggemos (2015), although LCA methodology is widely used in several industries of USA since 1960s, it is still not common in construction industry whereas construction industry is responsible from most of the greenhouse gas emissions in USA.

After UNE-EN ISO 14040 and UNE-EN ISO 14044 standards were released in 2006, many LCA tools and databases were created to be used in construction industry based on these standards. These databases depend on certain studies that are carried out in certain locations. However, product results may differ from location to location and finding the most suitable database is a crucial challenge of local LCA studies (Martinez-Rocamora *et al.*, 2016).

2.2.4. Life Cycle Assessment Tools

There are many different tools of LCA that offer different database. According to the tool that is used, LCA structure and impact categories may change. One of them is Ecoinvent which is a LCI and LCIA database. Performed studies are collected in its database and reviewed for further use by other LCA performers. Since many data about different geographic locations are available in its database, it can perform a reliable assessment (Howe *et al.*, 2017).

Athena EIE is a conceptual design tool for buildings which have many indicators without weighting. Its database was designed to see how early design changes affect environmental impact of a building (International Society of Sustainability Professionals, 2011).

Another tool is GaBi which is utilized in this study as well. It has a large database of processes from different industries. The developers accept data requests from users to widen their database. They also update the processes annually (Howe *et al.*, 2017; Carmody & Trusty, 2005).

Reliability of these databases is speculative. In a study carried out by Takano A, Winter S. and Hughes M, (2014) six different LCA tools (GABI, Ecoinvent, IBO, CFB Synergia, ICE) are compared for LCA of GHG emissions on three different buildings and overall results different in a range of 30% whereas difference in some building components escalates up to 180% (wood fiber board). It is stated that difference mainly arises from different databases of these tools. Another study on database evaluation of 10 LCA tools by Martinez-Rocamora (2016), found out that

Ecoinvent and GABI databases are the most complete, largest scoped, and most transparent among them.

2.3. Social Life Cycle Assessment

Society keeps companies responsible of their social impacts on various stakeholders. Companies need an assessment system to take sustainable decisions and show their sensitivity on sustainability to the society (Hauschild *et al.*, 2008). Many different tools to evaluate social responsibility have been developed and utilized by companies in corporate level. While these tools are focused on managing production process, individual S-LCA studies are conducted and tested worldwide in 2000s. With the method that was suggested by UNEP/SETAC Life Cycle Initiative, a step to standardization of S-LCA has been taken (Hsu *et al.*, 2013). S-LCA is defined by UNEP/SETAC Life Cycle Initiative - which is an essential body that created the main structure of the method - with following words: "A social life cycle assessment (S-LCA) is described as ‘a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle" (UNEP/SETAC Life Cycle Initiative, 2011)

In UNEP/SETAC Life Cycle Initiative guidelines, (2009) similarities between LCA and S-LCA are listed as follows:

- They share a common trunk which consists in the ISO framework (goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation); although there are some specificities for each of these phases in S-LCA.
- Both have a huge need for data.
- Both work as iterative procedures.
- They encourage and request peer review when communication to the public or comparative assertions are planned.
- They provide useful information for decision-making.

- None have the purpose to provide information on whether a product should be produced.
- Both conduct hotspots assessments that play the same role.
- Both conduct data quality assessment.
- They do not generally express impacts by functional unit, if semi-quantitative or qualitative data are used.

As the methodology is defined by UNEP/SETAC Life Cycle Initiative (2009), S-LCA methodology mainly follows ISO 14040 framework with some adaptations. Thus, it is carried out in four phases: (i) goal and scope of the study; (ii) inventory; (iii) impact assessment; and (iv) interpretation.

Goal and Scope Definition

Like other LCA methods, first step of any S-LCA is to define the goal and scope of the study. This step includes definition of functional unit, description of product utility, overview of the stakeholders concerned and setting-up boundaries. Some lifecycle steps can be excluded if valid reasons are given by the commissioned person who carries out the assessment (UNEP/SETAC LCI, 2009). The functional unit describes the function to be fulfilled or achieved by the product and the period during which the function is carried out (CEPMC, n.d.).

Main stakeholders are defined by UNEP/SETAC LCI (2011) as; workers/ employees, local community, national or global society, consumers and value chain actors. Also, other categories including NGOs, public authorities, future generations *etc.* can be added.

While defining the goal of the study, system boundaries, reference alternative scenarios, *etc.*, three points require attention. Firstly, geographical system boundaries are defined to include different countries' unique social conditions and cultures. For example, workers' satisfaction with working conditions should be evaluated with reference to local conditions. Secondly, if the assessment is to be conducted as a part of an overall sustainability assessment, product utility and functional unit must be described with considerably more precision than is usual in the LCA. For example, symbolic utility aspects like "prestige" should be described in detail. Thirdly, indicator selection study is of pivotal importance due to sheer number of potential social aspects for the analysis (Grießhammer *et al.,* 2007).

Life Cycle Inventory Assessment

Second step is the one requires further development most (UNEP/SETAC LCI, 2009). This is the phase where sub-categories are defined and indicators are created according to each stakeholder. In this stage, sub-categories are classified according to stakeholders and impact categories. Data types of the indicators to assess sub-categories can be qualitative and quantitative which means, data should be treated before used in final calculation (UNEP/SETAC LCI, 2011).

While defining social indicators, key aspects originate in three areas; social impacts on production chain and end-of-life management like worker human rights, wages, social rights, *etc.*, social repercussions of product use like effects of technologic device usage on children and indirect repercussions on society like indigenous people rights or effects on national economic development (Grießhammer *et al.,* 2007). Large scale aspects like national or global data are called "generic data" (UNEP/SETAC LCI, 2011).

Life Cycle Impact Assessment

Impact assessment phase requires more than development since the methodology is not defined in UNEP/SETAC LCI Guidelines for Social Life Cycle Assessment of Products (2009). According to PROSA guidelines, like LCA, the key elements of this step for S-LCA include analysis of data quality, classification characterization and optionally, normalization. In this phase, qualitative data is transferred into a quantitative form (Grießhammer *et al.,* 2007).

A preliminary list of criteria to assess data quality is given in UNEP/SETAC LCI (2009) guidelines as follows:

- Validity: Do the data collected and the indicators used provide information on what is intended to be measured?
- Relevance: Are the right data and indicators being used to measure what is meant to be measured?

- Measurement methods: Are the measurement methods used to generate and/or collect the data appropriate?
- Completeness: Does the data gathered cover the needs of the study?
- Accessibility/Documentation: How well is the data documented?
- Uncertainty: How certain are the results?

Results Interpretation

Last stage of the research - like E-LCA - has an open-ended structure that can be interpreted according to the data results. As is the case with E-LCA, this phase of S-LCA requires a peer review and stakeholder consultancy. However, since S-LCA methodology is still at an early stage, there are few examples that has completed the research this way (UNEP/SETAC LCI, 2011).

Like LCA, completeness, significance and consistency with the defined goal for key elements are checked in this step. Ideally, the interpretation should be carried out in collaboration with stakeholders. If a single score result is demanded, weighting can be carried out with user defined weighting values (Grießhammer *et al.*, 2007).

2.3.1. Brief History of S-LCA

Although various aspects of social responsibility were the subject of action by organizations and governments as far back as the late 19th century, the term "social responsibility" has come into widespread use in 1970s. Since attention to social responsibility has been focused primarily on business in the past, "corporate social responsibility" is a more familiar term to most people than "social responsibility". The early social responsibility concept is centered on charitable activities and subjects like labor rights and fair operating practices have a much older history. Other subjects like human rights, environment, consumer protection, corruption, *etc.* are added over time which constitute backbone of current S-LCA structure (ISO, 2010).

Discussions on how to deal with social and economic assessment of products throughout their life cycle started in 1980s. One of the first initiatives was Project Group of Ecological Economics within Öko Institut in 1987 and SETAC workshop report on a conceptual framework for LCIA in 1993. Both initiatives worked on creating a holistic approach to combine social and environmental aspects of life cycle assessment as well (UNEP/SETAC LCI, 2011).

In the early 2000s, life cycle thinking became more popular globally after mentioned in the World Summit on Sustainable Development Declaration in 2002 by UNEP. There, it is also mentioned that some of our choices may have socio-economic impacts as well and these impacts may affect all actors throughout the life cycle chain and eve society (Paragahawewa *et al.,* 2009).

In 2000s, many authors argued about social life cycle assessment or tried to carry it out. These studies include an indicator assessment study by Brent and Labuschange (2006), a social life cycle framework study by Dreyer, Hauschild and Schierbeck (2006), an application experience of S-LCA method in New Zealand (Grieβhammer *et al.*, 2006) and S-LCA methodology studies (Jørgensen *et al.,* 2008; Klöpffer, 2003). The first step for standardization of S-LCA method was "Guidelines for Social Life Cycle Assessment of Products" of UNEP/SETAC Life Cycle Initiative in 2009. It was a directive for S-LCA studies that is derived from LCA method which is also based on ISO 14040 and 14044 standards for LCA (Reitinger *et al.,* 2011). Although stakeholders, subcategories and indicators are mostly defined in the guideline, no consistent or specific method is proposed (Hsu *et al.,* 2013).

In its early stages, S-LCA is generally compared to conventional LCA and it is considered that it has a great potential to add a further dimension to LCA (Paragahawewa *et al.,* 2009). Elements of social responsibility assessment reflects the expectations of society at a certain time and are therefore liable to change (ISO, 2010).

2.3.2. Social LCA Studies

Since there are no global standards for S-LCA method and framework individual S-LCA studies in the literature are investigated. To understand the development of the method, studies are examined in chronological order. It is possible to divide the studies according to their types before and after UNEP/SETAC Life Cycle Initiative

Guidelines (2009) about S-LCA. Moreover, some new attempts take place in the literature that aim to combine LCA, S-LCA and LCC in one Life Cycle Sustainability Assessment (LCSA) after the release of UNEP/SETAC Life Cycle Initiative's (2011) LCSA guidelines. The stakeholder and impact categories in the literature were collected whenever they are available to create the framework of this study in following chapters. While doing so, studies that focus on certain aspects or stakeholders of S-LCA are excluded. To conduct a systematic literature review at this stage, first 100 papers in Google Scholar search with "social" and "LCA" keywords were selected. Most of the papers were acquired from first 5 pages of Google Scholar search results (approximately 90% of total studies). In the next 5 pages following the first 5, studies mostly mention social aspect as a requirement of any sustainability assessment and some of them even address S-LCA method as we use today; but they conduct only E-LCA in the end.

- **Early S-LCA Studies**

Studies that were conducted before publication of international guidelines lack a global methodological structure but some main elements of S-LCA were introduced in them such as impact categories and functional unit. One of the oldest case studies about social sustainability assessment is conducted by combining ecological LCA methods and suggested social parameters to create a comprehensive method (O'Brien *et al.,* 1996). The method is called Social and Environmental Life Cycle Assessment (SELCA) approach and the case study was conducted on two different life cycles of coal. It inherits an early inventory framework of S-LCA.

In 2005, new studies emerged to extend the framework of S-LCA. In one of the studies, the method is called "corporate social and environmental performance measuring" and it extends application of standard LCA by adding more phases and impact categories to it (Gauthier, 2005). Another study by Hunkeler and Rebitzer (2005) analyzes historical development of LCA and its state at the time of the study. Also, it estimates that future LCA studies (2010-2020) are going to be conducted as holistic life cycle sustainability assessment studies (LCSA). Another paper that analyzes the situation of social sustainability assessment at the time of its creation, points out the potential and necessity of S-LCA rather than framework and inventory suggestions (Hauschild *et al.,* 2005). According to the paper, holistic sustainability approach is required and studies should be conducted in global level both in E-LCA and S-LCA. Also, sustainability education and sustainable management are two important subjects that countries should pay attention for sustainable development.

Investigated studies that belong to 2006, clearly shows some maturity in terms of category and indicator development. Sustainability approach of a framework study on S-LCA research covers a company's efforts to lower their negative influences on people who are affected while also making profit to survive (Dreyer *et al.,* 2006). This approach includes economic sustainability within the overall sustainability understanding. In the study of Dreyer and her colleagues, both universal documents and specific company data are taken as a reference while doing the impact assessment. One of the main findings of the study is that social impacts are related with how production processes are conducted by companies rather than individual production processes themselves. The impact categories are divided into compulsory and optional ones. Universal laws and guidelines are used along with country specific development goals to create a basis of research. Since a company's influence on stakeholders cannot be quantified with a functional unit as it can be in E-LCA, money flows within the production chain are taken as references to determine company hierarchy and thereby functional unit. Another attempt to combine economic and social aspect of sustainability within a framework, offers a detailed damage category scheme that aims to estimate and cover consequential damages of life cycle impacts which occur out of the life cycle scope of a product as well (Weidema, 2006). The study of Norris (2006) only focuses on health impacts that are resulted from economic activities within a product's complete lifecycle to suggest characterized connections between economic activities and health impacts depending on empirical knowledge. The study offers a local characterization scheme as a result and indicates the expectations about availability of global characterization schemes to conduct simplified scientific S-LCA studies in the future. Some attempts to define social sustainability assessment indicators are done in 2006 as well. In the study of Labuschagne and Brent, (2006) a literature review is conducted on commonly used S-LCA indicators to use them in South Africa process industry. It reveals that local data about process and technology to conduct a S-LCA was not available in South Africa at the time of the study.

There are two significant studies that were conducted in 2007 about S-LCA. First one is an attempt to employ social wellbeing measures that are covered in SETAC standards (Consoli, 1993) which are not covered in ISO-14047 standards for LCA. Social measures are not quantified but some case-specific impacts of fishing and seafood packaging were added to the LCA inventory. The study used LCA framework rather than an individual S-LCA method. Second study is a LCA study in oil and gas and agricultural biotechnology which points out complex parameters of current sustainability demands of society and offers a framework on how companies can take sustainability measures within their production chain (Metos & Hall, 2007). The study investigates case studies that are performed in various sectors in different countries to investigate changes in sustainability gradings of production system with respect to a simple decision change in the product chain and to investigate which processes, actors and technologies are affected from the change.

- **S-LCA Studies After International Guidelines**

Starting from 2007, a series of guidelines were published each year which are PROSA (2007), SEEBALANCE (2008), UNEP/SETAC (2009) and ISO 26000 (2010). S-LCA studies mostly based their structures on these guidelines after release of each. These guidelines were utilized in this study as well to form a framework. In this section, the guidelines are highlighted as milestones.

PROSA: PROSA (Product Sustainability Assessment) (Öko-Institut e.V, 2007), is probably the oldest tool that have been created to assess social and economic aspects of product lifecycle. First guideline was created in 1997 by Öko-Institut and it took the current shape in 2007 edition. The first version of the methodology was rarely used back in 90s unlike its counterpart; E-LCA methodology (Öko-Institut e.V, n.d.). Though their structures are somewhat different, S-LCA guideline of UNEP & SETAC and S-LCA part of PROSA guidelines share many common building blocks since they affected each other during the creation process. On the other hand, PROSA is a fundamental tool that gathers all three main types of sustainability assessment studies under one guideline and connect them on pairwise comparison charts.

This guideline also has an integrative approach. After goal and scope definition and market and context analysis phases, brainstorming and assessment studies are conducted for S-LCA, E-LCA, LCC and Benefit Analysis (BA) which is actually an assessment of the product's psychological and practical benefits from the consumer point of view. BA indicators are the most inconvenient ones among them to standardize. They are redefined for each product, user group and society. For example, u-value should be one of the main indicators of a BA on insulation materials since it measures the efficiency the user gets from a constant amount of insulator.

As it happens, PROSA is an improvement tool rather than a comparison tool. The last stage of the assessment structure requires a strategy planning to heal detected hot spots. Still, impact categories can apply to various types of S-LCA studies and it has been the first methodological framework that affected many studies back then.

One year before UNEP/SETAC guidelines, many studies were performed to create a S-LCA framework which formed a solid ground to build the guidelines. The study of Jørgensen and his colleagues (2008) was a S-LCA methodology comparison study. It does not represent stakeholder approach and defines its own categories. The comparison is limited with LCA-like frameworks. The study found out that little attention was paid to the usage stage of life cycle in studies up to that date. It claims that only relevant indicators must be selected for each individual study. In the article of Klopffer (2008) on life cycle sustainability assessment, it is stated that overall LCSA will be possible with definition of new standards by ISO. It presents two methods to combine different types of sustainability assessment. First one is to individually perform LCC, LCA and S-LCA and to combine them afterwards. Second one involves performing a single life cycle sustainability assessment study by introducing extra impact categories to standard LCA. This way, it introduces an early approach to LCSA. In Hutchins and Sutherland’s (2008) study, a framework was created around some main social categories rather than stakeholder approach. The study was planned to help companies on their corporate decision-making processes. A significant feature of the study is its normalization effort with reference to international statistics for each indicator. Another article summarizes S-LCA methodology creation experience from 2004 to 2008 to derive lessons from the process. It points out that environmental and social impacts should be comparable and consistent since their effects on each other may need to be studied. According to the article, the method must be originated from the goal of the assessment which may be labeling, management or decision making. It focuses on worker category and keeps society impact assessment optional. It also points out some major hot-spots that are not covered within the stakeholder approach.

SEEBALANCE: An important method that was introduced on LCSA in 2008 is SEEBALANCE (Social, Economic, Environmental Balance) method (Schmidt *et al.,* 2008). The method is constructed by selecting major hot-spots about social sustainability in the literature and defining the methodological concept that is originated from classical LCA. It includes six stakeholder categories. Apart from common stakeholders of S-LCA, (employees, local community, society, suppliers/partners and end users) the method introduces "future generations" category to include some environmental impacts within the same framework. SEEBALANCE framework is included among other sources to create the framework of this study. Also, an economic analysis like LCC has been suggested that was conducted within the life cycle scope of a product to enable weighting among companies that are involved in production of the product.

UNEP & SETAC LCI: UNEP & SETAC Life Cycle Initiative (2009) guideline was one of the first attempts to create a S-LCA directive. Thus, it had a quite definitive structure. Each step is narrated in detail and weaknesses and future improvements were pointed out wherever possible. Though it does not have a definitive indicator list for each of its defined impact categories, it points out how to define them depending on the framework. However, suggested indicator definition process depends mostly on subjective approach of the assessment performers based on an elaborate research on the related industry. Thus, it needs to be performed by a group of qualified professionals to reach reliable results. Thus, indicator definition process depends on former studies that were performed by such experts on the field. UNEP/SETAC (2011) also published holistic LCSA guidelines two years after its S-LCA guidelines. When their holistic methods were compared, SEEBALANCE and UNEP/SETAC's LCSA have completely different hierarchic structures. (Figure 2.7).

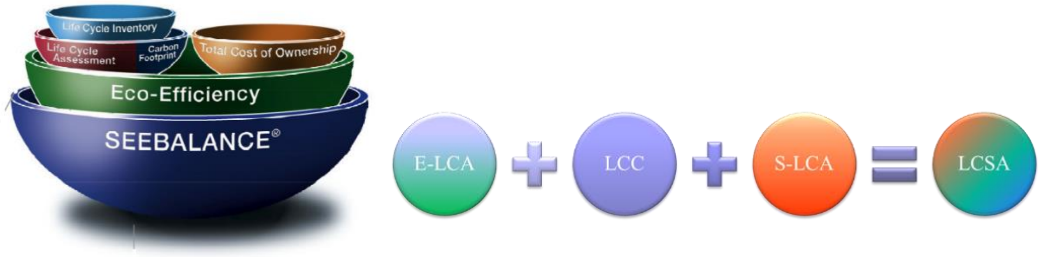


Figure 2.7 Comparison of SEEBALANCE and UNEP/SETAC methods in terms of hierarchy (Muller & Saling, 2011; UNEP/SETAC, 2011)

In 2010, various frameworks were created with different scopes and inventories. One of them is a social impact characterization study that reduces impact categories to four main categories under human rights topic according to International Labor Organization (ILO) conventions to render the suggested method simple and feasible for companies. It mainly focuses on characterization of indicators for these four categories which are forced labor, discrimination, freedom of association and collective bargaining and child labor (Dreyer & Hauschild, 2010). Another study combines separately conducted LCA, LCC and S-LCA studies with a final weighting system to obtain a single score comparison table (Finkbeiner *et al.*, 2010). It does not use stakeholder approach for S-LCA but it categorizes social impacts in local, national and global sectors. Also, the study focuses on graphical visualization methods of the results to render them legible to both expert and non-expert audiences. On the other hand, this study's social sustainability part is not comprehensive in comparison with other S-LCA studies in the literature.

Apart from framework creation and testing, there are some methodology evaluation studies that were published in 2010 as well. Firstly, a research to understand "sustainability" and "LCA" concepts were conducted to propose a method to combine them within a LCSA framework (Heijungs *et al.*, 2010). It basically uses the framework that was suggested in ISO LCA standards with some modifications. For example, inventory analysis and impact assessment steps were combined and they were performed together. Reductionist approach of classical LCA is questioned and some primary reviews are made about performing a holistic sustainability assessment without going into detail. Secondly, another study from Jørgensen and his colleagues (2010) is a critical study that aims to increase the reliability of the assessment by questioning social consequences of a product that occur out of product's life cycle scope. It introduces additional indicators to measure social impacts of other social consequences. Third study was created by Jørgensen and his colleagues (2010) as well. It conducts a specific review on two subjects; current indicators' validity to determine "wellbeing" of children as a stakeholder and validity of child labor presence as an indicator to give an idea on social areas of protection (AoP). The article analyzes all concepts and terminologies mentioned within these subjects in detail and compares their usages in case S-LCA studies. Such a scientific social study should be applied for each indicator to evaluate their relevance, validity and proper forms should be suggested wherever possible.

ISO 26000: ISO also published its 26000 directive in 2010. ISO 26000 directive is composed of guidelines to evaluate a company's socially responsible behavior to its related stakeholders to ensure a sustainable community. Although it is not an overall assessment tool of a products lifecycle phases, it is referred as one of the limited number of social sustainability assessment directives in UNEP & SETAC guideline. The directive covers health ecosystem, social equity and good organizational governance aspects of sustainability. Thus, it covers environmental impact categories that are deducted from this part of the assessment. Although schematic overview of this directive has a different structure from a LCA, it follows a similar path. Namely, first five clauses cover the first step (goal and scope definition) of LCA with further extensions to understand the sustainable development and social responsibility terms. On clause 7, impact categories and sub-categories are defined in detail.

Unlike UNEP & SETAC guideline, ISO 26000 directive implements a different structure by linking stakeholders and impact categories instead of using stakeholders as a superior level of categorization. Sub categories of each impact category are defined and descripted in detail. Using this information, a similarly structured table to UNEP & SETAC guideline is created. Stakeholders are defined with respect to descriptions of impact categories in this study and other guidelines' classification methods of intersecting impact categories.

- **Holistic LCSA Attempts**

In 2011, UNEP/SETAC's LCSA guidelines were published and studies mostly aimed to inherit a holistic LCSA method since then. Most of these studies questioned how to combine all three assessment methods in one single method.

Study of Ciroth and Franze (2011) covers a detailed complete life cycle assessment of a notebook. Particularly, social hotspots were detected on production and informal recycling phases. Some assumptions were made to simplify the assessment process like presuming raw material locations according to national statistics. E-LCA was conducted as well. The framework and inventory for S-LCA is adapted from UNEP/SETAC guidelines (2009). Since the framework were not derived from the guidelines identically, impact category and stakeholder lists were evaluated while creating the inventory for this study. Another study about past, present and future of S-LCA analyzes its historical development and its state at the time of the study (Guinée *et al.*, 2011). Also, it claimed that LCA studies would be conducted as LCSA studies in 2010s.

Zamagni's study (2012) conducts a literature review on "sustainability" and "LCA" terms and offers some recommendations for LCSA for practitioners. Firstly, it points out the maturity difference between LCC, LCA and S-LCA that leads to inconsistency among them. It recommends focusing on that topic to practitioners. Secondly, it questions if it is feasible to conduct a single LCSA instead of three sustainability assessments and encourages it. Finally, it promotes practitioners to question if uncertainty is inevitable for LCSA and how can it be managed.

A framework that is unusual to LCSA practitioners was introduced in the study of Macombe and her colleagues (2013) about S-LCA of biodiesel production. In the research, a social life cycle assessment was conducted via complementary approach, which was performed by adding social impact categories to LCA. The stakeholder system was defined as a hierarchic system with different level categories namely; company, regional and state levels. The paper concludes by claiming that a social life cycle assessment with suggested method is not yet possible and assessment framework requires many researches on different parts of the assessment like system boundary definitions. Companies also suggested to adapt scientific social data gathering and reporting methods to make these assessments possible. Expert knowledge to interpret processes in the product chain to estimate impacts is suggested to be another way of scientific social life cycle assessment. On the other hand, framework of a S-LCA study that is conducted in the same year on palm oil biodiesel is used as a reference to create this study's framework (Manik *et al.,* 2013). The framework follows UNEP/SETAC guidelines and stakeholder approach. Another borrowed framework is of Foolmaun and Ramjeeawon's study (2013) on comparative S-LCA of polyethylene terephthalate bottles. The study conducts separate comparative environmental and social LCA studies that are focused on their disposal phases. In impact assessment phase, reference values consisting of midpoints, max values and min values were used to create a scoring table. Correspondingly, scores higher than mid-point were categorized as positive impacts and scores lower than midpoint are categorized as negative impacts proportionately with their difference. Another S-LCA implementation on technologic domain is conducted to compare technologies rather than products or production methods and focuses on applicability of S-LCA (Lehmann *et al.,* 2013). Indicators were mostly adapted from UNEP/SETAC guidelines and interpreted to filter relevant categories. The study points out that conducting a full life cycle social sustainability assessment for the selected case is not yet feasible for companies due to lack of data. Also, it points out that without implementation of theoretic measures, social sustainability is not possible.

Aparcana and Salhofer (2013) conducted a literature review on current S-LCA methods to create a framework. The inventory was mostly composed of semi-quantitative indicators. The study focuses on creating a framework rather than testing it. Later in 2017, another study was conducted by the same practitioners to apply their framework. Data was mostly collected via interviews. A simple binary grading system was used to transform qualitative information into quantitative data (Aparcana & Salhofer, 2017).

A study on S-LCA as a management tool by Arcese, Lucchetti and Merli (2013) applies S-LCA to tourism sector for the first time according to its claim. It uses the framework of UNEP/SETAC (2009) directly and thus, it is not used as a Reference to avoid iteration. Indicators were mostly determined via interviews to detect hot-spots of the sector. The study was conducted successfully and it claims that S-LCA can be conducted in tourism sector comprehensively by using UNEP/SETAC (2009) guidelines. The last article about S-LCA in 2013 is obtained as conference proceedings. The authors realized the gap that is left in UNEP/SETAC guidelines (2009) about impact assessment phase and suggested a method to fill this gap. For each quantitative indicator, they introduced performance reference points (PRPs) which are country-specific statistics to use as references for each indicator. The assessment is concentrated on "worker" stakeholder category (Hsu & Hu, 2013).

Considering the studies that are conducted in 2014, it is possible to state that S-LCA method that was suggested in UNEP/SETAC guidelines (2009) has reached to a certain maturity and started to be used widely. Most of the frameworks that were published in 2014 have been used to build this study's framework. To begin with, a study on application challenges of S-LCA tests its method on a holistic sustainability assessment of different fertilizer products (Martinez-blanco *et al.*, 2014). The amount of working time in each step of the production phase is used as the functional unit. The study conducts a complete S-LCA by studying all material production processes. Site specific data and generic data are used as data sources. The study points out lack of definition of social targets to base the results on. Since number of the methodological obstacles faced were too high, the study could not be completed with an interpretation phase. Although many obstacles faced, the study encourages further studies on S-LCA to reach the desired level of maturity. Another study on subcategory assessment methodology reviews studies up to UNEP/SETAC guidelines (2009) and evaluates most of them as incomplete or subjective (Petti *et al.*, 2014). The study itself aims to propose an objective method for sub-category evaluation phase of S-LCA. The paper suggests a sub-category assessment method for sub-category classification during impact assessment phase. It conducts a four-level assessment system for companies according to their promotion and fulfillment of defined basic requirements. The paper also encourages application of its own framework on various assessment studies all around the world to test it. Framework of the study is deemed original and used as a reference for this study. Lastly, a study that claims to have revisited S-LCA method is investigated among 2014 studies (Wu *et al.*, 2014). It conducts a holistic evaluation of S-LCA methodology itself to point out different methods that are utilized on each step of S-LCA. During impact characterization phase, the study classifies two approaches. First one is the bottom-up structure that depends on hierarchic summation of indicators where second one has its own definitive functions to process data coming from the indicators. Other classifications of the study are given on Figure 2.8.

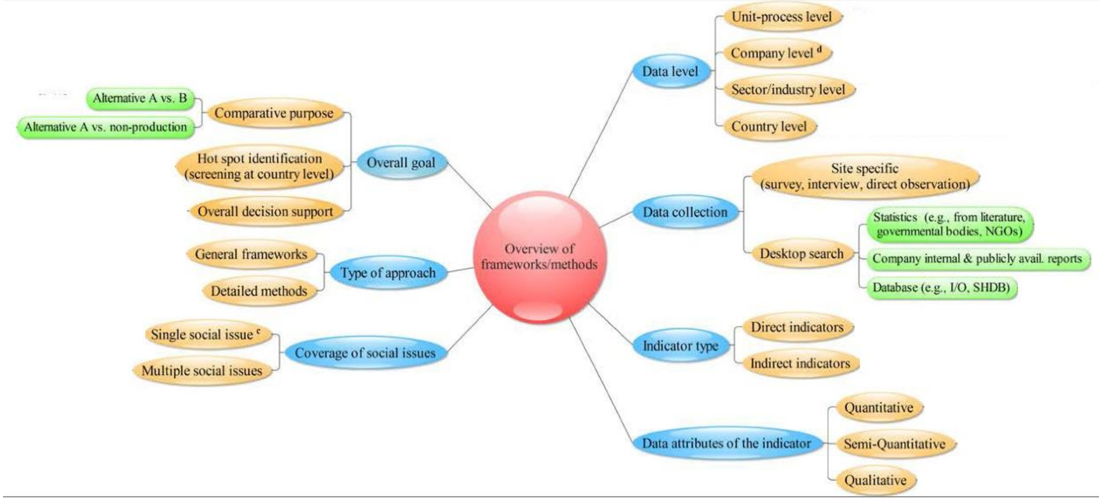


Figure 2.8 Classification scheme of S-LCA methods (Wu *et al.*, 2014)

A significant study that conducts both S-LCA and E-LCA separately in 2015 has been conducted on welding technologies (Chang *et al.*, 2015). The functional unit is defined as 1-meter weld seam. S-LCA study is focused on remuneration satisfaction of workers and potential health risks of selected welding technologies. The study aims to acquire results rather than creating and testing a framework. Thus, no suggestions or challenges about the method are included.

Another significant report of 2015 on S-LCA methodology is published by Joint Research Centre which is composed of different studies and approaches and it consists of five chapters (Sala *et al.*, 2015). The first part forms a baseline to inventory assessment, by selecting six of United Nations' 2030 sustainable development goals on social issues and two on governance of the transition towards sustainable development are selected (Figure 2.9). In this chapter, S-LCA, LCA, social impact and social benefit concepts are investigated to detect differences and similarities between them.

Figure 2.9 Selected UN 2030 sustainable development goals (Sala *et al.*, 2015)

On the second part, necessity of conducting S-LCA is questioned in business, policy making and NGO levels. Also, S-LCA examples for them are investigated. For business point of view, the argument focuses on SEEBALANCE method and its previous applications mostly. Social responsibility scheme examples are given on Table 2.1. The NGO section of the report contains a detailed list of indicators for S-LCA. Fair trade and supply chain analyses are defined as potential tools to improve S-LCA methods in business (Sala *et al.*, 2015).

Type	Examples	Pertinent to
International Policy Frameworks	The UN 'Protect, Respect, Remedy' framework Int. Labor Organization (ILO) Conventions Millenium Development Goals UN International Human Rights Treaties and Instruments	Corporations, Facilities, Governments
Principles and Codes of Conduct	UN Global Compact Own Codes of Conduct (e.g. Walmart, Ikea)	Corporations, Facilities, Governments
Sustainability Reporting Frameworks	Global Reporting Initiative UNCTAD Corporate Responsibility Indicators	Workers, Local Community, Society, Value Chain Actors
SR Implementation Guidelines	ISO 26000 OECD Guidelines for Multinational Enterprises	Corporations, Facilities, Governments
Auditing and Monitoring Framework	AIM-PROGRESS (facility level) Global Social Compliance Programme SAI/IFC PS2 (Social Accountability Int. Standard) SAI SA8000 BSCI (Business Social Compliance Init.)	Workers, Value Chain Actors
Financial Indices	FTSE4 Good Index Series (corporations and 1st tier suppliers) The Vigeo Group Sustainable Rating Indices Dow Jones Sustainability Indexes	Workers, Local Community, Society, Value Chain Actors
Methods	UNEP/SETAC methodological sheets for S-LCA of Products (relevant at Corp., Facility, Unit Process) Oxfam Poverty Footprint BASF Seebalance	Workers, Consumers, Local (and national) Community, Society, Value Chain Actors

Table 2.1 Examples of social responsibility schemes (Sala *et al.*, 2015)

Third section summarized history, present state and future expectations about S-LCA method. Also, it investigates different S-LCA studies that are conducted in different levels (micro and macro) for different products. Fourth section introduces Social Hotspot Database (SHDB) method which simply aims to provide access to best available social risk and opportunity information at the most granular level possible as well as to provide methods and tools to calculate and simplify this information down to a single grading method. Other method that is introduced in this chapter is PSILCA framework (Ciroth & Eisfeldt, 2015) that is also included among database references of this study. Last section introduces positive impacts and indicator categories in S-LCA by sharing the results of a systematic literature review. Indicator lists of various methods are broken down according to their types (i.e. descriptive, quantitative, semi-quantitative) and potentials for application of positive impact indicators are questioned (Sala *et al.*, 2015).

Finally, three significant studies that are published in 2017 are detected. First one is Aparcana & Salhofer's (2017) attempt to test their own framework on a case study which is already mentioned in previous paragraphs. Second one is another study from Jørgensen and his colleagues (2017) that questions relevance and feasibility of conducting a S-LCA study from company point of view by conducting a S-LCA study for a company through interviews. According to the results, companies mostly disagree that their social responsibility is limited with the suggested S-LCA framework which leads to question S-LCA's coverage. Also, companies mostly don't find it feasible and possible to conduct a full life cycle assessment of a product with all chain actors. The last study is an attempt to test common LCSA method on a case study about photovoltaic modules for the first time (Traverso *et al.*, 2017). Result comparisons are done in both S-LCA and LCSA levels. The study points out S-LCA indicator creation and LCSA weighting as two main challenges of the assessment.

Another significant directive was published in 2016 by Global Reporting Initiative (GRI). It is an overall impact reporting tool that covers economic, social and environmental aspects of sustainability which was designed to be used by reporting organizations. These three sustainability categories as well as general disclosure information and management approach directive are covered in different series. The standards designed to allow assessment executers to focus on a specific aspect of sustainability if they please. Each section is composed of a series of disclosures and each disclosure have three main parts. On the top, primary and secondary (if there is any) reporting requirements are defined. Recommendation section with encouraged actions follows the requirements. Lastly, guidance section with background information of the disclosure completes the section. Information in each disclosure section is used in forthcoming phases as a set of standards to create reliable surveys along with other standards. However, disclosure topics are taken as impact categories and evaluated among other sources to find out most common ones. Like ISO:26000 standards, there are no definitive stakeholder categorization. So, categorization was done using similar sources and information in disclosures.

- **Selected Studies**

Apart from the guidelines and directives, some studies were selected to shape the research structure according to their availability, compatibility and comprehensiveness. They are mostly based on at least one of the guidelines mentioned above. However, each of them are reinterpretations rather than direct appliances. Thus, they were evaluated on the same basis with the guidelines mentioned previously. Some of the studies follow a significantly different structure. In some studies, environmental indicators were introduced into the social and economic framework by including future generations as a stakeholder (Paragahawewa *et al.,* 2009; Muller & Saling, 2011). Some studies defined every detail up to indicators to measure social impacts (Ciroth & Franziska, 2015) whereas some studies only formed the basic framework up to impact categories level (Saranella *et al.,* 2015; Brent & Labuschagne 2006; Hutchins & Sutherland 2008). To create a common evaluation medium between these studies, some of them required sub-category recategorization (Paragahawewa *et al.,* 2009; UNCTAD, 2008; Brent & Labuschagne 2006) and for some of the categories were created to organize sub-categories since there were none (Manik *et al.,* 2013; Hosseinijou *et al.,* 2014; Ciroth & Franziska, 2015; Muller & Saling, 2011).

- **Additional Sources**

Other studies are mostly based on at least one of the guidelines mentioned before. However, each of them are reinterpretations rather than direct appliances. Thus, they are evaluated on the same basis with the guidelines mentioned previously. Some of the studies follow a significantly different structure. In some studies, environmental indicators are introduced to the social and economic framework by including future generations as a stakeholder (Paragahawewa *et al.,* 2009; Muller & Saling, 2011). Some studies defined every detail up to indicators to measure social impacts (Ciroth & Franziska, 2015) whereas some studies only formed the basic framework up to impact categories level (Saranella *et al.,* 2015; Brent & Labuschagne 2006; Hutchins & Sutherland 2008). To create a common evaluation medium between these studies, some of them required sub-category recategorization (Paragahawewa *et al.,* 2009;

UNCTAD, 2008; Brent & Labuschagne 2006) and for some of the categories were created to organize sub-categories since there were none (Manik *et al.,* 2013; Hosseinijou *et al.,* 2014; Ciroth & Franziska, 2015; Muller & Saling, 2011).

2.3.3. Social LCA Challenges

The biggest challenges about S-LCA are the ones that arise from its own nature. S-LCA deals with large numbers of qualitative data, since numeric information will be less capable of addressing the issues at hand. Some quantitative data on the other hand, may need to be supported with verbal interpretations. For example, minimum wages of workers in a company can be calculated and compared with others in the sector but they may need to be evaluated in the domain of living standards as well (UNEP/SETAC LCI, 2009).

On the other hand, there is not enough experience with use and implementation of S-LCA for international standardization as there is in E-LCA with ISO 14040 and 14044 (Reitinger *et al.,* 2011). Also, definition of international social targets is required to compare results to place them on a scale. Considering E-LCA methodology has reached to a maturity in almost 50 years after it was first conducted in 1960s and S-LCA methodology goes back not earlier than late 2000s, S-LCA is still under development (Paragahawewa *et al.,* 2009). These are some of the challenges of current S-LCA studies as well as one of the motivations since each research puts a building block to future S-LCA methodology (Martinez-Blanco *et al.,* 2014).

Another challenge that S-LCA method faces is its compatibility. S-LCA can be a carried out as a free-standing analysis tool or in combination with LCA and LCC. In this case, care must be taken to coordinate the key parameters with LCA and LCC (Grießhammer *et al.,* 2007). Coordination requirements are suggested in Product Sustainability Assessment Guideline (PROSA) as a checklist:

- Feedback of the initial results from one tool to the input data and assessments for the other tools. Changes required?
- Functional unit defined equivalently? Different depending on target group?

- System boundary and geographical scope defined uniformly or equivalently? Patterns of use defined uniformly?
- Dealing with different "cost bearers" in Life-Cycle Costing, but uniform "impact bearer" in Life-Cycle Assessment (namely, the environment)?
- Dealing with especially relevant qualitative results in Social LCA and less relevant but hard figures in Life-Cycle Costing?
- Are the LCA, Life-Cycle Costing and Social LCA based on significantly different data?
- Normalization to the same reference (e.g. number of products, branch of industry, whole national economy)? Fair and symmetrical overall evaluation? Fair and symmetrical communication of findings?

UNEP/SETAC LCI (2011), lists research and development areas for further development of S-LCA method in its Life Cycle Sustainability Assessment (LCSA) report as such:

- the relationship between the function and the product utility;
- methodological sheets for the stakeholder subcategories to support the inventory analysis needs;
- methods for the assessment of impacts and cause-and-effect relationships for social and socioeconomic aspects;
- areas of protection;
- scoring systems;
- review process guidance;
- communication formats and the relationship between LCC and S-LCA,

On the other hand, S-LCA results can vary according to the companies involved. This is one of the differences between S-LCA and LCA since LCA results can be standardized according to standard process data and data aggregation is possible for this reason (Dreyer *et al.*, 2006).

2.4. Life Cycle Costing

LCC basically measures the total financial cost (or benefit) of a system throughout its lifecycle (Nilsson & Bertling, 2007). LCC costs are classified as internal and external costs according to Rebitzer and Hunkeler (2003) where internal costs are the ones that occur directly within the life cycle and external financial costs (or externalities) are indirect costs that may eventually have impact on society and environment. Externalities are covered by other assessment methods but if it is observed that the taxes and subsidies within the community are fair, the assessment may be simplified by ignoring externalities and eliminating the need for other assessment methods.

LCA and LCC are not different versions of the same method. Despite the name similarity, LCC was not originated from LCA. Norris (2001) points out the differences between two methods as follows; LCA aims to measure all environmental impacts caused by all processes in the life cycle of a product whereas LCC measures direct money inflows and outflows from the decision-maker point of view. In other words, stakeholders are not necessarily affected directly from the processes in LCA and S-LCA whereas in LCC, stakeholder(s) are directly affected. Also, while functional unit of LCA can be defined by the researcher specifically for the study, LCC units are monetary units. Another important difference is that, timing of the process is crucial for LCC whereas it is traditionally ignored in LCA. Although the methods are different, employing a LCC study within LCA allows a more holistic approach to measure sustainability of a system (Rebitzer *et al.*, 2004).

Usage of LCC in building industry is quite common. Some studies were analyzed to grasp remarkable points that can be used in the LCC study. LCC method was mostly used in studies that involve green building technologies. For example, on their research, Al-Karaghouli and Kazmersk (2010) compare life cycle cost of photovoltaic systems including net present cost, initial cost and electricity cost with those of a baseline scenario with a conventional generator. While this study is only performed on economic parameters, Carter and Keeler (2008) evaluated extensive vegetated roof system in terms of life cycle cost benefits by comparing net present value of the green roof system with conventional roofing and the study supports its positive economic findings with social benefits as well. Although LCC only works with monetary units, in some studies time can be a unit of comparison as well. In the study of Leckner and Zmeureanu, (2011) life cycle cost of a NZEB with a cogeneration system was compared with a conventional house in cold climate by using payback time as the comparison unit to see feasibility of NZEB. The assessment is reperformed to employ a solar cogeneration system but due to high local initial cost, payback time was calculated to be much higher than acceptable levels. In such a study where a single design option is compared with the baseline scenario, there is a need to set a time limit to define the acceptable interval. In this research however, comparison is principle and there is no need to define a payback time limit.

2.5. Summary and Highlights of the Literature Review

The research was substantially shaped by literature review. For this reason, literature inferences are regarded as one of the result topics of this study. This section summarizes chapter 2 and detects the hotspots in the literature.

It was learned from literature review that due to recent energy crisis, sustainability concept gained importance in the last few decades globally. Considering that sustainability concept gained importance due to energy cost, financial pressures, resource conservation and worldwide ecologic awareness, modern sustainable architecture measures tend to focus on economic and ecologic areas whereas vernacular architecture employed a holistic sustainability approach depending on the context. On the other hand, sustainability measurement tools have reduced complex environmental complications to measurable frameworks but while doing so, scope of sustainability have been reduced unilaterally to environmental sustainability.

Social, economic and cultural aspects of sustainability have been attached to environmental sustainability development tools as further verbal evaluation parameters. However, they are not adapted into the framework. Also, it was observed that ecologic and economic parameters of sustainability show consistency from study to study whereas social measures differ due to lack of standardization.

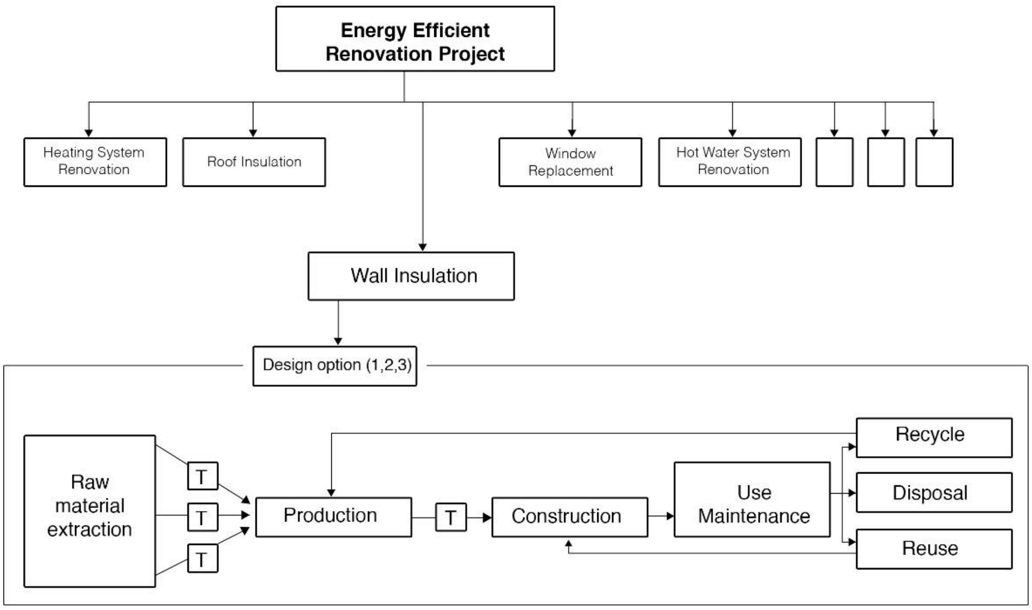
Social sustainability parameters appear in early sustainability schemes as specific parameters to the study. Intersections between scopes of different social sustainability assessment studies increase as the time progresses. As the studies increase and methodology develops, new features are added to the framework like multiple stakeholder categories, normalization attempts and adaptation with other assessment topics (environmental and economic).

There are some major guidelines that shaped the current S-LCA methodology which are PROSA (2007), SEEBALANCE (2008), UNEP/SETAC (2009) and ISO 26000 (2010). However, the literature lacks standardization on S-LCA indicators and recent studies tend to include a literature review of older dissertations to build the framework. All these studies should be used as a reference to create complete sets of S-LCA parameters for various products and services by a group of qualified professionals of that industry.

CHAPTER 3

MATERIALS AND METHODS

This multi-layered study aims to suggest a holistic approach for sustainable building material selection process. Since the study's origin was energy efficiency in buildings, the assessment method was tested on a pilot thermo-modernization project in Turkey. Research structure and methodology on assessment of efficiency in terms of sustainable thermo-modernization is suggested as a whole process including each thermo-modernization step that is defined in Energy Performance in Buildings Regulation (2008) (Figure 3.1). Scope of this study is limited with insulation material selection only. Baseline methodology of this research can be applied on other areas of energy efficient renovation projects as a product comparison study.



T: Transportation

Figure 3.1 Sustainability assessment scope of the study

The assessment method is composed of three phases based on three pillar sustainability approach that was derived from literature review. The focus of the study is to create a holistic comparison method to assess social, environmental and economic aspects of sustainability assessment all together to detect and eliminate data overlaps, suggest an efficient method for data transfer and test this method on a certain scope of thermo-modernization process to see its applicability. Furthermore, the research also places emphasis on social sustainability assessment since among all three pillars of sustainability assessments, it is the most immature one that needs research for further development.

3.1. Methods

In this section, research methods are explained in detail.

Overall sustainability assessment aims to conduct LCA, S-LCA and LCC studies one by one to obtain a simplified impact score from each assessment step that can be combined and interpreted all together. In order to form a data source for the assessment process, building information model (BIM) of the related building should be created. BIM is utilized because it can store all quantity data of the building materials of all phases of the construction as well as different design scenarios that are created for comparison.

Each assessment step begins by defining goal and scope as it is required in ISO 14040 and 14044 standards for LCA. After the goal and scope are defined, the methodological structure is shaped according to the scope of assessment. First of all, there are some key points that must be defined in the beginning of the overall assessment,

- Product utility
- Difference between design options
- Functional unit

First of all, it is important to state the approach of the sustainability assessment. Different assessment structures were examined especially for S-LCA in the literature review section. Sustainability assessment can be conducted with a benefit-impact comparison approach as it was exemplified in Prosa Guidelines (Grießhammer *et al.,* 2007). This method compares social, economic and ecologic benefits of the related product with their impacts on the same chart to draw a gain-loss profile. The method also suggests an alternative approach to the conventional LCA method. However, this method is based on the conventional LCA method for all assessment topics as they were exemplified in UNEP/SETAC Life Cycle Initiative guidelines (2011). In this approach, a product utility is defined that is based on the main function of the product. Utility definition is used to determine a functional unit on the following steps.

Secondly, differences and similarities between different design options have to be stated. Since the method is suggested as a comparative approach between different options, there is no need to calculate the impacts of same applications for each design option. In a BIM software, only differing elements should be connected to design options whereas other elements should be kept out of the scope. If a CAD software is used and quantities are calculated manually, only quantities that vary from option to option should be included. For example, if different heating systems are being compared, all of their related products that are specific to that system should be included and the rest should be excluded. If a ventilation duct for a heating system option cannot be used for the other systems, duct materials should be included and subtracted materials on the building to install the ducts should be calculated. Similarly, if different insulation materials are applied with same details, other common layers of the surface can be excluded.

Finally, a functional unit should be defined related to the product utility. Functional unit can be a quantity related to the major function of the product. For instance; for structural material options, it can be the material quantity to obtain the same shear strength value on a certain spot for each option. Design parameters like ceiling height or aesthetics are kept out of scope since they are not related with sustainability parameters of this study. Functional unit should be related to a practical function because the results should be understood by decision makers. An assessment based on a unit quantity of a product regardless of its function can be represented and used as a research finding but cannot be interpreted by the decision makers.

Overall flowchart of the study is given on Figure 3.2. The flowchart was created for insulation materials as a baseline model that can be modified according to different building materials. Process No 1: Building Energy Simulation is the specific process of this study that is required to calculate the functional unit. According to the functional unit definition, the process should be redefined. Other steps are common for all building material assessments.

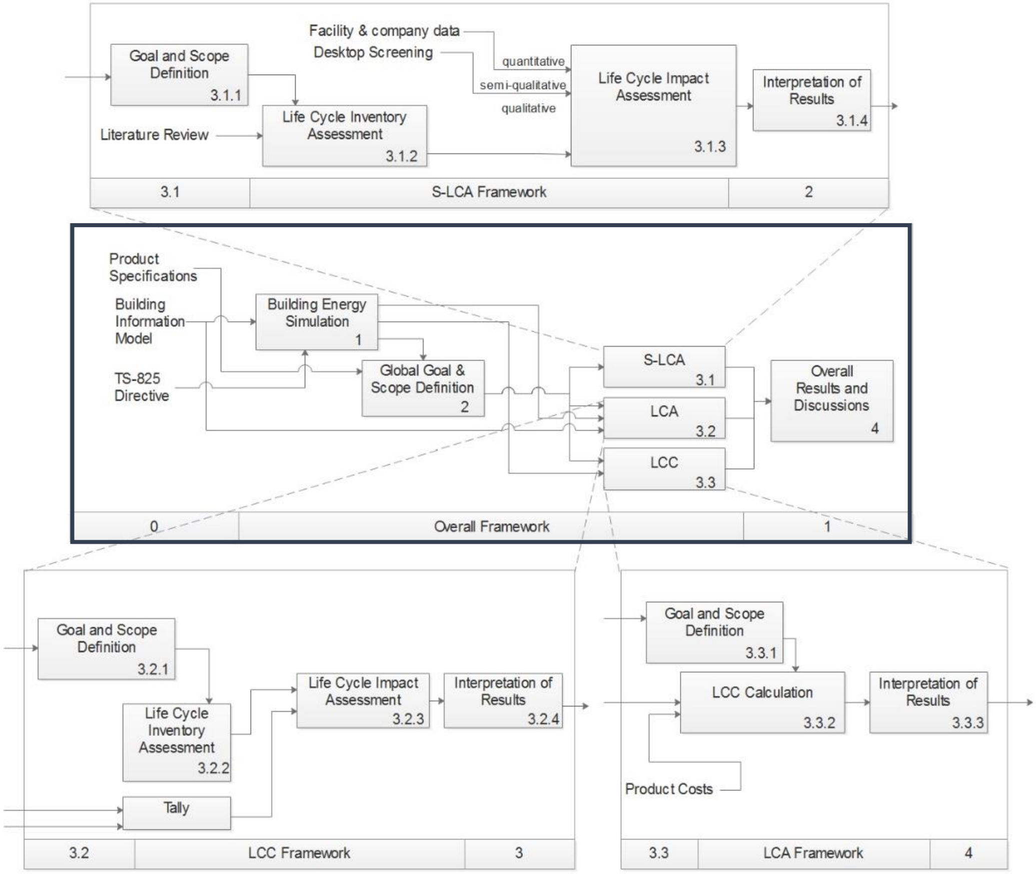


Figure 3.2 General flowchart of the study

The E-LCA (No 3.1) process is conducted with a software called Tally which is a plugin of Revit. Other steps are formed according to ISO 14040 standards. On process number 3.2.3., impact assessment of product materials is performed by using existing LCA databases. On this step, a national database is recommended for reliable results. If the database does not exist for that country, most widely used databases are utilized. Tally uses GaBi database from Thinkstep a.g. which is one of the most commonly used databases. Thus, Tally is utilized for LCA.

S-LCA method is constructed on conventional LCA approach. Database for S-LCA impact categories is created in this study to allow utilization for other studies with different scopes. Impact categories and indicators are defined by using existing S-LCA studies. Measurement parameters, on the other hand, are defined for the case study in the Materials section. These parameters should be developed for each study via literature review and expert revision.

LCC method is based on cost implications that are related to the decision-making body. A gain-loss calculation is conducted within the goal and scope definitions. For this reason, product quantity for the same amount of financial gain cannot be a functional unit of the overall assessment.

Processes 3.1, 3.2 and 3.3 should return a single score evaluation result for each design option. If the assessment is based on a single impact category (i.e. price), the singular result can be utilized directly. However, if the assessment study contains more than one impact categories (i.e. environmental impacts), various impacts within each assessment study should be summed up individually. For this summation, firstly, a normalization process must be conducted to re-distribute the results on a common scale with same boundaries and secondly, a weighting process must be conducted to sum up impact values according to their weights. Figure 3.3 shows a schematic representation of how raw numeric data is placed on a single graph after normalization and how these values change after multiplication with their own weighting factors. Details of this schematic representation are explained in following pages. After single-score results are obtained, they are interpreted and used for decision-making.

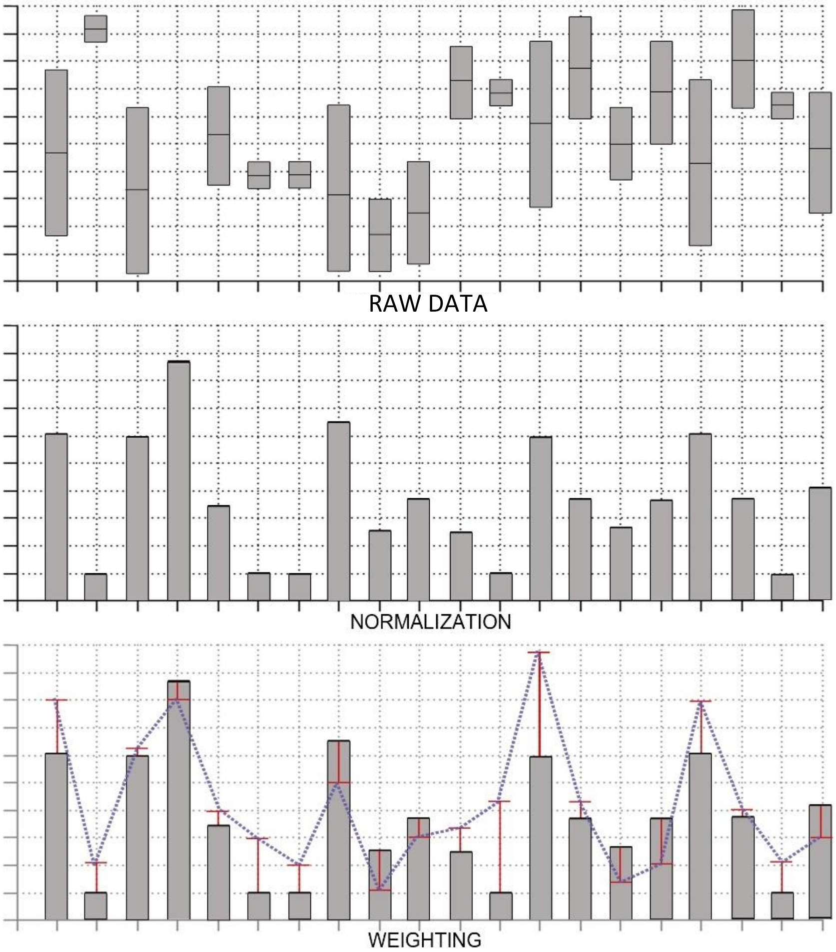


Figure 3.3. Schematic representation of normalization and weighting processes

3.1.1. Building Energy Demand Calculation

This step of the study is based on the product utility definition. The aim is to define a functional unit that can be used for sustainability assessment phases. Case study is conducted on insulation material comparison and product utility and functional unit definitions are done in the materials chapter. Thus, this section aims to reveal the calculation method of the functional unit. For a different case study on a different subject, (i.e. window selection, water storage tank selection, structural material selection, etc.) this section must be re-created according to the product utility.

Insulation materials are applied to minimize the heat loss of a building. Division of their thermal transmittance coefficient to their thickness returns their thermal transmittance index value. Thus, different insulation materials with different thermal transmittance coefficients can provide same amount of thermal resistance with proper thicknesses. For this study, same amount of heating demand is obtained by using proper thicknesses of insulation materials. Calculation steps are explained in following paragraphs according to TS 825 standards for Turkey.

First of all, total u values (thermal transmittance index) of each building element that form the building envelope must be calculated. Building envelope includes all insulated surfaces between insulated volumes and outdoors or uninsulated volumes like storage areas, technical rooms, unoccupied roof volumes, etc. U value is the reciprocal of R value (thermal transmittance resistance index). To calculate R value, thermal transmittance coefficient (λ) and material thickness (d) is used as shown in Equation 3.1. Relation between R and u values are shown in Equation 3.2.

$$R = \frac{d}{\lambda}$$ Equation 3.1

$$u = \frac{1}{\mathrm{R}}$$ Equation 3.2

U value of each building element of the building envelope must be calculated to proceed to the next step. By using λ values and thicknesses of each layer of a building element as well as inside and outside surface pre-calculated heat transmittance resistance values that were obtained from TS 825 standards' page 8 (2008), total heat transmittance index (u value) of building envelope is calculated by using Equations 3.3 and 3.4.

$$U = 1/ (R_i+R+R_e)$$ Equation 3.3

$$R = (d_1/ \lambda_1) + (d_2/ \lambda_2) + \ldots + (d_n/ \lambda_n)$$ Equation 3.4

After u values are calculated ($W/m^2.K$), they are used for the calculation of their heat losses. For heat loss calculation, Equation 3.5 is used where q is heat flow density (W/m^2), and θ_i and θe are interior and exterior temperatures (°C) respectively.

$$q = U \times (\theta_i - \theta e)$$ Equation 3.5

In a properly insulated building, this heat loss is compensated partly by solar heat gain, indoor appliances and indoor activities. Remaining part of the heat loss is compensated by the heating system actively. By calculating these heat losses and gains, required active heating energy demand can be calculated. Since outdoor temperature and solar gain potential varies throughout the year, heating demand is calculated monthly. These monthly values are summed up afterwards to find the yearly demand. Monthly heating demand is calculated by using Equation 3.6 in Joule where H is the specific heath loss of the building that is calculated by using Equation 3.7, Q_i and Q_e are interior and exterior monthly average temperatures in °C, μ is the monthly utilization factor for interior heath gains, φ_i and φ_s are interior and solar heath gains in Watts (W), and t is duration of a month in seconds. On Equation 3.7, H_T and H_v are heat loss via transmittance and heat loss via ventilation respectively. Transmittance heat loss is calculated by multiplying each surface's thermal transmittance index (u) and area in the building envelope separately and summing the results. Calculation specifications about each variable are explained in TS 825 (2008) standards.

$$Q_{month} = [\, H(Q_i - Q_e) - \mu_{month}(\varphi_i + \varphi_s)] \times t \qquad \text{Equation 3.6}$$

$$H = H_T + H_v \qquad \text{Equation 3.7}$$

A parametric calculation table using these formulas and specifications must be created since insulation material selection is performed at the beginning of the whole calculation process. Thus, only changing the related λ value of the insulation material, the results can be obtained immediately. The resulting yearly energy demand must be lower than the maximum allowance in TS 825 standards. In this case, the minimum required insulation material thickness for design options should be determined.

According to ISO14044 (2006); a functional unit must be defined for a LCA study. While each sustainability assessment has its own method and scope definition, a common functional unit was defined to ensure compatibility among different assessment results. Thus, functional unit is defined as the optimum material quantity that provides the same amount of thermal insulation quality.

3.1.2. E-LCA Structure

Sustainability assessment steps are based on conventional LCA methodology. For this reason, general framework of the study is designed to allow necessary data inputs and outputs flow throughout the system. Required inputs for LCA are material quantities according to functional unit definition and all related specifications about production, usage and disposal phases of the product from related environmental product declarations (EPD). This study does not aim to apply the existing LCA method directly but rather, to modify it to fit the holistic assessment framework. Thus, LCA process in this study is performed via Tally software. Predefined product specifications were utilized and transportation distances were entered manually according to the production flowchart of the products.

The first step of a LCA assessment is to define goal and scope of the assessment. According to the defined scope, LCA is performed in a conventional way for related products within the given life cycle scope. Scope definition should be given with the reasons as well. The goal definition should specify the format of the output from this study. In order to use the results in the holistic assessment framework, a single score result should be obtained. In other words, different results from various impact categories should be simplified to a single comparable result. These extra steps which are classified as “optional” in ISO 14042 directive (2000) for conventional LCA framework, are necessary for the holistic assessment. Normalization and weighting details are explained in following pages.

LCA assessment is performed with Revit’s Tally plugin but it can be performed via an alternative method or software by using same databases. Life cycle inventory assessment data comes from EPD documents of related products. Tally’s inventory data had been created via collaboration of Kieran Timberlake and Thinkstep. For impact assessment, Tally uses GaBi database along with GaBi 6 software. Life cycle impact categories in Tally database had been selected and described according to TRACI 2.1 characterization scheme (Bare, 2012; Guinée et al., 2001; Wildnauer, 2013). Impact category selection, category classification, and category definition steps were automatically performed within Tally software. Impact categories within Tally framework and their brief definitions are defined as such:

Acidification Potential (AP) - kg SO_2 eq

Acidification potential is a measure of a molecule's capacity to increase hydrogen ion (H+) concentration in the presence of water, thus decreasing the PH value. This acidification process can result with fish mortality, forest decline and deterioration of building materials. It is measured as SO_2 equivalent.

Eutrophication Potential (EP) - kg N eq

Eutrophication impact results from excessive amounts of macronutrients including nitrogen (N) and phosphorus (P). Increase in nutrients may cause an undesirable shift in species composition and increased biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, this impact leads to depressed oxygen levels resulting from extra consumption of oxygen in biomass decomposition.

Global Warming Potential (GWP) - kg CO_2 eq

Greenhouse gasses like carbon dioxide and methane cause increase in the absorption of radiation emitted by the earth, which leads to increased greenhouse effect. This may have significant negative effects on ecosystem health, human health and material welfare.

Ozone Depletion Potential (ODP) kg - CFC-11 eq

This impact category is a measure of air emissions that contribute to the depletion of stratospheric ozone layer which leads to higher levels of ultraviolet rays reaching the earth’s surface. Increase in these rays causes negative effects on human health and planet health.

Smog Formation Potential (SFP) - kg O_3 eq

Ground level ozone is created by various chemical reactions that occur between volatile organic compounds (VOCs) and nitrogen oxides (NOx) in sunlight. Prolonged exposure to ozone causes many health risks for humans including respiratory issues, bronchitis, asthma, emphysema and ecological damages like crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities and industrial facilities.

Primary Energy Demand (PED) - MJ

This indicator measures the total amount of primary energy that is extracted from the earth. It is expressed in energy demand from non-renewable sources (petroleum, natural gas, etc.) and renewable sources (hydropower, wind energy, solar, etc.) Results of the measurements on renewable and non-renewable.

Although these impact categories are classified automatically, it is suggested to investigate similar studies in the literature to understand main reasons behind impact potentials. An example literature review for LCA impact categories was conducted in the Materials section.

To render comparison of categories possible, each impact data needs to be demonstrated in a chart with a common unit. Normalization operation was applied for this reason. Normalization provides a ratio of each impact data to a reference country's related total impact. Total impact per capita was also used for normalization. This reference country data is called "normalization factor". Preferably, normalization factors are acquired from local data where assessment takes place. Although there have been some attempts to create such a database for Turkey, (Öztaş & Tanaçan, 2015) there is not sufficient data for each impact category. For this reason, TRACI 2.1 database that has been used for impact assessment was used for normalization as well. Values that were used in this normalization process are reference values of US-Canada for 2008 (Table 3.1)

After normalization, weighting should be performed to compare impact values among themselves and come up with a single environmental impact score for each material. Weighting values are available for Turkey in YDED-TR model (Öztaş & Tanaçan, 2015). Normalization and weighting values are given on Table 3.1. Normalization and weighting should be performed by using Equation 3.8 where each impact potential value (IP) was divided to related normalization factor (NF), multiplied with related weighting factor (W) and summed up for each material to eventually obtain total impact value (TIV). In this equation, i set is composed of product options which are rock wool (1), glass wool (2) and XPS (3) for this study and j set is composed of impact categories which are AP (1), EP (2), GWP (3), ODP (4) and SFP (5).

$$\mathrm{TIV}_k = \sum_{1}^{5} \frac{IP_{ij} \times W_j}{NF_j} \qquad \begin{matrix}(i=1,2,3)\\(j=1,2,3,4,5)\end{matrix} \qquad \text{Equation 3.8}$$

Table 3.1. Suggested weighting and normalization values

Weighting	0,03	0,05	0,15	0,03	0,03
Normalization Factor (TRACI 2.1, US-CA 2008 - per capita)	94,60	20,4	24000	0,146	1450
Abbreviation	AP	EP	GWP	ODP	SFP
Impact Category	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Depletion Potential**	**Smog Formation Potential**

If a whole building assessment will be performed, results should be calculated for each building material independently. Then, results should be multiplied according to the functional unit. In this case, functional unit is based on kilograms. So, materials should be multiplied with their mass quantities and summed up afterwards to compare building design options. In this study, LCA is focused on thermal insulation materials only.

3.1.3. S-LCA Structure

S-LCA evaluation structure was mainly derived from Guidelines for Social Life Cycle Assessment of Products (2009) directive of UNEP & SETAC and ISO 14040 framework for E-LCA with some adaptations. UNEP & SETAC (2009) directive is also an adapted form of current environmental life cycle assessment tools namely: ISO 14040: principles and framework and ISO 14044: requirements and guidelines to social aspects.

The directive itself claims that the maturity of the suggested methodology is open for improvement. Significantly, working category and inventory parts need further development. For working categories, stakeholder approach should be included along with worker, consumer, local community, society and value chain actor categories. Similarly, a further research on inventory categories and sub categories is required to determine the significance and weight values of each of them.

Finally, the directive suggests conducting a case study that include S-LCA, E-LCA and LCC for a greater understanding of the linkages among the methodologies. Such a research would build the basis for an integrated approach and during these studies, potential overlaps must be identified (UNEP & SETAC, 2009). This statement is one of the main motivations behind this study.

It is important to underline that S-LCA framework in this study is created universally. The framework can be utilized for different geographical specifications. However, indicator items and evaluation parameters in the Materials section are prepared specifically for Turkey. For this reason, when this study is reperformed for a different location and different scope, steps in the Materials section must be performed from the beginning. S-LCA steps in the Materials section are performed to show example utilization of the method.

As it is defined by UNEP & SETAC (2009), S-LCA methodology was carried out in four phases: (i) goal and scope of the study; (ii) inventory; (iii) impact assessment; and (iv) interpretation.

- **Goal and Scope Definition**

This section aims to define the goal and scope of social impact comparison of selected design options. This chapter of the study includes description of functional unit, product utilities, stakeholders that are concerned and specific boundaries. Step-by-step, the research aims to answer these questions:

- How the process should be carried out to determine impact categories, stakeholders, assessment criteria and eventually indicators for the assessment?
- How these impact categories relate to and effect different stakeholders?

- What is possible further research fields concerning assessment studies building materials?

According to ISO 14044 (2006); product utility must be defined within the scope of the study and functional unit is a requirement. Product utility is defined as the role that the product plays for its customers (UNEP, 2009). In this chapter, the assessment is focused on social impacts of processes which are irrelevant to a determined functional unit or quantity (Manik *et al.,* 2013). S-LCA data is mostly qualitative and it is difficult to relate the results specifically to functional unit (UNEP, 2009). For this reason, a functional unit was not used during the assessment of each building material but general functional unit that is defined in general definitions chapter was used to compare assessment results of different building materials. If there are more than one building elements, impacts should be multiplied with mass percentages of each of them since functional unit is kilograms. Also, if the assessment is conducted on raw materials that compose the product, raw material mass percentages should be used similarly to calculate the total impact of them.

E-LCA framework depends on material quantities whereas S-LCA method has little dependency on them. Rather, S-LCA is concerned about people who are involved in each step of the life cycle. These different groups of people are called stakeholders which create the backbone of the study. According to UNEP (2011), these stakeholders can be workers/employees, local community, national or global society, consumers, value chain actors, NGOs, public authorities, future generations, *etc.* This scheme was defined in a different way in ISO 26000 directive (2010) as society, company and other stakeholders (Figure 3.5). According to this scheme, organization has an impact on the society according to its expectations from the company and stakeholders according to their interests. Unsatisfaction of these interests and expectations result in negative impacts to each. While these are the most frequently used stakeholders for any S-LCA study, some new stakeholders can be added if they play a significant role in the life cycle of a product. In the end, assessment is focused on company's activities.

Figure 3.4 An organization’s social responsibility to different stakeholders (ISO 26000: 2010)

To define the stakeholders in a reliable way, Former studies and directives were analyzed in the literature. 16 sources were analyzed in total and although some similarities, framework is different in each of them. These sources include directives of UNEP (United Nations Environment Programme), SETAC (Society of Environmental Toxicology and Chemistry), ISO (International Organization of Standardization) and GRI (Global Reporting Initiative) and their suggested framework, stakeholders and inventories as well as some sample researches from literature. To find sample researches, a systematic literature review was conducted in chapter 2 and studies were selected from approximately 50 similar studies in the literature according to their framework compatibility to the utilized system. Firstly, researches with available databases are selected and others are eliminated. Secondly, studies that utilize stakeholder method are selected and other methods that cannot be evaluated in this framework are eliminated. From selected studies, those who utilized less than three stakeholder categories are also eliminated because the suggested method does not focus on a certain stakeholder category.

Stakeholder lists of each source were collected on an excel table to see the most frequently included stakeholders (Table 3.2). Only sources that include at least three different stakeholder groups were included since some studies are only focused on one stakeholder group. During this evaluation, research studies and directive inventories were evaluated as the same. Still, directives are underlined on the table.

Table 3.2 Inclusion of stakeholders in selected sources

STAKEHOLDER	Grießhammer et al., 2007	UNEP/SETAC, 2009	UNCTAD, 2008	Paragahawewa et al., 2009	Reitinger et al., 2011	GRI, 2016	ISO, 2010	Hosseinijou et al., 2014	Muller & Saling, 2011	Ciroth & Franziska, 2015	Hutchins & Sutherland 2008	Saranella et al., 2015	Brent & Labuschagne 2006	Manik et al., 2013	Azapagic, 2002	Ciroth & Franze, 2011	Foolmaun & Ramjeeawon, 2013	Martínez-blanco et al., 2014	Petti, et al., 2014	TOTAL	Normalized	weight
Employees/Workers	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	19	1	0,3
Local/Regional Community(s)	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	18	0,9	0,2
Society/National Community	●	●	●	●	○	●	○	●	●	●	●	●	●	●	●	●	●	●	●	17	0,9	0,2
Users/Consumers	●	●	○	●	●	○	○	○	●	●	○	○	○	●	●	●	○	●	●	11	0,6	0,1
Supply Chain Actors	○	●	○	○	○	●	●	●	○	●	○	○	○	●	●	●	○	○	●	9	0,5	0,1
Future Generations	○	○	○	●	○	○	●	○	●	○	○	○	○	○	○	○	○	○	○	3	0,2	
Company	○	○	○	●	○	●	●	○	○	○	○	○	○	○	○	○	○	○	○	3	0,2	

According to evaluated sources, workers, local community and society are by far the most commonly used stakeholders. Consumers and value chain actors (except consumers) are following them. Future generations and company executives are the least used ones in S-LCA studies. Upon further analyzing these stakeholder bodies, an obvious reason behind the unpopularity of them was realized. Future generations are mostly related with environmental impact categories like resource and energy use, renewable energy percentage, toxicity potential, biodiversity, *etc.* To eliminate intersection between different assessment studies in this research, these categories should be subtracted. Besides, future generations are included in studies where S-LCA is performed solitarily without other assessments. On the other hand, company stakeholder category is mostly related with economic categories like company stability and investment profitability as well as some important social categories like executive-worker relations, fair salary, *etc.* However, in some studies that are assessed, these economic categories are excluded and relevant social categories are evaluated with different stakeholders. Thus, apart from being the least common ones, future generations and company stakeholders are kept out of the scope because of their content.

To set a limit to the scope of the stakeholders, the original sequence of numbers on the table were normalized to determine the location of the boundary line. Since the aim was to select values with higher numbers, the values were normalized as shown in Equation 3.9.

$$Xs_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \qquad (i = 1,2, \ldots n) \qquad \text{Equation 3.9}$$

Where Xs_i refers to normalized (standardized) value, of i[th] index, X_i is the calculated value of the stakeholder, x_{max} equals 16, x_{min} equals 0 and n equals 7 as there are 7 stakeholders. According to this calculation, normalized values of the stakeholders are shown in the Table 3.2. Median point is set as limit which equals to 0,5 and rounded values equal to and greater than 0,5 are selected. Exact value of the limit value is 0,47. According to the table, the stakeholders are defined in the scope of workers, local communities, society, consumers and supply chain actors.

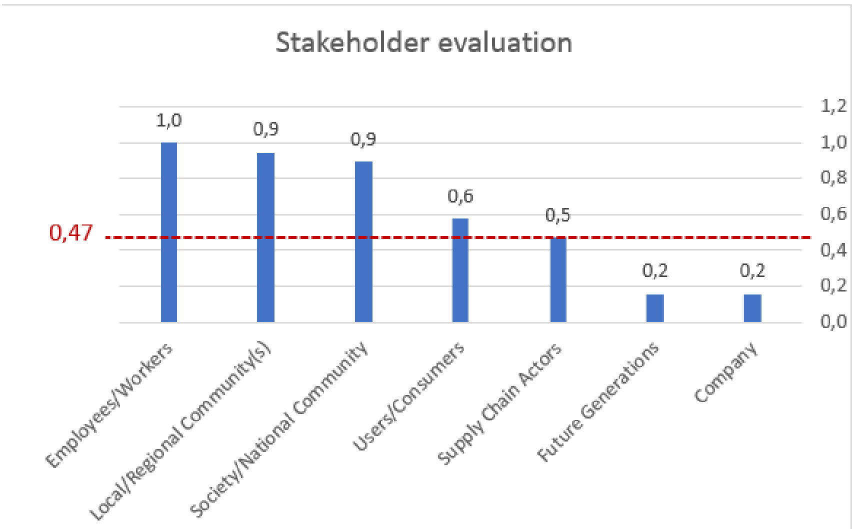


Figure 3.5 Weights of stakeholder categories according to literature review

From normalized scores of selected 5 stakeholder categories, weighing scores are calculated using Equation 3.10 where X_w is the weight of the stakeholder element and m is the total number of selected stakeholders which equals to 5 in this case Rounded results are available on Table 3.2.

$$Xw_i = \frac{Xs_i}{\sum_1^m Xs_i} \qquad (i = 1,2, \dots n) \qquad \text{Equation 3.10}$$

Scope of the method covers all the production phases of insulation materials related with selected insulation materials. As it was mentioned with the reasons in previous sections, the framework is limited with cradle-to-gate scope of thermal insulation material supply chain that covers all phases of raw material supply, thermal insulation module production and transportation processes. Another framework within this scope is defined for the test study in results & discussions section. System boundary is defined by this cradle-to-gate process as well as five selected stakeholders and impact categories that are defined in the next section.

- **Life Cycle Inventory Assessment**

This phase of the study is where assessment structure is built by defining impact categories, sub-categories and indicators. Consequently, boundaries of the assessment scope became clearer with definition of stakeholders, impact categories and system boundaries. It is essential to state that since all these elements should be redefined in each study, final results would be different if this research was reconducted by different bodies with different scope definitions. Thus, creating the assessment structure is regarded to be more crucial than gathering final data results and assessment structure was defined in a systematic way to eliminate objective judgements as much as possible.

Social lifecycle assessment covers all the steps in the lifecycle of a product within the given scope according to the defined workflow. Within these steps, all impact categories including health and safety of different parties, human rights, social security, contribution to national economy and technology and fair trade were assessed in relation with the definition of involved stakeholders on previous section. Afterwards, impact categories were further divided into indicators for evaluation. Most of the indicators were composed of qualitative data that needed to be converted into quantitative.

- **System Boundaries**

There are two main aggregation (data collection) phase in S-LCA. First one was conducted in life cycle inventory phase where all elements of the assessment are collected from the specific indicators to larger categories with respect to unit process locations as well (UNEP & SETAC, 2009). The other aggregation process was conducted in impact assessment phase. Literature was the main source of aggregation for this study. Literature database that have been used to define stakeholders were further analyzed to harvest information about the research structure of each study. The hierarchical process of the assessment was shown in Figure 3.6 from UNEP & SETAC (2009) S-LCA guidelines. It was realized that more recent studies that are published from 2013 up to today does not follow UNEP & SETAC (2009) hierarchy order of stakeholder, category, sub category, indicator. Sub-categories are generally taken as main impact categories and they were not categorized once more. This approach is also applied in this study. Thus, all these impact categories were collected under selected stakeholder categories and divided into indicators that were defined in some of the examined sources. Each item in all levels of the assessment system was gathered from literature

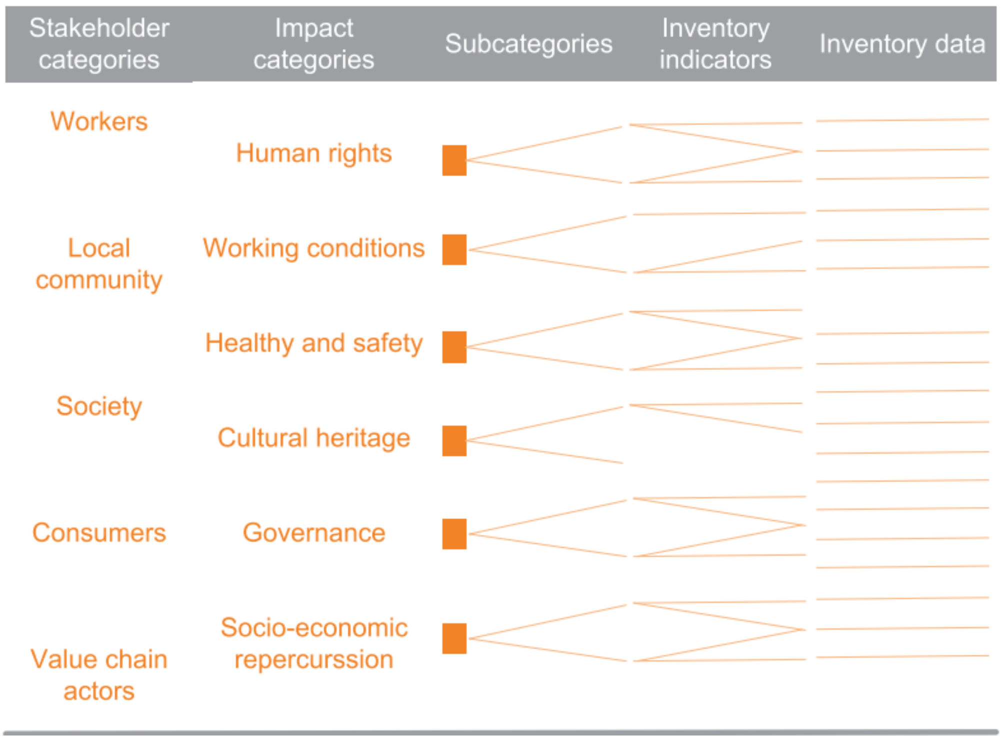


Figure 3.6 Hierarchic system of S-LCA (UNEP/SETAC, 2009)

- **Impact Category Definition**

Considering these specific points about these reference studies, a table for each selected stakeholder group was created including impact categories, their definitions and their weighting values. Similar to stakeholder evaluation in previous section, impact categories were evaluated according to their occurrence rate in different studies and normalized scores were used to set a limit to the impact category list. To do that, same normalization formula (Equation 3.9) and weighting formula (Equation 3.10) were applied to total impact category occurrence rates. Again, values equal to or greater than 0,5 were selected to ensure that category occurs in most of the mentioned studies. So that, case specific impact category elements were filtered out. Lower limit can be increased or decreased to redefine the scope for another study. In such a case, weight values must be recalculated.

In following chapters of inventory creation phase; specifications and scope definitions of stakeholders; selection criteria, general definitions and weightings of impact categories, their selection criteria, detailed descriptions, data sources and types of indicators were explained. Similar impact categories were merged together to prevent them from lowering each other's weighting scores. Eliminated impact categories are also given on related tables. It is important to note that S-LCA is an iterative process (UNEP/ SETAC, 2009). Thus, following tables and specifications in this chapter were not created in given order but developed parallelly by feeding each other.

Workers (Employees)

In every given social sustainability assessment study reference, either "workers" or "employees" was included as a stakeholder party. However, its definition is considerably flexible since worker/employee refers to different parties depending on the location of the assessment (office, factory, construction site, *etc.*). For this study, this stakeholder category only covers “workers” that are involved in the “production phase” of the product within the cradle-to-gate scope. In other words, workers were limited with the production facility borders. Workers that are involved in the raw material extraction and disposal phases were not covered. Also, construction workers who apply the sheathing are covered in “user” category to an extend since they are a part of downstream process.

Selected impact categories for workers are given on Table 3.3. According to the filtering rule, first 7 impact categories were selected for the study and they were interpreted to determine evaluation criteria. Apart from specific information that are obtained for each indicator, following information were to be obtained from companies for general evaluation on this stakeholder category: (UNEP & SETAC,2009; GRI, 2016)

- Total number of workers in the factory.
- Total number of workers with a working contract
- Types of workers
- Average weekly working hours
- Total number of workers by gender.

Apart from factory data, these impact categories require data from worker surveys and executive interviews.

Table 3.3 Inclusion of “worker” impact categories in selected sources

1.Employees-Workers	Grießhammer et al, 2007	UNEP/SETAC, 2009	UNCTAD, 2008	Paragahawewa et al, 2009	Reitinger et al, 2011	GRI, 2016	ISO, 2010	Hosseinijou et al, 2014	Dasmohapatra, 2012	Muller & Saling, 2011	Ciroth & Franziska, 2015	Hutchins & Sutherland 2008	Saranella et al, 2015	Brent & Labuschagne 2006	Manik et al, 2013	Azapagic, 2002	TOTAL	Normalized	weight
Health and Safety in work	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	16	**1**	0,2
Equality of opportunity and treatment & fair interaction / No discrimination	●	●	●	●	●	○	●	●	●	●	●	●	●	○	●	●	14	**0,875**	0,175
Adequate remuneration	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●	○	12	**0,75**	0,15
Abolition of forced labour	●	●	○	●	●	○	●	●	○	●	○	○	●	○	●	●	10	**0,625**	0,125
Social Security	●	●	●	○	●	○	○	○	●	●	○	●	●	●	●	○	10	**0,625**	0,125
Abolition of child labour	●	●	○	○	●	○	●	●	●	●	○	○	●	○	○	●	9	**0,563**	0,113
Freedom of association, collective bargaining & workers' participation	●	●	○	○	●	○	●	●	○	●	○	○	●	○	●	●	9	**0,563**	0,113
Adequate working time	●	●	○	●	○	○	○	●	○	●	○	○	●	○	●	○	7	0,438	
Training and Education	○	○	●	○	●	○	○	○	●	○	○	○	○	●	○	●	5	0,313	
Human rights	●	○	○	○	●	●	○	○	○	○	○	○	○	○	○	●	4	0,25	
Job satisfaction	●	○	○	○	○	○	○	○	●	○	○	○	○	○	○	●	3	0,188	
Employee social benefits	○	○	○	○	○	○	○	●	○	●	○	○	○	○	○	○	2	0,125	
Labour Practices / Company Communication	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	1	0,063	
Employee Influence on company	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	1	0,063	

Local Community

Local community contains people who live or work in any areas (close or distant but affected) that are socially impacted by the organization's operations. Local community scope was defined with respect to lifecycle flowchart of each product. Production locations are taken as the local area of assessment. Local community assessment measures if organization's activities restrict basic indigenous rights or freedoms of the local community (access to resources, delocalization, safety, health) or introduce a social value to it (community engagement, employment, investment) (Ciroth & Eisfeldt, 2015). Also; according to ISO 26000 (2010) directive, a company should contribute in development of innovative technologies to help social and environmental issues of the community.

Impact categories that may affect local community are given on Table 3.4. After filtering, 5 impact categories were selected among them. Data was mostly obtained in the form of facility information and executive interviews. Then, they may be supported via desktop screening.

Table 3.4 Inclusion of “local community” impact categories in selected sources

2.Local Community	Grießhammer et al, 2007	UNEP/SETAC, 2009	UNCTAD, 2008	Paragahawewa et al, 2009	Reitinger et al, 2011	GRI, 2016	ISO, 2010	Hosseinijou et al, 2014	Dasmohapatra, 2012	Muller & Saling, 2011	Ciroth & Franziska, 2015	Hutchins & Sutherland 2008	Saranella et al, 2015	Brent & Labuschagne 2006	Manik et al, 2013	Azapagic, 2002	TOTAL	Normalized	weight
Local Employment	○	●	●	○	●	●	●	●	●	●	○	●	○	○	●	●	11	**1**	0,256
Safe & healthy living conditions in community	●	●	○	○	●	●	●	●	○	●	○	●	●	○	●	○	10	**0,909**	0,233
Respect of Human Rights	●	●	○	○	●	●	○	●	○	●	○	●	●	○	●	●	10	**0,909**	0,233
Community engagement	●	●	○	○	●	●	○	○	○	○	○	○	○	○	●	●	6	**0,545**	0,14
Delocalization and Migration	○	●	○	●	○	○	○	●	○	●	○	○	●	○	●	○	6	**0,545**	0,14
Maintaining & improving social and economic opportunities	●	○	●	○	○	●	○	○	○	○	○	●	○	●	○	○	5	0,455	
Respect to cultural heritage	○	●	○	●	○	●	●	○	○	○	○	○	○	○	●	○	5	0,455	
Access to Material Resources	○	●	○	○	○	○	●	○	○	●	○	○	○	○	●	○	4	0,364	
Access to Immaterial Resources	○	●	○	○	○	○	○	○	○	○	○	○	○	○	●	○	2	0,182	
Family Support	○	○	○	○	○	○	○	○	●	○	●	○	○	○	○	○	2	0,182	
Community education & training	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	1	0,091	
Technology development and access	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	1	0,091	
Integration of disabled/disadvantaged citizens	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	1	0,091	

Consumer (User)

Consumers are individuals who purchase or use property, products or services for private purposes (ISO, 2010). Apart from being one of the stakeholder categories, consumers are also the main group of people that assessment focuses on. All other impact categories were actually originated from complex decision-making process of modern consumers that take environmental and socio-economic impacts into consideration when choosing a product (UNEP & SETAC, 2009). One of the main goal definitions; "product utility" was defined according to consumer needs and demands (Grießhammer *et al.,* 2007). Another important aspect of this stakeholder category is that they are a part of downstream process which should be treated differently than upstream categories. In a more extensive study where other upstream processes are involved; upstream and downstream processes should be evaluated within themselves and combined after.

In this particular case, consumers were defined as contractors, building managers and building residents who are both involved in thermal insulation material selection process and lived in the insulated building during the period between sheathing and thermal insulation material disposal/recycle or building demolishment operations. End of life process was not covered.

According to filtering procedure, only three impact categories were selected. Although the study was conducted on a real building, it simulates the results of four different scenarios where different insulation materials are applied on the building. Thus; data required for consumer related indicators are mainly created by verifying executive interviews with desktop screening.

Table 3.5 Inclusion of “end-user” impact categories in selected sources

3.Consumer-User	**Grießhammer et al, 2007**	**UNEP/SETAC, 2009**	**UNCTAD, 2008**	**Paragahawewa et al, 2009**	**Reitinger et al, 2011**	**GRI, 2016**	**ISO, 2010**	**Hosseinijou et al, 2014**	**Dasmohapatra, 2012**	**Muller & Saling, 2011**	**Ciroth & Franziska, 2015**	**Hutchins & Sutherland 2008**	**Saranella et al, 2015**	**Brent & Labuschagne 2006**	**Manik et al, 2013**	**Azapagic, 2002**	**TOTAL**	**Normalized**	**weight**
Protection of the user’s / consumer’s health and safety	●	●	○	●	●	●	○	●	○	●	○	●	●	○	○	●	10	**1**	0,5
Complete & understandable product information	●	○	○	○	●	●	○	○	○	●	○	●	○	○	○	○	5	**0,5**	0,25
Transparency	○	●	○	●	○	○	○	●	○	●	○	○	○	○	●	○	5	**0,5**	0,25
Protection of user’s / consumer’s privacy	●	●	○	○	●	●	○	○	○	○	○	○	○	○	○	○	4	0,4	
Fair competition & marketing practices	●	○	○	○	○	●	○	○	○	○	○	●	○	○	○	○	3	0,3	
Feedback accessibility	○	●	○	○	○	●	○	○	○	○	○	●	○	○	○	○	3	0,3	
Quality of product or service	●	○	○	○	○	○	○	○	○	○	○	●	○	○	○	●	3	0,3	
End of life responsibility	○	●	○	○	○	○	○	○	○	●	○	○	○	○	○	○	2	0,2	
Customer accessibility to services	○	○	○	○	○	●	○	○	○	○	○	●	○	○	○	○	2	0,2	
Enhancing the user’s / consumer’s social and economic possibilities	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	1	0,1	
Fair contractual practices	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	1	0,1	
Education & Awareness	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	1	0,1	
Feedback influence	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	1	0,1	

Society

Social responsibility of an organization is related with its ability to monitor and adapt the instantaneous demands and expectations of the society (ISO, 2010). One of the expectations of the society is that the organization should contribute to sustainable development of its society by developing innovative technologies or contributing to national economy (UNEP & SETAC, 2009). Also, it is generally encouraged by the national societies to demonstrate support for internationally defined laws and guidelines (UNCTAD, 2008). It is possible that company profits and society profits coincide. Society is defined in national level.

Selected five impact categories about society and their weight scores are given in Table 3.6. Society in question is Turkey. Thus, company information, executive interview and desktop screening data was evaluated with respect to national data.

Table 3.6 Inclusion of "society" impact categories in selected sources

4.Society	Grießhammer et al, 2007	UNEP/SETAC, 2009	UNCTAD, 2008	Paragahawewa et al, 2009	Reitinger et al, 2011	GRI, 2016	ISO, 2010	Hosseinijou et al, 2014	Dasmohapatra, 2012	Muller & Saling, 2011	Ciroth & Franziska, 2015	Hutchins & Sutherland 2008	Saranella et al, 2015	Brent & Labuschagne 2006	Manik et al, 2013	Azapagic, 2002	TOTAL	Normalized	weight
Anti-corruption & no improper involvment in political activities	●	●	●	○	●	●	○	●	○	○	○	○	●	○	●	●	9	**1**	0,27
Contribution to the national economy and stable economic dev	●	●	●	○	○	○	●	●	○	●	○	○	○	○	●	○	7	**0,78**	0,21
Prevention of armed conflicts	●	●	○	○	○	○	○	●	○	●	○	○	●	○	●	○	6	**0,67**	0,18
Contribution to national technology / R&D	○	●	○	○	○	○	●	●	○	○	○	●	○	●	●	○	6	**0,67**	0,18
National commitments to sustainability issues	●	●	○	○	●	○	○	○	○	○	●	○	○	○	●	○	5	**0,56**	0,15
Compliance to social & economic laws	○	○	●	○	●	●	○	○	○	○	○	○	●	○	○	○	4	0,44	
National healty and safety	●	○	○	○	○	○	○	○	○	●	○	○	●	○	○	○	3	0,33	
Protection of intellectual property rights	●	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	2	0,22	
Employment creation	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	1	0,11	
Transparent business information	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	1	0,11	
Education (illiteracy rate)	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	1	0,11	
Foreign Direct Investment (FDI)	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	1	0,11	
Imports from developing countries	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	1	0,11	

Supply Chain Actors

Supply chain actors include each party that are involved in the product's lifecycle except users and workers (UNEP & SETAC, 2009). Supply chain is defined as a sequence of activities or parties that provides products or services to the organization (ISO, 2010). Thus, supply chain actors are defined for each process location on the lifecycle flowchart of a product. For each step, related process actors are supply chain actors. Selected impact categories are shown in Table 3.7.

Table 3.7 Inclusion of “supply chain actors” impact categories in selected sources

5.Supply Chain Actors	Grießhammer et al, 2007	UNEP/SETAC, 2009	UNCTAD, 2008	Paragahawewa et al, 2009	Reitinger et al, 2011	GRI, 2016	ISO, 2010	Hosseinijou et al, 2014	Dasmohapatra, 2012	Muller & Saling, 2011	Ciroth & Franziska, 2015	Hutchins & Sutherland 2008	Saranella et al, 2015	Brent & Labuschagne 2006	Manik et al, 2013	Azapagic, 2002	TOTAL	Normalized	weight
Fair Competition	○	●	○	○	○	●	●	●	○	●	○	○	○	○	●	●	7	**1**	0,41
Promoting social responsibility among partners	○	●	○	○	○	●	○	●	○	●	○	○	○	○	○	●	5	**0,71**	0,29
Supplier relationships	○	●	○	○	●	○	●	○	○	●	○	○	○	○	○	●	5	**0,71**	0,29
Respect of intellectual property rights	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	1	0,14	
New suppliers are screened using social criteria	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	1	0,14	
Negative social impacts on supply chain: detection and corection	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	1	0,14	
Corruption	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	1	0,14	

- **Indicator List**

Inventory indicators are the parameters that provide the most direct evidence of the condition or result they are measuring. They have type and unit measurement characteristics (UNEP & SETAC, 2009). Unlike E-LCA, indicator definition is one of the essential steps of S-LCA since there are not definitive parameters yet (Grießhammer *et al.,* 2007). Since it is a social subject, a sheer number of indicators can be a subject of the assessment. Thus, it is important to select only relative ones. Indicators are generally defined via common dialogue between an expert group of people who are conducting the assessment and stakeholder parties (UNCTAD, 2008).

According to Product Sustainability Assessment Guideline, (PROSA) social impacts may occur in the upstream chain and the end-of- life management of the product's lifecycle (labor related issues); repercussions of product use (impacts during usage phase), and indirect repercussions on society (impacts on national and local society) (Grießhammer *et al.,* 2007). In order to decrease subjectivity. Indicator lists were extracted from examined sources whenever available. There are three indicator lists that are based on a large scope literature review conducted by a group of experts (Grießhammer *et al.,* 2007; GRI, 2016; Ciroth *et al.,* 2015). Each indicator was associated with their related impact categories. Table 3.8 shows the primary indicator list. While creating the primary indicator table, subjective interpretation was kept in minimum. Only, similar indicators were modified and merged and some indicators that are related with environmental issues were extracted. Each indicator was rated according to their occurrence in three mentioned sources. These ratings were utilized to determine indispensability of each indicator in second edition of the list.

Table 3.8 Preliminary list of indicators

STAKEHOLDERS ID NO	overall weight	weight	IMPACT CATEGORIES DESCRIPTIONS	INDICATORS	Grießhammer et al, 2007	GRI, 2016	Ciroth et al, 2015	Total
WORKERS	0,258							
1.1	0,045	0,174	HEALTH AND SAFETY					
1.1.1			Health and Safety in work	Number of accidents at work	●	●	●	3
1.1.2			Health and Safety in work	Number of recognized occupational diseases and reports on elevated health risks	●	●	●	3
1.1.3			Health and Safety in work	Workplaces associated with noise, fumes, dust, heat, insufficient illumination	●	○	○	1
1.1.4			Health and Safety in work	Basic measures and arrangements to maintain and increase safety at work	●	●	●	3
1.1.5			Health and Safety in work	Measures and arrangements to maintain and increase health at work	●	●	●	3
1.1.6			Health and Safety in work	Access to clean drinking water and sanitary facilities at work	●	○	○	1
1.1.7			Health and Safety in work	Policies and programmes to combat HIV/AIDS and/or other locally important health issues (dengue, malaria, alcoholism etc.)	●	●	○	2
1.2	0,038	0,147	DISCRIMINATION					
1.2.1			Equality of opportunity and treatment & fair interaction	Voluntary commitments by the company in the field of equal opportunities and treatment	●	○	○	1
1.2.2			Equality of opportunity and treatment & fair interaction	Reports on discriminatory practices of the company	●	●	●	3
1.2.3			Equality of opportunity and treatment & fair interaction	Proportion of women in management positions	●	●	●	3
1.2.4			Equality of opportunity and treatment & fair interaction	Ratio of salary of women wages to men	○	○	●	1
1.2.5			Equality of opportunity and treatment & fair interaction	Proportion of disabled employees	●	○	○	1
1.2.6			Equality of opportunity and treatment & fair interaction	Reports on harassment and mobbing	●	○	○	1
1.2.7			Equality of opportunity and treatment & fair interaction	Reports on sexual harassment	●	○	○	1
1.2.8			Equality of opportunity and treatment & fair interaction	Measures and programmes to maintain and increase equal opportunities and treatment	●	●	○	2
1.3	0,036	0,138	REMUNERATION					
1.3.1			Adequate remuneration	Average level of performance-related incentives	●	○	○	1
1.3.2			Adequate remuneration	Ratio of corporate minimum wages to local costs of living	●	○	○	1
1.3.3			Adequate remuneration	Number of employees in the lowest remuneration segment	●	○	○	1
1.3.4			Adequate remuneration	Average level of performance-related incentives in the lowest remuneration segment	●	○	○	1
1.3.5			Adequate remuneration	Application of a transparent remuneration system	●	○	○	1
1.3.6			Adequate remuneration	Payment of wages in due time	●	○	○	1
1.4	0,033	0,128	FORCED LABOUR					
1.4.1			Abolition of forced labour	Voluntary commitments by the company on abolition of forced labour	●	○	○	1
1.4.2			Abolition of forced labour	Reports on cases of forced labour	●	○	○	1
1.5	0,028	0,11	SOCIAL SECURITY					
1.5.1			Social Security Rights	Evidence of breaches of obligatory social contributions	●	●	○	2
1.5.2			Social Security Rights	Duration and level of wage continuation in the case of illness	●	●	○	2
1.5.3			Social Security Rights	# of workers with a contract	○	○	●	1
1.5.4			Social Security Rights	Level of occupational pension schemes	●	●	○	2
1.5.5			Social Security Rights	Maternity protection and childcare	●	●	○	2
1.5.6			Social Security Rights	Additional occupational social contributions	●	●	○	2
1.6	0,026	0,101	CHILD LABOUR					
1.6.1			Abolition of child labour	Voluntary commitments by the company on abolition of child labour	●	○	○	1
1.6.2			Abolition of child labour	Reports on cases of child labour as defined by the ILO core labour standard conventions No. 138 and 182	●	○	○	1
1.6.3			Abolition of child labour	Male, female and total child labor rates.	○	○	●	1
1.7	0,028	0,11	FREEDOM OF ASSOCIATION					
1.7.1			Freedom of association, collective bargaining & workers' participation	Voluntary commitments by the company in the field of freedom of association & right to collective bargaining	●	○	○	1
1.7.2			Freedom of association, collective bargaining & workers' participation	Reports on hindering workers' organizations and their activities	●	●	●	3
1.7.3			Freedom of association, collective bargaining & workers' participation	Rate of unionization	●	●	●	3
1.7.4			Freedom of association, collective bargaining & workers' participation	Possibilities for collective bargaining	●	○	○	1
1.7.5			Freedom of association, collective bargaining & workers' participation	Possibilities for bottom-up communication				0
1.8	0,024	0,092	ADEQUATE WORKING TIME					
1.8.1			Adequate and fair working duration	Weekly working hours	●	○	○	1
LOCAL COMMUNITY	0,242							
2.1	0,055	0,228	LOCAL EMPLOYMENT					
2.1.1			Local Employment	Percentage of spending on locally based suppliers	○	○	●	1
2.1.2			Local Employment	Work force hired locally	○	●	●	2
2.2	0,055	0,228	HEALTH AND SAFETY					
2.2.1			Safe & healthy living conditions in community	Accidents connected to the company's activities	●	●	○	2
2.2.2			Safe & healthy living conditions in community	Negative and positive health impacts for the local population	●	●	○	2
2.2.3			Safe & healthy living conditions in community	Measures and arrangements to maintain and improve safe and healthy living conditions	●	●	○	2
2.3	0,059	0,246	HUMAN RIGHTS					
2.3.1			Respect to local human rights	Voluntary commitments by the company in the field of human rights	●	●	○	2
2.3.2			Respect to local human rights	Reports on human rights violations related to the company's activities	●	●	○	2
2.3.3			Respect to local human rights	Forced evictions / resettlements related to the company's activities	●	●	○	2
2.3.4			Respect to local human rights	Human rights training for employees, particularly for security staff	●	●	○	2
2.4	0,038	0,158	COMMUNITY ENGAGEMENT					
2.4.1			Community engagement	Information possibilities for residents	●	●	○	2
2.4.2			Community engagement	System to respond to community grievances	●	●	○	2
2.4.3			Community engagement	Breaches of obligations established by local political and social decision-making authorities	●	●	○	2
2.5	0,034	0,14	DELOCALIZATION					
2.5.1			Delocalization and Migration	Migrant workers in the sector %	○	○	●	1
CONSUMER/USER	0,226							
3.1	0,104	0,462	HEALTH AND SAFETY					
3.1.1			Protection of the user's / consumer's health and safety	Health opportunities / risks related to product use	●	○	○	1
3.1.2			Protection of the user's / consumer's health and safety	Accidents related to product use	●	●	○	2
3.1.3			Protection of the user's / consumer's health and safety	Fatalities related to product use	●	●	○	2
3.1.4			Protection of the user's / consumer's health and safety	Findings of product safety tests (incl. any awards, labels)	●	●	○	2
3.2	0,069	0,308	CONSUMER TRANSPARENCY					
3.2.1			Transparency	?	○	○	○	0
3.3	0,052	0,231	FEEDBACK ACCESSIBILITY					
3.2.2			Feedback accessibility	?	○	○	○	0

SOCIETY	0,145							
4.1	0,035	0,244	CORRUPTION					
4.1.1			Anti-corruption & no improper involvment in political activities	Evidence of corrupt and / or extortionate business practices	●	●	○	2
4.1.2			Anti-corruption & no improper involvment in political activities	Reports on improper involvement in political activities	●	●	○	2
4.1.3			Anti-corruption & no improper involvment in political activities	Corporate measures to combat corrupt business practices	●	●	○	2
4.2	0,032	0,222	CONTRIBUTION TO ECONOMY					
4.2.1			Contribution to the national economy and stable economic development	Contribution to GDP Direct investments	●	○	●	2
4.2.2			Contribution to the national economy and stable economic development	Contribution to the national budget (taxes paid minus subsidies received)	○	●	○	1
4.2.3			Contribution to the national economy and stable economic development	Contribution to the foreign trade balance	●	○	○	1
4.2.4			Contribution to the national economy and stable economic development	The sector's stability during market crisis	●	○	○	1
4.2.5			Contribution to the national economy and stable economic development	Evidence of tax evasion	○	●	○	1
4.2.6			Contribution to the national economy and stable economic development	Evidence of competition distorting business practices (monopolisation etc.)	●	○	○	1
4.3	0,026	0,178	CONFLICTS					
4.3.1			Prevention of armed conflicts	Link between economic activities and armed conflicts / Risk of conflict	●	○	○	1
4.4	0,026	0,178	CONTRIBUTION TO NATIONAL TECHNOLOGY					
4.4.1			Contribution to national technology / R&D	R&D Program participation	○	●	○	1
4.4.2			Contribution to national technology / R&D	Development of innovative products and services	●	○	○	1
4.5	0,026	0,178	NATIONAL COMMITMENT TO SUSTAINABILITY					
4.5.1			National commitments to sustainability issues	Awards for engagement in social and / or sustainability issues	●	○	○	1
4.5.2			National commitments to sustainability issues	Membership in alliances and programmes to support and promote sustainable business practices	●	○	○	1
4.5.3			National commitments to sustainability issues	Evidence of lobbying against implementing sustainability measures	●	○	○	1
4.5.4			National commitments to sustainability issues	Publication of a sustainability report or social report	●	○	○	1
SUPPLY CHAIN ACTORS	0,129							
5.1	0,053	0,409	FAIR COMPETITION					
5.1.1			Fair Competition	Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation	○	○	●	1
5.1.2			Fair Competition	Presence of policies to prevent anti-competitive behaviour Y/N	○	○	●	1
5.2	0,035	0,273	SOCIAL RESPONSIBILITY					
5.2.1			Promoting social responsibility among partners	Presence of codes of conduct that protect human rights of workers among suppliers	○	○	●	1
5.2.2			Promoting social responsibility among partners	Membership in an initiative that promotes social responsibility along the supply chain	○	○	●	1
5.3	0,041	0,318	SUPPLIER RELATIONSHIPS					
5.3.1			Supplier relationships	Interaction of the companies with suppliers (payment on time, sufficient lead time, reasonable volume fluctuations, appropriate communication...)	○	○	●	1

According to ISO 14044, (2006) a sensitivity analysis needs to be done during the modeling of the framework rather than at the end of the process to measure the effect of inclusion or exclusion of an indicator on the overall result. In quantitative analysis, 1% change in the overall result is often regarded as a significant change (UNEP & SETAC, 2009). Thus, a sensitivity analysis was conducted on the indicators to measure their overall weights (O_{wt}) by multiplying stakeholder category weights (C_{wt}) and impact category weights (I_{wt}) and dividing them to the total number of indicators (I_n) in the category item (Equation 3.11).

$$O_{wt} = \frac{I_{wt} \times C_{wt}}{I_n} \qquad \text{Equation 3.11}$$

Results of this calculation are shown in Figure 3.7. Due to high number of indicators in the literature on worker/employee and society stakeholder categories, indicators in these categories lost their significance because of their overall weights decreasing below 1%. Similarly, consumer related indicators became outliers due to their high significance rates. To create a more balanced assessment structure, limit significance rates were defined. Maximum value was set to 3% (lowest integer to exclude outliers) and minimum value was set to 1% (lowest significance rate that is mentioned in UNEP & SETAC guideline). This redefinition process of system boundaries is called significance analysis and it is required to increase the reliability of indicator weighting values and determine the optimum number of indicators per category. (Wallbaum *et al*., 2012; Jensen *et al*., 1997; UNEP/SETAC LCI, 2009) According to the significance results following actions will be taken:

- Exclusion of indicators should be applied when the indicators of an impact category have lack of significance due to excessive number of indicators.
- Inclusion of new indicators should be applied when the indicators of an impact category have too much significance due to insufficient number of indicators.

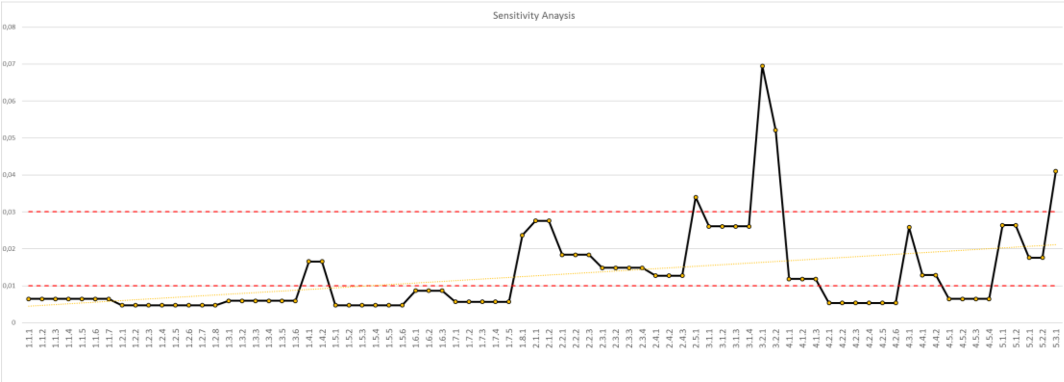


Figure 3.7 Indicator weights

A reduction task was done on the impact categories with lower overall weighing rates than 1%. While eliminating the indicators, ones with the lowest occurrence rates in all three indicator references and non-measurable indicators for this specific study were given priority. Indicators that were found too essential to exclude were kept in place. On the other hand, by introducing new indicators, outlying ones were normalized. Eliminated indicators are underlined on Table 3.8 whereas added indicators are underlined on Table 3.9. This inclusion and exclusion phase of the study involved some subjective treatment with a consideration of specific goal and scope definition. As it is shown in Figure 3.8, the lowest significance limit was fixed to 0,9% and the highest significance rate was fixed to 3% (With a 0,0004 margin of error). Thus, optimum number of indicators were determined for each category while impact category weighting ratios remained the same.

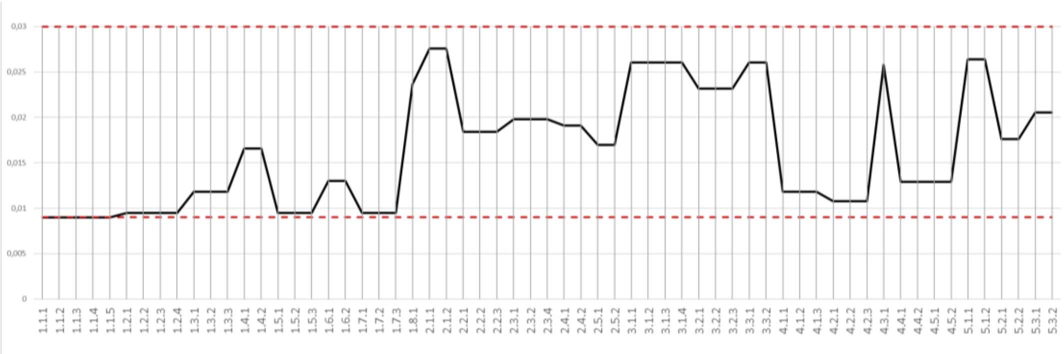


Figure 3.8 Final indicator list after sensitivity analysis

Second edition of the indicator table is shown on Table 3.9. Data supply opportunities from different parties including workers, companies, suppliers and executives have been be limited for this specific academic research. Some data could not be obtained. With more reliable information from larger parties, this assessment shall give more accurate results. Furthermore, to keep the results accurate despite the limited information, the indicators can be supported with a verification source that is different from the main source.

According to UNEP/SETAC, (2009) there are three forms of Social LCA data; quantitative, semi-quantitative (i.e. Likert scale rating responses) and qualitative (descriptive text).

Most of the indicators require qualitative data. For this reason, each indicator was evaluated in terms of value boundaries, (reference max or min values) value types, (higher is better or lower is better) and data supply method (interview, survey, desktop screening, *etc.*). Quantitative data on the other hand, was obtained in their own form and last results were evaluated and verified from two different sources before transferring the data to the final table to normalize them.

Table 3.9 Final indicator list after sensitivity analysis

STAKEHOLDERS ID NO	overall weight	weight	IMPACT CATEGORIES INDICATORS	Company Information	Survey / Interview	Desktop Screening	Qualitative	Semi-Quantitative	Quantitative
WORKERS	0,258								
1.1	0,045	0,174	HEALTH AND SAFETY						
1.1.1	0,009		Number of accidents at work	●	○	○	○	○	●
1.1.2	0,009		Number of recognized occupational diseases and reports on elevated health risks	●	○	○	○	○	●
1.1.3	0,009		Basic measures and arrangements to maintain and increase safety at work	●	○	○	○	○	●
1.1.4	0,009		Measures and arrangements to maintain and increase health at work	●	○	○	○	○	●
1.1.5	0,009		Policies and programmes to combat HIV/AIDS and/or other locally important health issues (dengue, malaria, alcoholism etc.)	○	○	○	○	●	○
1.2	0,038	0,147	DISCRIMINATION						
1.2.1	0,009		Reports on discriminatory practices of the company	●	○	○	○	○	●
1.2.2	0,009		Proportion of women in management positions	●	○	○	○	○	●
1.2.3	0,009		Ratio of salary of women wages to men	●	○	○	○	○	●
1.2.4	0,009		Proportion of disabled employees	●	○	○	○	○	●
1.3	0,036	0,138	REMUNERATION						
1.3.1	0,012		Average level of performance-related incentives	○	●	○	○	●	○
1.3.2	0,012		Ratio of corporate minimum wages to local costs of living	●	○	○	○	○	●
1.3.3	0,012		Payment of wages in due time	○	●	○	○	●	○
1.4	0,033	0,128	FORCED LABOUR						
1.4.1	0,017		Voluntary commitments by the company on abolition of forced labour	○	●	○	○	●	○
1.4.2	0,017		Reports on cases of forced labour	○	●	○	○	●	○
1.5	0,028	0,11	SOCIAL SECURITY						
1.5.1	0,009		Evidence of breaches of obligatory social contributions	○	●	○	○	●	○
1.5.2	0,009		Duration and level of wage continuation in the case of illness	○	●	○	○	●	○
1.5.3	0,009		# of workers with a contract	●	○	○	○	○	●
1.6	0,026	0,101	CHILD LABOUR						
1.6.1	0,013		Reports on cases of child labour	○	●	○	○	●	○
1.6.2	0,013		Reports on cases of young labour	●	○	○	○	○	●
1.7	0,028	0,11	FREEDOM OF ASSOCIATION						
1.7.1	0,009		Voluntary commitments by the company in the field of freedom of association & right to collective bargaining	○	●	○	○	●	○
1.7.2	0,009		Reports on hindering workers' organizations and their activities	○	●	○	○	●	○
1.7.3	0,009		Rate of unionization	●	○	○	○	○	●
1.8	0,024	0,092	ADEQUATE WORKING TIME						
1.8.1	0,024		Weekly working hours	●	○	○	○	○	●
LOCAL COMMUNITY	0,242								
2.1	0,055	0,228	LOCAL EMPLOYMENT						
2.1.1	0,028		Percentage of spending on locally based suppliers	●	○	○	○	○	●
2.1.2	0,028		Work force hired locally	●	○	○	○	○	●
2.2	0,055	0,228	HEALTH AND SAFETY						
2.2.1	0,018		Accidents connected to the company's activities	●	○	○	○	○	●
2.2.2	0,018		Negative and positive health impacts for the local population	●	○	○	○	○	●
2.2.3	0,018		Measures and arrangements to maintain and improve safe and healthy living conditions	○	●	○	○	●	○
2.3	0,059	0,246	HUMAN RIGHTS						
2.3.1	0,02		Voluntary commitments by the company in the field of human rights	○	●	○	○	●	○
2.3.2	0,02		Reports on human rights violations related to the company's activities	○	●	○	○	●	○
2.3.3	0,02		Human rights training for employees, particularly for security staff	○	●	○	○	●	○
2.4	0,038	0,158	COMMUNITY ENGAGEMENT						
2.4.1	0,019		Information possibilities for residents	○	●	○	○	●	○
2.4.2	0,019		System to respond to community grievances	○	●	○	○	●	○
2.5	0,034	0,14	DELOCALIZATION						
2.5.1	0,017		Delocalization or Migration resulted from company's activities.	○	●	○	○	●	○
2.5.2	0,017		Forced evictions / resettlements related to the company's activities	○	●	○	○	●	○
CONSUMER/USER	0,226								
3.1	0,104	0,462	HEALTH AND SAFETY						
3.1.1	0,026		Health opportunities / risks related to product use	○	○	●	●	○	○
3.1.2	0,026		Accidents related to product use	○	○	●	○	○	●
3.1.3	0,026		Fatalities related to product use	○	○	●	○	○	●
3.1.4	0,026		Findings of product safety tests (incl. any awards, labels)	○	○	●	●	○	○
3.2	0,069	0,308	TRANSPARENCY						
3.2.1	0,023		Consumers' ability to reach full ingredient information	○	○	●	●	○	○
3.2.2	0,023		Publication of a sustainability report	○	○	●	●	○	○
3.2.3	0,023		Precise and readily understandable information about safe use and maintenance	○	○	●	●	○	○
3.3	0,052	0,231	FEEDBACK ACCESSIBILITY						
3.3.1	0,026		Company's commitment to allow user feedbacks	○	●	○	○	●	○
3.3.2	0,026		System to respond user feedbacks	○	●	○	○	●	○
SOCIETY	0,145								
4.1	0,035	0,244	CORRUPTION						
4.1.1	0,012		Evidence of corrupt and / or extortionate business practices	○	●	○	○	●	○
4.1.2	0,012		Reports on improper involvement in political activities	○	○	●	●	○	○
4.1.3	0,012		Corporate measures to combat corrupt business practices	○	●	○	○	●	○
4.2	0,032	0,222	CONTRIBUTION TO ECONOMY						
4.2.1	0,011		Contribution to the national budget (taxes paid minus subsidies received)	●	○	○	○	○	●
4.2.2	0,011		Contribution to the foreign trade balance	●	○	○	○	○	●
4.2.3	0,011		Company's economic stability during market crisis	○	●	○	○	●	○
4.3	0,026	0,178	CONFLICTS						
4.3.1	0,026		Link between economic activities and armed conflicts / Risk of conflict	○	●	○	○	●	○
4.4	0,026	0,178	CONTRIBUTION TO NATIONAL TECHNOLOGY						
4.4.1	0,013		R&D Program participation	○	●	○	○	●	○
4.4.2	0,013		Development of innovative products and services	○	●	○	○	●	○
4.5	0,026	0,178	NATIONAL COMMITMENT TO SUSTAINABILITY						
4.5.1	0,013		Awards for engagement in social and / or sustainability issues	○	○	●	●	○	○
4.5.2	0,013		Membership in alliances and programmes to support and promote sustainable business practices	○	○	●	●	○	○

SUPPLY CHAIN ACTORS	0,129								
5.1	0,053	0,409	FAIR COMPETITION						
5.1.1	0,026		Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation	○	●	○	○	●	○
5.1.2	0,026		Presence of policies to prevent anti-competitive behaviour Y/N	○	●	○	○	●	○
5.2	0,035	0,273	SOCIAL RESPONSIBILITY						
5.2.1	0,018		Presence of codes of conduct that protect human rights of workers among suppliers	○	●	○	○	●	○
5.2.2	0,018		Membership in an initiative that promotes social responsibility along the supply chain	○	○	●	●	○	○
5.3	0,041	0,318	SUPPLIER RELATIONSHIPS						
5.3.1	0,021		Interactions: payment on time	○	●	○	○	●	○
5.3.2	0,021		Interactions: sufficient lead time	○	●	○	○	●	○

Survey and Interview questions as well as evaluation parameters are created for each indicator item in Materials section. Each indicator item is explained and parameters are created with individual literature reviews.

Indicators which are related to facility and company information are mostly quantitative. Numeric data is directly collected for these indicators and minimum and maximum borders are determined for normalization. No data conversion from qualitative to quantitative is required for these items (Table 3.10).

Table 3.10. Indicator items depending on facility and company information

STAKEHOLDERS ID NO	OW	W	IMPACT CATEGORIES INDICATORS
WORKERS	0,258		
1.1	0,045	0,174	HEALTH AND SAFETY
1.1.1	0,009		Number of accidents at work
1.1.2	0,009		Number of recognized occupational diseases and reports on elevated health risks
1.1.3	0,009		Basic measures and arrangements to maintain and increase safety at work
1.1.4	0,009		Measures and arrangements to maintain and increase health at work
1.2	0,038	0,147	DISCRIMINATION
1.2.1	0,009		Reports on discriminatory practices of the company
1.2.2	0,009		Proportion of women in management positions
1.2.3	0,009		Ratio of salary of women wages to men
1.2.4	0,009		Proportion of disabled employees
1.3	0,036	0,138	REMUNERATION
1.3.2	0,012		Ratio of corporate minimum wages to local costs of living
1.5	0,028	0,11	SOCIAL SECURITY
1.5.3	0,009		# of workers with a contract
1.6	0,026	0,101	CHILD LABOUR
1.6.2	0,013		Reports on cases of young labour
1.7	0,028	0,11	FREEDOM OF ASSOCIATION
1.7.3	0,009		Rate of unionization
1.8	0,024	0,092	ADEQUATE WORKING TIME
1.8.1	0,024		Weekly working hours
LOCAL COMMUNITY	0,242		
2.1	0,055	0,228	LOCAL EMPLOYMENT
2.1.1	0,028		Percentage of spending on locally based suppliers
2.1.2	0,028		Work force hired locally
2.2	0,055	0,228	HEALTH AND SAFETY
2.2.1	0,018		Accidents connected to the company's activities
2.2.2	0,018		Negative and positive health impacts for the local population
SOCIETY	0,145		
4.2	0,032	0,222	CONTRIBUTION TO ECONOMY
4.2.1	0,011		Contribution to the national budget (taxes paid minus subsidies received)
4.2.2	0,011		Contribution to the foreign trade balance

Some indicator items depend on qualitative evaluation from surveys and interviews. To translate the qualitative data into quantitative format, Likert scale is utilized. Each survey or interview question depends on a certain evaluation scale. The scale may be composed of simple answers like "yes" and "no" or more detailed choices that include “agree” and “disagree” options as well as “strongly agree”, “strongly disagree” and “not certain” options. Data is translated into quantitative format according to that scale and that scale also provides minimum and maximum values (Table 3.11).

Table 3.11. Indicator items depending on surveys and interviews

STAKEHOLDERS ID NO	ow	w	IMPACT CATEGORIES INDICATORS
WORKERS	0,258		
1.1	0,045	0,174	HEALTH AND SAFETY
1.1.5	0,009		Policies and programmes to combat HIV/AIDS and/or other locally important health issues (dengue, malaria, alcoholism etc.)
1.3	0,036	0,138	REMUNERATION
1.3.1	0,012		Average level of performance-related incentives
1.3.3	0,012		Payment of wages in due time
1.4	0,033	0,128	FORCED LABOUR
1.4.1	0,017		Voluntary commitments by the company on abolition of forced labour
1.4.2	0,017		Reports on cases of forced labour
1.5	0,028	0,11	SOCIAL SECURITY
1.5.1	0,009		Evidence of breaches of obligatory social contributions
1.5.2	0,009		Duration and level of wage continuation in the case of illness
1.6	0,026	0,101	CHILD LABOUR
1.6.1	0,013		Reports on cases of child labour
1.7	0,028	0,11	FREEDOM OF ASSOCIATION
1.7.1	0,009		Voluntary commitments by the company in the field of freedom of association & right to collective bargaining
1.7.2	0,009		Reports on hindering workers’ organizations and their activities
LOCAL COMMUNITY	0,242		
2.2	0,055	0,228	HEALTH AND SAFETY
2.2.3	0,018		Measures and arrangements to maintain and improve safe and healthy living conditions
2.3	0,059	0,246	HUMAN RIGHTS
2.3.1	0,02		Voluntary commitments by the company in the field of human rights
2.3.2	0,02		Reports on human rights violations related to the company’s activities
2.3.3	0,02		Human rights training for employees, particularly for security staff
2.4	0,038	0,158	COMMUNITY ENGAGEMENT
2.4.1	0,019		Information possibilities for residents
2.4.2	0,019		System to respond to community grievances
2.5	0,034	0,14	DELOCALIZATION
2.5.1	0,017		Delocalization or Migration resulted from company's activities.
2.5.2	0,017		Forced evictions / resettlements related to the company’s activities
CONSUMER/USER	0,226		
3.3	0,052	0,231	FEEDBACK ACCESSIBILITY
3.3.1	0,026		Company's commitment to allow user feedbacks
3.3.2	0,026		System to respond user feedbacks
SOCIETY	0,145		
4.1	0,035	0,244	CORRUPTION
4.1.1	0,012		Evidence of corrupt and / or extortionate business practices
4.1.3	0,01		Corporate measures to combat corrupt business practices
4.2	0,032	0,222	CONTRIBUTION TO ECONOMY
4.2.3	0,011		Company’s economic stability during market crisis
4.3	0,026	0,178	CONFLICTS
4.3.1	0,026		Link between economic activities and armed conflicts / Risk of conflict
4.4	0,026	0,178	CONTRIBUTION TO NATIONAL TECHNOLOGY
4.4.1	0,013		R&D Program participation
4.4.2	0,013		Development of innovative products and services
SUPPLY CHAIN ACTORS	0,129		
5.1	0,053	0,409	FAIR COMPETITION
5.1.1	0,026		Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation
5.1.2	0,026		Presence of policies to prevent anti-competitive behaviour Y/N
5.2	0,035	0,273	SOCIAL RESPONSIBILITY
5.2.1	0,018		Presence of codes of conduct that protect human rights of workers among suppliers
5.3	0,041	0,318	SUPPLIER RELATIONSHIPS
5.3.1	0,021		Interactions: payment on time
5.3.2	0,021		Interactions: sufficient lead time

Also, some data is provided via desktop screening. Each of them requires a specific evaluation system, conversion method and border values. Since data is mostly quantitative, they need specific interpretation processes to evaluate them within a quantitative scope (Table 3.12).

Table 3.12. Indicator items depending on desktop screening

STAKEHOLDERS ID NO	ow	w	IMPACT CATEGORIES INDICATORS
CONSUMER/USER	0,226		
3.1	0,104	0,462	HEALTH AND SAFETY
3.1.1	0,026		Health opportunities / risks related to product use
3.1.2	0,026		Accidents related to product use
3.1.3	0,026		Fatalities related to product use
3.1.4	0,026		Findings of product safety tests (incl. any awards, labels)
3.2	0,069	0,308	TRANSPARENCY
3.2.1	0,023		Consumers' ability to reach full ingredient information
3.2.2	0,023		Publication of a sustainability report
3.2.3	0,023		Precise and readily understandable information about safe use and maintenance
SOCIETY	0,145		
4.1	0,035	0,244	CORRUPTION
4.1.2	0,01		Reports on improper involvement in political activities
4.5	0,026	0,178	NATIONAL COMMITMENT TO SUSTAINABILITY
4.5.1	0,013		Awards for engagement in social and / or sustainability issues
4.5.2	0,013		Membership in alliances and programmes to support and promote sustainable business practices
SUPPLY CHAIN ACTORS	0,129		
5.2	0,035	0,273	SOCIAL RESPONSIBILITY
5.2.2	0,02		Membership in an initiative that promotes social responsibility along the supply chain

After the indicator items and their evaluation methods are determined one by one, they should be classified as “higher is better” (HIB) and “lower is better” (LIB). For LIB items, higher score means social impact and for LIB items, higher score means social benefit. After the scores are calculated for each item as it is explained in the Materials section, they need to be normalized according to HIB and LIB classification and their related formulas. After normalization, overall weighting values on Table 3.10, 3.11 and 3.12 can be used.

3.1.4. LCC Analysis Structure

To conduct a realistic assessment of sustainability, economic benefit analysis must be included. It is important to determine the main stakeholder for cost assessment. Cost assessment is conducted from one stakeholder’s point of view. Because, economic loss for one party can be a profit for another. Main decision-maker on the product selection is determined as the main stakeholder category.

In LCC, timing and context are quite important. LCA can work on a certain point of the economic flow. Since indirect economic impacts are evaluated within the scope of S-LCA, LCC only focuses on direct economic complications from a certain stakeholder’s point of view. This stakeholder must be the decision maker party.

If the building element has no contribution to the economic profit, only financial costs can be calculated as economic impacts. If usage of the building element brings economic profit as well, they have to be calculated together as an economic balance evaluation. Calculations should be done within a certain time scope rather than an instantaneous calculation.

Building insulation is applied for economic benefit via decrease in the heating demand of the building. For this reason, both appliance costs and decrease in the heating bills should be calculated and compared. After application, heating demand decreases instantly and each year heating cost stays the same under same price policies and climatic conditions theoretically. To compare the baseline uninsulated scenario and insulated design options via economical balance, payback period should be used.

Firstly, all economic costs of three design options' application processes including material and workmanship should be calculated. Then, yearly economic gain of each design option compared to the baseline scenario should be compared. Baseline scenario and design options should be compared for a certain period of time beginning from the application and ending when the total economic gain and economic cost equals at a certain time. A single economic score is derived from the payback period.

3.2. Materials

In this section, research materials to test the proposed method on a case study are provided and the case study is conducted. Throughout the section, necessary information that was explained in the Methods section are obtained, functional unit is determined via energy simulation and assessments are conducted.

As it was suggested in methods section, main product utility is based on thermal insulation function for insulation materials. While conducting the comparison study, insulation materials with similar construction details were selected for simplicity. Thus, a single material type (insulation materials) was included in the assessment while other application details are excluded. As it was stated in the methods section, assessment study can be applied for each building material separately and impacts can be summed up according to their mass quantities for LCA and S-LCA studies.

For LCC, financial losses and gains can be calculated all together for a building system in a single assessment.

3.2.1. Utilized Specifications of Insulation Materials

To run a proper assessment, specifications of each insulation material, their production flows, application details and ingredients are investigated. This information is used to define the scope and structure of various assessment studies in following chapters. Product stage of each insulation material is the evaluated scope for most of the S-LCA study. The reason why research on insulation materials are presented in this chapter instead of literature review is that they are specifications of insulation materials which are utilized in the calculations. Insulation material options with similar application details are selected for specific reasons. Rock wool was selected as the mineral wool option and it was compared with XPS which is the organic compound option. Glass wool is selected as an innovative sheathing application option to see if it can be a sustainable option to other insulation materials in this study.

- **Rock wool**

Rockwool consists of vitreous fibres with more than 18% oxides of sodium, potassium, calcium, magnesium and barium. It is produced from minerals, recycled glass and other basic materials of the industry. Domestically produced silica sand, dolomite and limestone are used as raw materials. Rockwool is an insulation material that provides thermal and acoustic comfort as well as fire resistance in buildings. Average density of the material is 70 kg/m^3 and average thermal conductivity is 0,035 W/mK. It is an inorganic material that is resistant to mold and rotting (Bau EPD GmbH, 2015; İzocam, 2017).

Production flow and system boundaries of rock wool are given in Figure 3.9. Rock wool production is a linear process. The production process starts by blending raw materials at appropriate ratios. The blend is transferred to glass ovens via automatic feeders. There, the temperature rises to 1250°C. The resulting melt is cured to homogenize and reduce the air bubbles. Homogenized melt reaches to 1450°C at the end of the curing process and kept at 1380°C to prepare for fiberization. The melt is fiberized by a platinum nozzle and mixed with phenol formaldehyde and process oil with the help of spraying nozzles. Then, the mixed fibers are transferred to forming section. The mixture is ventilated with hot air for polymerization and formed according to previously determined density and thickness values. The product is then cut into desired dimensions with guillotine and packed with PE-film (Bau EPD GmbH, 2015).

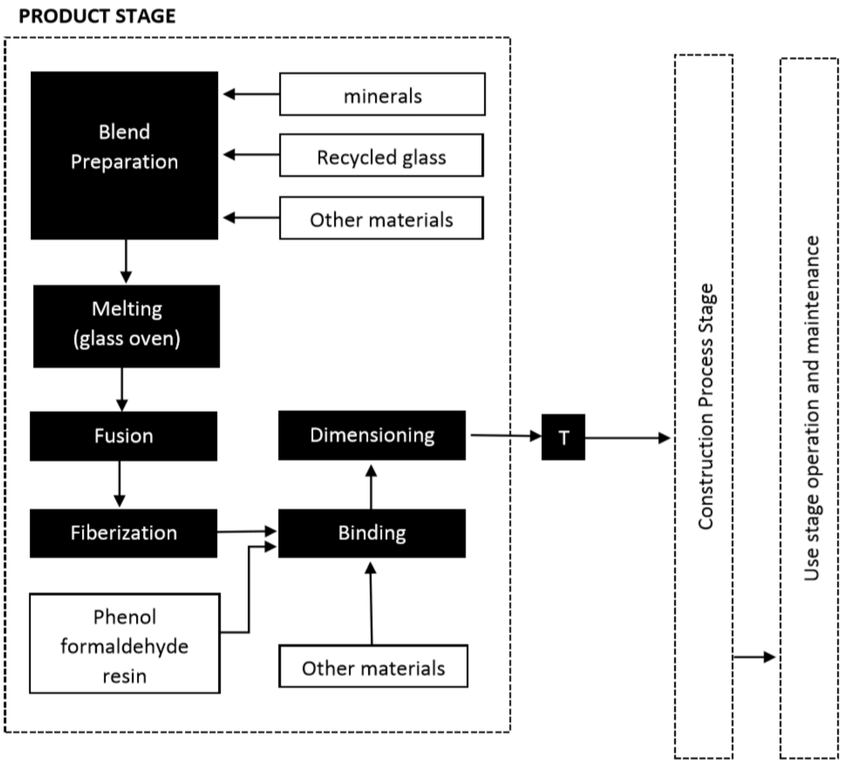


Figure 3.9 Rock wool production flow and system boundaries

- **Glass wool**

Glass wool consists of vitreous (silicate) fibers with more than 18% oxides of sodium, potassium, calcium, magnesium and barium. It is generally produced of recycled glass and other basic glass industry materials. Phenol-formaldehyde resin is used as a binder. Glass wool provides acoustic insulation and fire protection besides thermal insulation. Average density of the material is 13 kg/m^3 and average thermal conductivity is 0,04 W/mK. It is an inorganic material that is resistant to mold and rotting (Bau EPD GmbH, 2015; İzocam, 2017).

Glass wool is available on the market generally in forms of rolls and boards (Bau EPD GmbH, 2014). However, as an insulation material it is generally used on slabs, roofs or in walls with proper frames. Its tensile strength is not suitable to be used on sheathing. However, since it is one of the few mineral wools in the industry, it is also produced as sturdy battings to be used on exteriors. Although this application is not yet available in Turkey, insulation companies are currently conducting feasibility studies to create an alternative mineral wool sheathing for the industry. This quality is achieved by changing the fiber forming process of the production flow. This alternative weaving process does not change the energy and raw material inputs and environmental impact outputs significantly. So, standard production process of glass wool is taken as a basis to calculate environmental impacts but density of the material is taken from equivalent fiberglass battings as 48 kg/m^3 for 0,04 W/mK thermal conductivity (Owens Corning Insulation Systems, 2015).

System boundaries and production flowchart are indicated on Figure 3.10. The production process starts by blending raw materials at appropriate ratios to form a fibrous glass. The blend is transferred to glass ovens via automatic feeders. There, the temperature is risen to 1250°C to create appropriate environment for fusion. The resulting melt is cured to homogenize and reduce the air bubbles. The cured glass is gradually reduced to 1050°C to prepare it for fiberization. The conditioned glass is poured into the fiberization machine via the platinum nozzle. The material is fiberized in the machine due to high speed centrifugal force. Phenol formaldehyde binder is sprayed on the fibers and the fibrous glass material is shaped on the forming section with the help of dispersing airlet. The glass wool batting is subjected to 250°C air to polymerize the binder. There, desired density of the material is adjusted. Then, the material is cut to blankets with desired width and length. Small pieces are returned to fiber forming section for recycling. Finally, product is packed with PE-film (Bau EPD GmbH, 2015).

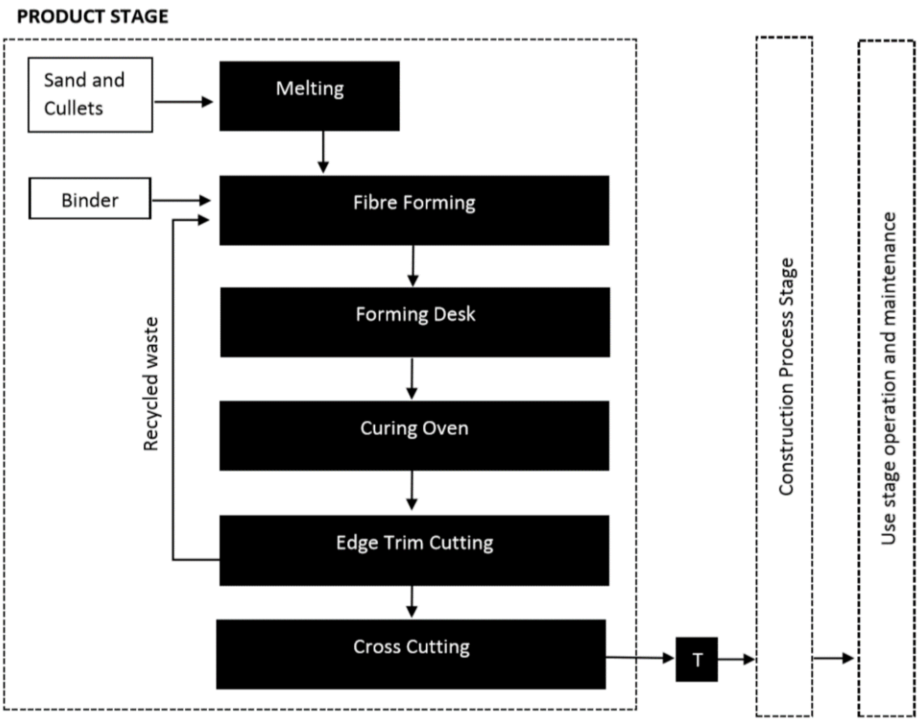


Figure 3.10 Glass wool production flow and system boundaries

- **XPS**

XPS is produced by extrusion of polystyrene by blowing with carbon dioxide and halogen free co-blowing agents. Polystyrene is produced from oil and gas. Hexabromocyclododecane is used as a fire retardant (EXIBA, 2014). Average density of the material is 30 kg/m^3 and average thermal conductivity is 0,03 W/mK.

Production flow and system boundaries of XPS is given on Figure 3.11. XPS foams are mostly made of polystyrene (90-95% by weight). Extrusion process of polystyrene uses electricity as the main energy source. Granules are melted in an extruder and a blowing agent is injected into them in high pressure. Pressure drop at the end of the extruder turns the material into a board with homogeneous closed cell structure. Then, the edges of the board are trimmed and the material is cut to desired dimensions. Dimensioned boards are packaged with polyethylene film bags.

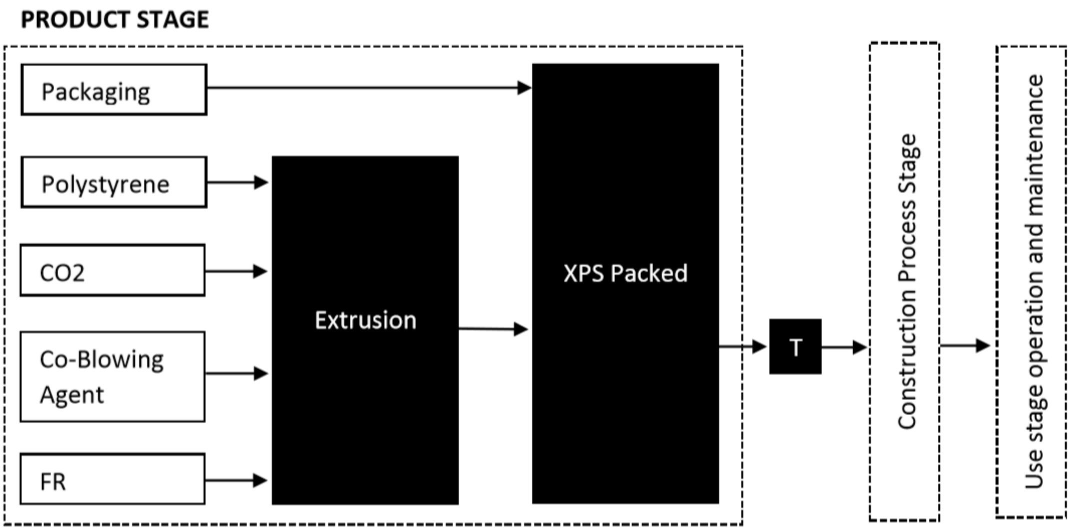


Figure 3.11 XPS production flow and system boundaries

3.2.2. Case Building Data

To test the method on a case building, a low income residential building typology was selected. Since current Fire Code in Turkey prohibits usage of ignitable insulation materials in buildings higher than 5 stories, a high building would require different detail drawings for each design option. To avoid introducing this extra input to the case study, a 5-story building was selected.

Selected building typology had been constructed in two different districts of Ankara. First neighborhood was built by Turk-İş confederation, mortgage bank and SSK (Social Security Institution) together with cooperative members in Aydınlıkevler district in 1972 with a capacity of 2566 flats. Due to excessive demand, the second neighborhood was built in 100. Yıl district in 1973 with 4906 flats. This time, a new high-rise typology that consists of 15 stories is introduced along with existing 5-storied types (Başaran *et al.*, 2015). The study is focused on the 5-storied typology in 100. Yıl district. Although the building plans have been modified by end-users, original project is used as a basis. Building drawings can be found in the appendix section.

Heating system in both districts was originally designed as a district heating system but now each block use individual natural gas fired boilers. Original buildings were built without insulation but exterior sheathing was applied to most of the 15-storied buildings. 5-storied buildings on the other hand, remain uninsulated today. 15-storied buildings were mostly insulated with XPS sheathing before it was restricted by current fire safety regulation (Binaların Yangından Korunması Hakkında Yönetmelik, 2017).

3.2.3. Building Energy Demand Calculation

Building Energy Evaluation was performed according to TS 825 standards (2009). The building is in Ankara which is in 3rd climate zone. First, building data was extracted from the BIM for each building element and u values were calculated according to Equation 3.3 where R_i is interior surface's heat transfer resistance, R_e is exterior surface's heat transfer resistance and R is total heat transfer resistance of the multi-layered section. R_i and R_e were obtained from TS 825 (2009) and R was calculated according to Equation 3.4 where d represents thickness and λ represents heat transmission coefficient of individual layers. Specific heat losses of surfaces were calculated by multiplying total areas and U values of individual building surfaces.

Table 3.13 Specific surface heat loss calculation of building elements without insulation

Type	Abbr.	Total Area (m^2)	U value ($W/m^2.k$)	Heat Loss (W/K)
Exterior concrete walls	WC	191	0,44	84,76
Exterior brick walls	WB	607	0,42	255,20
Windows (double pane)	F	103	2,10	216,30
Exterior Door (steel)	D	33	2,50	82,50
Roof (projection)	R	198	0,44	86,92
Foundation Pad	P	198	0,60	118,68
Grand Total	Σ	1300	-	844,36

Net specific heat loss was calculated by adding up specific heat loss of building envelope and ventilation heat loss. The building does not have a mechanical ventilation system. Thus, ventilation loss factor is 0,8 according to TS 825. In equation 3.12, Hv is ventilation heat loss, n_h is ventilation loss factor and V_h is total ventilated volume which is 2340 m^3.

$Hv = 0,33 \times n_h \times V_h$ Equation 3.12

$Hv = 0,33 \times 0,8 \times 2340 = 617,76$ W/K

Thus, total specific heat loss is 2207,87 + 617,76 = 2825,63W/K. Total heat demand was calculated as shown in Table 3.14.

Table 3.14 Total heat demand calculation for the case building without insulation

Months	Heat Loss			Heat Gain					
	Specific Heat Loss (W/K)	Temperature Difference (K,C)	Monthly Heat Losses (W)	Interior Heat Gain (W)	Passive Solar Gain (W)	Total (W)	Gain/Loss Ratio	Gain Utilization Factor	Heating Energy Demand (KJ)
January	2.825,63	19,30	54.534,61	14.750	1.658	16.408	0,30	0,96	103.700.783
February		18,90	53.404,36		2.203	16.953	0,32	0,96	99.576.538
March		14,90	42.101,85		2.833	17.583	0,42	0,91	69.967.754
April		8,90	25.148,09		3.422	18.172	0,72	0,75	30.881.870
May		4,60	12.997,89		3.963	18.713	1,44	0,50	9.717.054
June		0,50	1.412,81		4.149	18.899	13,38	0,07	137.980
July		negative	-		4.052	18.802	-	-	-
August		negative	-		3.730	18.480	-	-	-
September		1,80	5.086,13		3.051	17.801	3,50	0,25	1.773.303
October		7,40	20.909,64		2.307	17.057	0,82	0,71	23.727.731
November		13,40	37.863,41		1.656	16.406	0,43	0,90	61.842.258
December		17,70	50.013,61		1.429	16.179	0,32	0,95	92.591.370
								Yearly Total	493.916.640

Total energy demand for one year is 493.916.640 kJ which is equal to 137.199 kWh and heat demand per unit volume is 59 kWh. According to the formula in Appendix A of TS 825 (2009) standards, maximum heat demand calculation of this building is 21 kWh. This value can be achieved with 6 cm thick rockwool, 7 cm thick glass wool or 5 cm thick XPS when specific heat loss and total heat demand calculations are re-performed using the same steps again. Example calculation for rockwool insulation is reperformed in Table 3.15 and optimum thickness is calculated. Same process is repeated for other insulation materials. While calculating heat demand of the insulated scenario, only exterior sheathing of single material was applied. Sheathing should be applied as shown in Figure 3.12. Insulation thickness changes with respect to the material. U values for rock wool, glass wool and XPS have been acquired from companies respectively; 0,037 W/m2.k, 0,039 W/m2.k, 0,030 W/m2.k.

Table 3.15 Specific surface heat loss calculation of building elements with rockwool insulation

1		2	3	4	5	6	7	8
Heath transmitting surface		Building elements	Building element thickness d (m)	Thermal transmittance coefficient λ (W/mK)	Thermal transmittance resistance R (m^2K/W)	Thermal transmittance index u (W/m^2K)	Heath transmitting area A (m^2)	Heath loss A x u W/K
Exterior concrete walls	WC	Ri			0,13			
		Plaster	0,01	0,5	0,02			
		Concrete	0,25	1,65	0,15			
		Insulation	0,07	0,037	1,89			
		Plaster	0,01	0,5	0,02			
		Re			0,04			
Total					**2,25**	**0,44**	**191**	**84,76**
Exterior brick walls	WB	Ri			0,13			
		Plaster	0,01	0,5	0,02			
		Brick	0,13	0,47	0,28			
		Insulation	0,07	0,037	1,89			
		Plaster	0,01	0,5	0,02			
		Re			0,04			
Total					**2,38**	**0,42**	**607**	**255,20**
Windows	F					**2,1**	**103**	**216,30**
Exterior Door	D					**2,5**	**33**	**82,50**
Roof (projection)	R	Ri			0,13			
		Roof insulation	0,08	0,04	2,00			
		Roof concrete	0,12	2,5	0,05			
		Plaster	0,01	0,5	0,02			
		Re			0,08			
Total					**2,28**	**0,44**	**198**	**86,92**
Foundation pad	P	Ri			0,17			
		Wood raft	0,005	0,13	0,04			
		Leveling concrete	0,05	1,4	0,04			
		Pad concrete	0,1	1,1	0,09			
		Raft insulation	0,04	0,03	1,33			
		Re			0			
Total					**1,67**	**0,60**	**198**	**118,68**
Total Heat Loss via Transmittance							**1330**	**844,36**
Heat Loss via Ventilation								**617,76**
SPECIFIC HEAT LOSS								**1462,12**

Months	Heat Loss			Heat Gain			Gain/Loss Ratio	Gain Utilization Factor	Heating Energy Demand (KJ)
	Specific Heat Loss (W/K)	**Temperature Difference (K,C)**	**Monthly Heat Losses (W)**	**Interior Heat Gain (W)**	**Passive Solar Gain (W)**	**Total (W)**			
January		19,30	28.218,88		1.658	16.408	0,58	0,82	39.504.772
February		18,90	27.634,04		2.203	16.953	0,61	0,80	37.504.132
March		14,90	21.785,56		2.833	17.583	0,81	0,71	24.898.180
April		8,90	13.012,85		3.422	18.172	1,40	0,51	9.965.572
May		4,60	6.725,74		3.963	18.713	2,78	0,30	2.881.982
June	1.462,12	0,50	731,06	14.750	4.149	18.899	25,85	0,04	37.387
July		negative	-		4.052	18.802	-	-	-
August		negative	-		3.730	18.480	-	-	-
September		1,80	2.631,81		3.051	17.801	6,76	0,14	496.326
October		7,40	10.819,68		2.307	17.057	1,58	0,47	7.520.659
November		13,40	19.592,39		1.656	16.406	0,84	0,70	21.846.071
December		17,70	25.879,49		1.429	16.179	0,63	0,80	34.734.185
								Yearly Total	179.389.268

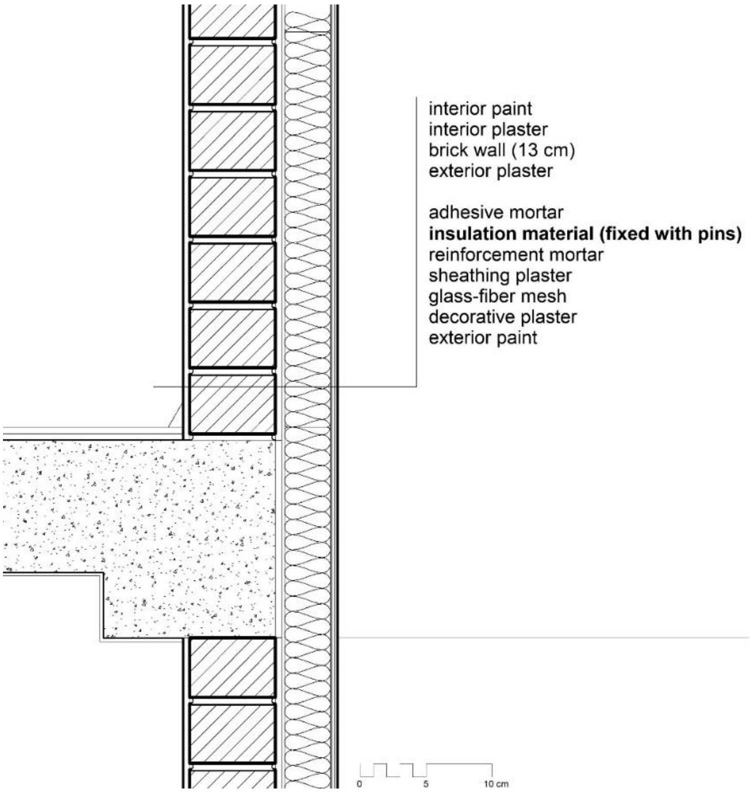


Figure 3.12 Standard detail of wall with sheathing

The method was tested on a real building in a certain climate zone. Therefore, material quantity is a significant parameter. Quantity of the used material was specified as the functional unit of all three assessments to form a common ground among them. This quantity was calculated in the basis of heat loss and designated energy demand variance. In all three design options with different insulation materials, calculated target yearly energy demand is the same. The functional unit was defined as; quantity of insulation material in kilograms with a thickness that gives desired thermal resistance value to provide a constant yearly energy demand per volume according to TS 825 standards (21 kWh/m3 for this specific building). Thus, functional unit is kilograms. According to building energy demand simulations and density information of each insulation material, quantities were calculated as they are given in Table 3.16. These values were calculated as minimum thermal insulation thicknesses to obtain the maximum allowed heating energy demand that is specified in TS 825 standards.

Table 3.16 Insulation material quantity calculation according to TS 825 standards

	density (kg/m3)	thickness (m)	area (m2)	volume (m3)	mass (kg)
rock wool	70	0,07	810	56,7	3969
glass wool	48	0,08	810	64,8	3110
XPS	40	0,06	810	48,6	1944

3.2.4. E-LCA Study

The E-LCA was conducted as a comparative study between three different insulation material scenarios. While comparing different design scenarios, sheathing materials that are similar on each application were kept out of scope.

- **Goal and Scope Definition**

Aim of this study is to evaluate environmental impacts of three insulation materials' production processes in a comparative way. In the end, an environmental impact value was expected via weighting and normalization. The study is based on material quantities that were defined according to heat demand calculation. Thus, functional unit was defined as kilograms and quantities were given on Table 3.16.

LCA studies are generally carried out for the whole lifecycle of a material (cradle-to-grave or cradle-to-cradle) including raw material extraction, material production, installation, usage and disposal/recycle phases. Scope of this study is limited up to construction phase (cradle-to-gate with options) (Figure 3.13) (BRE, 2013) since construction phase of these materials contains similar processes; thermal insulation materials do not cause any environmental damage during usage phase and there is no previously defined recycle/disposal strategy for this study to obtain data.

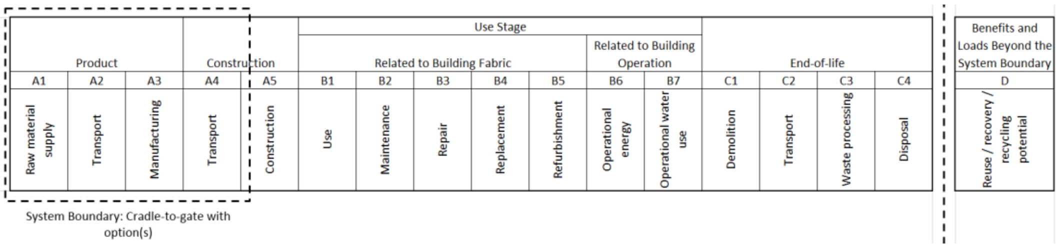


Figure 3.13 System boundary definition (BRE, 2013)

E-LCA study was performed within Revit software by using the Tally plugin. The plugin uses its own database that is based on environmental product declarations (EPDs) for E-LCA study. The database was created via collaboration of Kieran Timberlake and Thinkstep. LCA modeling of Tally has been conducted in GaBi 6 software using GaBi databases. The data used represent US and the year 2013.

- **Life Cycle Inventory Assessment**

To perform E-LCA on Revit, existing building data was defined as the main model and different insulation materials with respective thicknesses were applied as different design options. So that, each design option could be edited individually without interfering with each other. Upon selecting a defined design option, material quantities exclude unselected options and only show one insulation material application. This information was transferred directly into Tally plug-in and sheathing materials that are similar in each application like plasters were defined as “dummy materials” to keep them out of the evaluation scope. Then, insulation materials on each design option that comes from Revit were transformed into Tally materials with pre-defined environmental data. Densities of materials were re-entered from values in Table 3.16 to calculate mass quantities.

Manufacturing phase of Tally assessment (A1 and A3) includes raw material extraction, processing, intermediate transportation, final manufacturing and assembly processes. Infrastructure (buildings and machinery) required for the manufacturing and assembly of insulation materials are not included.

Transportation distances (A2 and A4) were entered for each design option individually by defining transportation method. Total transportation impact was divided into two phases; transportation of raw materials (A2) and transportation of insulation material to the site (A4). Transportation of raw materials were calculated according to freight distance and mass fractions in percentage. Site transportation was calculated directly by measuring distances between production facility and construction site. The site is in Ankara. Production locations of materials are defined as İzocam facilities for mineral wools and ODE Isıpan for XPS (Selected facilities for E-LCA are not necessarily the same with the facilities selected for S-LCA).

According to given assumptions, transportation distances of insulation materials from production facility to the site are given on Table 3.17 for each insulation material.

Table 3.17 Transportation distances between production facility and site

	company	facility location	freight distance (km)	freight type
Taş yünü	İzocam	Gebze	400	truck
Cam yünü	İzocam	Tarsus	465	truck
XPS	ODE Isıpan	Çorlu	570	truck

Assessment of the manufacturing phase of the study includes all materials required for the end product's manufacturing; including raw materials, hardware, sealants, binders, coatings, *etc.* with a 1% cut-off factor by mass (except known materials that have high environmental impact at low levels) by default in Tally. Similarly, materials with mass fractions that are less than 1% percent were excluded from raw material transportation calculation. To calculate environmental impact of raw material transportation, raw material mass fractions were acquired along with locations of each raw material supplier.

Transportation calculation of rock wool raw materials are given on Table 3.18 (Bau EPD GmbH, 2015; MTA Genel Müdürlüğü, nd.). Locations of most of the raw materials are provided in EPD of İzocam rock wool. Missing locations were defined as the closest extraction points for related materials.

Table 3.18 Transportation distances of raw materials to the production facility with mass fractions for rock wool

Component	Function	Mass fraction (%)	Location	Freight Type	Distance (km)	Weighted Distance
Recycled Glass	Mineral raw material	28	İstanbul	truck	90	25,2
Quartz sand	Mineral raw material	22	Çatalca, İstanbul	truck	130	28,6
Dolomite	Mineral raw material	16	İzmit	truck	50	8
Limestone	Mineral raw material	10	İzmit	truck	50	5
Basalt	Mineral raw material	5	Çorlu, Tekirdağ	truck	190	9,5
Iron ore	Mineral raw material	5	İstanbul	truck	90	4,5
Sodium sulphate	Mineral raw material	>1	Beypazarı, Ankara	truck	300	0
Phenolic resin	Binder	4	Gebze, İzmit	local	0	0
Additives	Binder	2	Gebze, İzmit	local	0	0
Auxiliary materials	Hydrophobing agents Adhesion agents Auxiliary materials for coloring	>1 (total)	NA	truck	0	0
Glass veil	Facing	7	Gebze, İzmit	local	0	0
				TOTAL	truck:	80,8

Transportation calculation of glass wool is given on Table 3.19 (Bau EPD GmbH, 2014). Facing material (glass tissue) of glass wool battings is supplied from Poland. Although it has a low mass fraction, its high unit emission value caused by freight makes a significant effect on the assessment.

Table 3.19 Transportation distances of raw materials to the production facility with mass fractions for glass wool

Component	Function	Mass fraction (%)	Location	Freight Type	Distance (km)	Weighted Distance
Recycled Glass	Glass raw material	60	Kırklareli	truck	1110	666
Borax pentahydrate	Glass raw material	6	Kırka, Eskişehir	truck	612	36,72
Quartz sand	Glass raw material	2	Feke, Adana	truck	170	3,4
Soad ash	Glass raw material	4	Mersin	truck	25	1
Colemanite	Glass raw material	2	Kestelek, Bursa	truck	833	16,66
Magnesite	Glass raw material	>1	Kütahya	truck	711	0
Feldspar	Glass raw material	6	Muğla	truck	840	50,4
Manganese dioxide	Glass raw material	>1	Kilis	truck	335	0
Sodium nitrate	Glass raw material	>1	Bulgaria	truck	1330	0
Phenol formaldehyde resin	Binder	6	Gebze, İzmit	truck	890	53,4
Additives	Binder	3	Gebze, İzmit	truck	890	26,7
Auxiliary materials	Hydrophobing agents Adhesion agents Auxiliary materials for coloring	>1 (total)	NA	truck	0	0
Glass tissue	Facing	6	Poland	truck + barge	2500 + 720	15000 + 4320
Non-woven textile	Facing	2	Gaziantep	truck	270	5,4
				TOTAL	truck:	2359,68
					barge:	4320

Transportation calculation of XPS is given on Table 3.20 (International EPD System, 2014; EXIBA, 2014). XPS is mostly a polystyrene product. Thus, the most significant emission occurs during transportation of polystyrene.

Table 3.20 Transportation distances of raw materials to the production facility with mass fractions for XPS

Component	Function	Mass fraction (%)	Location	Freight Type	Distance (km)	Weighted Distance
Polystyrene	Raw material	90	Adana	truck	1050	945
Nucleating Agent	Nucleating Agent	<1	NA	NA	0	0
Additives (e.g. Pigments)	Additive	<1	NA	NA	0	0
HBCD	Flame retardent	2	İstanbul	truck	115	2,3
CO2 and co-blowing agents	Blowing agent	12	Niğde	truck	890	106,8
				TOTAL	truck:	1054,1

Transportation distances and freight types for three insulation materials were entered to Tally manually by adding weighted raw material distances to construction distances. According to pre-defined program flows, processes, resources, energy inputs and waste and emission outputs of Tally plug-in, the comparative E-LCA study was conducted.

- **Life Cycle Impact Assessment**

Life cycle impact categories in Tally database had been selected and described according to TRACI 2.1 characterization scheme (Bare, 2012; Guinée *et al.*, 2001; Wildnauer, 2013). Impact category selection, category classification, and category definition steps were automatically performed within Tally software. Steps that are classified as "optional" in ISO 14042 directive (2000) which are normalization and weighting were also performed manually. Impact categories within Tally framework are listed as such:

- Acidification Potential (AP) - kg SO_2 eq
- Eutrophication Potential (EP) - kg N eq
- Global Warming Potential (GWP) - kg CO_2 eq
- Ozone Depletion Potential (ODP) kg - CFC-11 eq
- Smog Formation Potential (SFP) - kg O_3 eq
- Primary Energy Demand (PED) - MJ

To understand main reasons behind impact potentials, similar studies in literature were investigated. Firstly, most of the impact potentials are associated with insulation materials' manufacturing phase. Although end-of-life impacts are not covered, they do not contribute to overall impact values more than 10%. Highest impact of end-of-life scenario occurs in XPS's eutrophication impact. In case of incineration instead of landfill, XPS's global warming potential increases dramatically. In general, production of blowing agents and flame retardants have insignificant effect on total impact potential of XPS (Knauf Insulation, 2016).

Acidification potential of rock wool is mostly associated with SO_2 and NO_x emissions along with a certain amount of HCl emissions (Çamur, 2010; PCR, 2012). For glass wool, most of the acidification potential is caused by manufacturing. Binders contribute to this category in very small amounts (3%-5%). Most of the acidification potential is caused by NO_x and SO_2 through energy generation and direct emissions during the melting process (Saint-Gobain Isover, 2008). For XPS, acidification is associated with combustion of fossil fuels for power generation (Knauf Insulation, 2016).

Highest effect of rock wool production on eutrophication is resulted from ammonia and NOx emissions. Ammonia emissions occur following the application of binding agents and NOx emissions occur as a result of melting process (PCR, 2012). Similar processes and emissions are applicable for glass wool as well. Production of phenolic resins as a binder material is another reason behind eutrophication potential for glass wool (Saint-Gobain Isover, 2008).

Global warming potential of rock wool production is mainly associated with CO2 emissions during melting process. Other processes on the production chain also contribute to global warming due to thermal conversion of natural gas (PCR, 2012). For glass wool, main reason of impact potential is CO2 as well. With most of it resulting from combustion of natural gas (Eurima, 2012; Saint-Gobain Isover, 2008). Raw materials for binders are other reasons behind emissions that contribute to global warming (Saint-Gobain Isover, 2008).

Primarily, emissions that are associated with electricity supply causes ozone depletion potential for rock wool (PCR, 2012). Glass wool's ozone depleting emissions are also related with indirect processes like energy supply. There is no direct emission of halogenated hydrocarbons that are utilized during the production (Saint-Gobain Isover, 2008). For XPS, main reason is also energy supply (Knauf Insulation, 2016).

For rock wool, main reason that causes smog formation (photochemical ozone creation) is methane gas emission as a volatile organic compound (Çamur, 2010). Non-methane VOCs are emitted after application of binding agents and production of packaging film as well (PCR, 2012). For glass wool, main reasons behind smog formation are raw material supply and binders. Phenolic resin releases most of the organic emissions into water and NOx emissions into the air (Saint-Gobain Isover, 2008). For XPS, emissions of blowing agents have the biggest impact on smog formation (Knauf Insulation, 2016).

3.2.5. S-LCA Study

The aim is to find out which thermal insulation material has the biggest social impact according to LCA methodology in the given scope. In the following parts, some further reductions on the framework were done depending on some assumptions, system limitations and data incompleteness for the efficiency of the study. The previously developed framework in Methods section was used for the evaluation. It is expected that such evaluations will promote policies concerning social sustainability in building material production.

The study was conducted on a certain portion of the life cycle of the material covering the production, installation and usage phases. Unlike E-LCA, S-LCA scope includes certain impacts on usage phase as well. Social impacts that occur during production phase mostly effect worker, supplier, local community and society stakeholders. Installation and usage phases, on the other hand, cover the portion of the material's life cycle that starts after its delivery to the site and ends before its demolition. Impacts occur during these phases mostly effect users

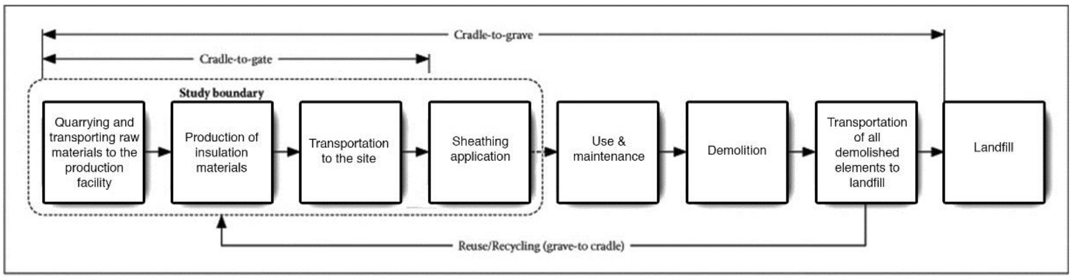


Figure 3.14 LCA phases and system boundaries for insulation materials

System Boundaries

For this assessment, three different thermal insulation materials were selected as rock-wool, glass-wool, XPS. Before obtaining specifications, lifecycle schemes and production details of each insulation material, it was required to create the general framework of the research since S-LCA does not have an explicit assessment structure that is as mature as E-LCA.

- **Indicator Items and Commentaries**

In this section, indicator items are analyzed one by one and assessment methods, scoring systems and score boundaries are set for each of them. This framework of the research was created specifically for this study as an example and it can be developed if indicator items and evaluation parameters are prepared by a group of experts and evaluation is performed on a larger scope. Specifically, each indicator item should be prepared by a multidisciplinary committee with occupational health and safety experts, individuals from the related industry, representatives of local community, academicians, etc. If the assessment is conducted within a national certification program, confidential factory and company data can be acquired, worker and local community surveys can be applied on a large group of participants and interviews may return more reliable answers. Following set of indicator items and evaluation parameters were prepared by a single LCA performer and surveys were performed on a limited number of company representatives to set an example for the application of S-LCA study. Following topics explain the constitution of the indicators one by one. Tables that show exact assessment parameters of each indicator individually can be found in the Appendix B section.

Workers – Health and Safety

Employees are responsible with keeping records of health and safety issues in the workplace according to Turkish occupational health and safety statute (İş Sağlığı ve Güvenliği Kanunu, 2012: clause 14). Also, they are responsible with having an expert team conduct a risk analysis to detect and analyze possible risks in terms of health and safety of the workplace (İSGK, 2012: clause 10). These reports and risk analyses are used as main information source to feed the indicator data.

Number of reported accidents at work: Occupational accidents are defined as incidents that occur on the workplace, on the way to or from the workplace and any work-related activity that occurs outside of the workplace that results with a fatal or non-fatal injury (ILO, 2009). On account of simplicity, incidents that caused at least non-fatal injuries that have been reported by the organization are accepted as occupational accidents. For calculation, occupational accident frequency rate equation is used (Atalay, 2009). Information is verified by worker survey on a Likert scale. Mental injuries are not considered (ILO, 2009). Reportable injuries are defined by Mine Safety and Health Administration (MSHA) as incidents that require medical treatment or result in death, loss of consciousness and inability to perform current job duties (Güngör, 2004).

Number of recognized occupational diseases and reports on elevated health risks: Occupational diseases are defined as any disease that is contracted from an exposure to a risk factor arising from work activities (ILO, 2009). Diseases have to be reported by the employer for insurance premium. (İSGK, 2012: clause 14) These reports are used as a basis of evaluation. Occupational diseases are listed by European Union as; any disease contracted as a result of an exposure to risk factors arising from work activities including: chemical agent based skin, lung or other diseases, infectious and parasitic diseases, work related physical diseases, *etc.* (EUR-Lex, 2003). These definitions are used in the worker survey.

Basic measures and arrangements to maintain and increase safety at work: According to Turkish occupational health and safety statute, employers have to conduct or procure a risk analysis on health and safety issues (İş Sağlığı ve Güvenliği Risk Değerlendirmesi Yönetmeliği, 2012: clause 5). Methodology of this analysis is defined as a risk detection, analyzation, definition of control measures, documentation and measure implementation (İSGRDY, 2012; clause 7). Risk analysis uses a risk value for each health and safety indicator that is defined as: (Risk Value = Probability x Impact) (Buturak, 2015) Total risk values are used to assess general measures on safety issues.

Measures and arrangements to maintain and increase health at work: Employers have to implement necessary measures against physical, chemical and biological dangers in the workplace according to the risk analysis (İş Hijyeni Ölçüm Test ve Analiz Laboratuvarı Hakkında Yönetmelik, 2017: clause 5). Workers' cooperation in implementation of health and hygiene measures is as important as creation of control measures by employer (Council of the European Communities, 1989). For this reason, ILO defines worker related preventive measures about occupational health, as well as employer related ones (Alli, 2008).

Total risk values on health issues are used to assess general measures on protection of occupational health. If separation of health and safety indicators is not possible, indicator no 3 and 4 are assigned with same total number.

Policies and programs to combat important health and safety issues: This indicator is the generalized version of eliminated health and safety category indicators. It basically measures the number of certificates (OHSAS 18001, ISO 45001, *etc.*) ad awards of the organization on health & safety issues.

Workers – Discrimination

Discrimination at work is defined as:

> *…any distinction, exclusion or preference made on the basis of race, color, sex, religion, political opinion, national extraction or social origin, which has the effect of nullifying or impairing equality of opportunity or treatment in employment or occupation (ILO Convention 111, 1958: article 1).*

In Turkish Labor Law, discrimination subjects are listed as; language race, skin color, gender, disability, political view, belief, religion, *etc.* and these (İş Kanunu, 2003: clause 5) Hindering equal opportunity for everyone is a huge obstacle to sustainable development (Norris *et al.*, 2013).

Reports on discriminatory practices of the company: According to Turkish Labor Law, if exposed to any discrimination act, the worker can demand a compensation that is worth up to four monthly salary if he/she can prove it (İ.K, 2003: clause 5). It is presumed that workers have no trouble getting their due. Number of reports on such appeals are used as a measurement tool on yearly basis.

A worker survey can be applied as a supporting measurement tool or an alternative tool in case facility information is not available.

Proportion of women in management positions: According to ILO, (1958: article 1) any distinction act that is caused by the requirements of the job is not regarded as discrimination. Thus, factory job positions that may require specific physical features are excluded from the study and the assessment is focused on number of women on the executive board. On Labor Law, discrimination is not defined in favor of any gender (except gender specific rights like maternity leave). Thus, imbalance on any side of the number of workers equation from different genders is evaluated as a negative social impact.

Ratio of salary of women's wages to men's: In Turkish labor law, it is clearly stated that gender cannot be a reason of difference in application of basic social rights in workplace and it cannot affect directly or indirectly the salary given for a definitive job (İ.K, 2003: clause 5). According to Turkish Statistics Institute data, women are paid 1.3% less if they have a bachelor's degree and 1% less if they have a high school degree than their male counterparts with same backgrounds for a certain job (Gürbüz, 2016). Thus, average male and female salaries on the same department with same specifications are compared. Details are given on impact assessment section.

Proportion of disabled employees: According to Turkish Labor Law, in private sector organizations with more than 50 employees, it is compulsory to employ disabled workers at least 3% of total employees (İ.K, 2003: clause 30). It is also encouraged in international laws to provide special measures for disabled people and it is not evaluated as discrimination (ILO, 1958: article 5). While checking the proportions of disabled workers to total workers, calculations are done in basis of employee number rather than person*hour scale since disabled people may require a special schedule.

Workers – Remuneration

Remuneration and eventually worker satisfaction is measured in this impact category. For this, wages are evaluated in their local context, delays in payment are checked and incentives are also included in the assessment.

Average level of performance-related incentives: Performance related incentive (PRI) is a financial conferral system to employees after a measurement of their performance or inspection of objective fulfilment to increase worker satisfaction and effectiveness (Suff *et al.,* 2007). A strong performance measurement system that is either individual or team based is a prerequisite of PRIs (Pay Research Bureau, 2016). Also, in a successful PRI system, performance criteria and award/penalty elements should be clearly defined and explained to the workers (Tuncel, 2013). Each company has a different incentive method according to their needs. Thus, this indicator is redefined as a qualitative parameter that is transformed into a checklist that measures basic requirements of a successful PRI system for qualitative assessment. Main evaluation structure is based on executive interview on a basis of certain checklist items. Same survey can be applied to a group of workers for verification.

Ratio of corporate minimum wages to local costs of living: Rate of remuneration is measured by comparing it to current local poverty threshold.

Payment of wages in due time: According to Turkish Labor Law, (İ.K, 2003: clause 34) if salaries are not paid on due dates, workers' work stoppage action is not evaluated as a strike and employers are charged with the highest interest rate on deposit. Payment on due dates is evaluated with a basic survey question on Likert scale to workers.

Workers – Forced Labor

In Turkish Constitution, it is clearly stated that forced labor is forbidden and compulsory service can only be demanded by the State in case of emergency (Türkiye Cumhuriyeti Anayasası, 1982: clause 18). Violators of this law are sentenced to imprisonment (Türk Ceza Kanunu, 2005: clause 117). Radical changes about working conditions as it is defined in İ.K. (2003: clause 22) like changing the workplace and forcing the employee working on that location without his/her consent is also evaluated as forced labor (Çomoğlu, 2013). Undoubtedly that, detecting forced labor as it is mentioned in the constitution would be regarded as denouncement. However, it is not clear to which extend minor cases are accepted as occupational crime. Thus, this impact category is based on employees' ideas about the working conditions.

Voluntary commitments by the company on abolition of forced labor: Survey questions are prepared according to ILO Convention No. 105 about abolition of forced labor (ILO, 1957).

Evidence of forced labor: Survey questions are prepared according to ILO Convention No. 29 about forced labor (ILO, 1930).

Workers – Social Security

In this impact category, certain basic social rights of workers are evaluated including pension schemes, social security, sick leaves and contracts.

Evidence of breaches of obligatory social contributions: As it is defined in Turkish Social Security Law, employees who are employed by a person or a party have social security right and employers pay their social security contributions from their own share (Sosyal Sigortalar ve Genel Sağlık Sigortası Kanunu, 2006: clause 4). In Turkey, health and social security systems have been combined under one institution since 2006 (TC. SGK, 2016). This indicator evaluates the opinions of the workers about application of social contributions law.

Duration and level of wage continuation in the case of illness: In case of illness or injury that is proven with a medical report, the worker has the right to paid leave during the time interval that is given on the report. During this time, the employer has the right to fire the employee by paying the severance pay. According to Turkish Labor Law, sick leaves cannot be subtracted from the annual leave right (I.K, 2003). Since it is a special occasion, workers' opinions on the application of that right is asked for the sake of simplicity. This indicator can be developed by getting data from a holistic research of workers who used their health-related paid leave rights for various durations.

Number of workers with a contract: For this indicator, ratio of workers with a contract is calculated with respect to total number of workers on the department. Results are normalized by equalizing minimum value of the ratio to zero.

Workers – Child Labor

Child labor practice may be a promoter for sustainable development in short term but children who are put to work instead of education are at risk of becoming a forgotten generation. Sustainable development cannot leave any stakeholders of the society behind (Norris *et al.,* 2013). In Turkish Labor Law, child workers are defined as children who completed their compulsory primary school education and turned 14 and young workers are defined children between 15 and 18 ages. Suitable jobs for both bodies are defined in Labor Law. Factory production works that various chemicals are involved are listed among unsuitable works. Thus, young and child labors are assessed with different indicators (Çocuk ve Genç İşçilerin Çalıştırılma Usul ve Esasları Hakkında Yönetmelik, 2004).

Reports on cases of child labor: On ILO Convention No 138, the minimum age of workers is defined with minimum duration of compulsory education if not lower than 15. In any case, workers who are younger than 15 years are accepted as child workers. In this indicator, evidence of such a child labor act is questioned.

Total Child Labor Rates: Ratio of child and young workers are evaluated and calculated in two different equations. Youth age limit also covers child age interval. So, child workers are calculated two times to emphasize their importance.

Workers – Freedom of Association

According to ILO Convention No 87, workers have right to establish any association and union and arrange internal affairs independently (1948). This impact category is related to application of this convention.

Voluntary commitments by the company in the field of freedom of association & right to collective bargaining: By using executive interview, company's association and collective bargaining rights policy is questioned to understand if any supportive measures are taken. Worker survey is used for verification or an alternative data source if no satisfactory data is obtained from the main source.

Reports on hindering workers' organizations and their activities: Workers' involvement in unions cannot be a matter of choice when employing or firing a worker (Sayın & Tümer, 2014). Worker experiences are considered on this subject.

Rate of unionization: To calculate rate of unionization, number of member workers are divided to number of total workers.

Workers – Adequate Working Time

According to Turkish Labor Law, maximum working time in a facility is defined 7,5 hours daily for 6 days a week working schedule (I.K, 2003: clause 63). That equals to 45 hours weekly.

Rate of unionization: To calculate adequate working time rate, 45 is subtracted from weekly total working time. If the result is negative, it is compensated to

Local Community – Local Employment

Local development activities are mostly invested and supported by private sector. Private sector can create local businesses that also activate other local service and products and they can also attract money from outside of the community (ILO, 2006). A company's reliance on local workforce and supply chain actors contributes to local industry and the local economy over time (Eyster *et al.*, 2006). Local employers have extensive knowledge about local community issues that can help organizations to build strong relations with community. Also, employees can promote local sustainable development by transferring business skills to local organizations (Norris *et al.*, 2013). For this impact category, it is important to define local community borders. The local community definition is limited to the closest district to the facility's location.

Percentage of spending on locally based suppliers: Reliance on local suppliers is more sustainable since it contributes to local industry and reduce emissions and externalities created by long-distance transport (Smith, 2007). Supply chain is defined for each product. According to locations of these suppliers, foreign ones get zero-point, national ones get 0,5 point and local ones get 1 point. Each supplier's score is multiplied with their mass contribution to final product. Kilogram is used as functional unit. If the whole economic breakdown of procurement budget is available, budget that is allocated to each supplier can be used in weighting as an alternative method.

Work force hired locally: A company can contribute to local sustainable economic growth by increasing local commitment in employment and partnership (Knockaert, Maillefert, 2004). However, compatibility of a company to its location's social and economic level determines its ability to hire local workforce. For example, a high-tech company's decision to not hire local workforce in a location where a majority of people have low educational profile can be evaluated as a sustainable decision (OECD, 2007). It also measures sustainability of the industry's location. In order to detect the origins of the workforce, shuttle records are used.

Local Community – Health and Safety

Apart from potential benefits and opportunities that a company offers to its local environment, there are also potential risks related to company's operations including accidents, structural failures, releases of hazardous materials, exposure to diseases and use of security personnel (International Finance Corporation, n.d.). For sustainable development, public health and safety should keep pace with economic progression (Norris *et al.,* 2013). Scope of this impact category only covers operational and productional activities of facilities. Establishment and disclosure phases are not evaluated.

Accidents connected to the company activities:

A local business brings many safety risks to its local community as well as opportunities (ILO,2006). National Service Center for Environmental Publications, (1999) included chemical accident prevention, emergency preparedness and community outreach as three main criteria of their community safety awards program. Prevention of these risks is covered in indicator number 2.2.3. To understand basic safety risk potential of the facility, yearly reported accidents are evaluated.

Negative health impacts for the local population:

Local businesses may bring contagious diseases that are carried by its employees in case of absence of sufficient health measures or sanitary implementations in the workplace as well as non-contagious diseases resulting from exposure to hazardous materials during transportation (ILO, 2006). This indicator is evaluated according to reported health issues related with company's activities in local community.

Measures and arrangements to maintain and improve safe and healthy living conditions: Upon studying three different sources, certain parameters are created to check local community related health and safety measures according to their relevance, significance and measurability (Mkhabela & Gow-Smith, 2015; International Finance Corporation, 2007; Craxton, 2014). These principles form a checklist to develop a computational result.

- Employees' exposure to communicable diseases have a potential to effect local community as well.
- Transportation of hazardous materials must be handled with care by trained employees.
- Traffic accidents are one of the most significant causes of injury and fatality in local community.
- Waste that is created on-site should be properly secured and safely transported to only pre-registered disposal site.
- An efficient emergency response plan is essential for safety and well-being of local community.

Local Community – Human Rights

"Do not harm" approach that was developed by Harvard University professor John Ruggie rests on three main pillars:

- States are obliged to protect against human rights abuses by companies.
- Corporations are obliged to act with due diligence to ensure that their activities do not adversely affect the rights of those living on the targeted lands.
- Victims of adverse impacts have the right to seek a remedy (Quick, 2014).

The United Nation's "Protect, Respect and Remedy" framework is also created on these three pillars. The operational principles of corporate responsibilities pillar states that organizations should operate in due diligence to human rights by assessing actual and potential human rights impacts, integrating and acting upon the findings, tracking responses, and communicating how impacts are addressed (United Nations Human Rights Office of the High Commision, 2011). Although it is not common among states to give more importance to local people's rights over economic development, local people play a vital role on sustainable development (Norris *et al.*, 2013).

Although the criteria related to this impact category become more significant when analyzed in a context of an international corporation in an undeveloped country, they are also valid for developing and developed countries. So, data collection for this impact category is kept on executive interview and desktop screening level.

Voluntary commitments by the company in the field of local rights: Unilever is one of the largest convenience food producers and consequently one of the biggest palm oil users in the world. Luckily, it has a Sustainable Palm Oil Sourcing Policy that includes specific local community rights criteria apart from anti-deforestation policies such as no exploitation of people and communities and driving positive social and economic impact for smallholders and women (Unilever, 2016). Although not very extensive, Unilever's human rights criteria are adapted from United Nations Human Rights Office of the High Commision's (2013) Free, Prior and Informed principles which is also adapted to companies from various other sources. The sources are tracked down to reach to a more extensive list about local community rights violations of organizational activities of corporations. While doing so, intersecting items with other indicators are extracted. A list of possible commitments that only cover company related activities that are applicable to developing and developed countries as well as undeveloped countries is created from several sources as such: (ILO, 1989; United Nations, 2008; United Nations Development Group, 2009)

- Companies should prevent any action that can deprive local people of their cultural values or ethnic identities.
- Companies should prevent any action that invades possession of lands, territories and resources of local community.
- Any form of forced population transfer, forced eviction or migration should be avoided.

Results are also verified through desktop screening.

Reports on human rights violations related to the company's activities: A list of possible violations is extracted from the list on indicator number 28. Results are also verified through desktop screening.

Human rights training for employees, particularly for security staff: According to Quick (2014), human rights principles must be a policy that all personnel including partners should have a compulsory training on and if the facility is in a foreign country, the education should include local traditions as well. In order to protect local community's rights, especially security personnel who has police powers has to be trained about human rights (UNHROHC, 2012). In Turkey, such a training that includes legal education is compulsory for individuals that are planning to be a private security personnel (Özel Güvenlik Hizmetlerine Dair Kanun, 2004: clause 14). However, an additional training that is given by the company is required to specialize the personnel on local human rights.

Local Community – Community Engagement

Community engagement is a two-way process that includes information flow from company to local community stakeholders and vice-versa (AccountAbility, 2011). This impact category evaluates if an organization includes community stakeholders in relevant decision-making processes and to what extent organization engages with the community (Norris *et al.,* 2013). Community participation in decision making process is one of the main principles of sustainable development (UN, 1992).

Information possibilities for residents: For a sustainable development, organizations should transfer knowledge to the community through formal training programs and general community education initiatives (Norris *et al.,* 2013). On the other hand, project level reporting, multi-stakeholder dialogue approach and transparency policy are some other approaches to allow community engagement through information sharing (Wilson, 2014). Level of information possibilities for residents is measured through interview.

System to respond to community grievances:

For a complete community engagement process, a company should develop a system to respond to community. A Company’s response mechanism may include establishing policies, objectives and targets, governance structure, management systems and processes, action plans, stakeholder engagement, measurement and monitoring of performance or assurance (AccountAbility, 2008).

Local Community – Delocalization and Migration

Delocalization and migration resulted from company's activities: According to International Covenant on Civil and Political Rights: (1996: article 12) everyone lawfully within the territory of a state shall, within that territory, have the right to liberty of movement and freedom to choose his residence. Any delocalization or migration resulted from economic activities of the company (not war or politics) is evaluated as a violation of local community rights for this impact category (Muthu, 2014). Involuntary delocalization and migrations can lead to long-term social and economic troubles for local community that leads to a negative social sustainability impact (Norris *et al.,* 2013).

Forced evictions / resettlements related to the company’s activities: Forced eviction is defined as “the permanent or temporary removal against their will of individuals, families and/or communities from the homes and/or land which they occupy, without the provision of, and access to, appropriate forms of legal or other protection.” (UN Committee on Economic Social and Cultural Rights (CESCR), 1997) Private sector businesses can undertake activities that result in forced evictions or resettlements such as construction in large scale and resource extraction (UNHROHC, 2014). It is important to state that, in a full-scope of a life cycle assessment, this indicator is quite significant when evaluating raw material extraction phase.

User – Health and Safety

Since public health and safety is a prerequisite for a good quality of life, it is one of the main pillars of sustainable development (Norris *et al.,* 2013). Consumers have a basic right to benefit from a certain product or service without risking their health and safety (ISO 26000, 2008) Consumer product safety act (2011) defines product as any article or component that is produced or distributed for sale to a consumer for use in or around a permanent or temporary household or residence. Health and safety impacts of the product use are evaluated in the basis of insulation materials and evaluations mainly depend on general desktop screening of these materials. Previous health and safety impacts covered production phases of insulation materials. This impact category covers usage phase as well as sheathing application process and user stakeholder definition covers health and safety risks to foremen as well as residents.

Health opportunities / risks related to product use: Health and safety implications to consider about insulation materials are mainly fire safety, indoor air quality, mold, corrosion, carcinogenic potential and toxicity potential (Zang, 2016; Rose & Gordon, 2006; Liss, 2017; Stec & Hull, 2010; Levin & Barch, 1989; Hesterberg & Hart, 2002). Among these health and safety impacts, fire safety is the most relevant one for the usage phase of insulation materials that are applied as an exterior sheathing but it is covered in indicator number 35. Indoor air quality, mold and corrosion are irrelevant for exterior applications. Toxicity and carcinogenic potential is included since it has impact on foremen on installation phase. Indicator results are obtained from desktop screening and executive interview.

Accidents related to product use: Safety risks and potentials of insulation materials are evaluated for this indicator item. Most significant safety risk of insulation materials is fire risk. For this reason, insulation materials are graded according to their fire safety classes. Fire safety classes are explained in Turkish Fire Safety in Buildings Directive (Binaların Yangından Korunması Hakkında Yönetmelik, 2017). According to it, insulation materials that are applied on buildings higher than 6,5 meters must be at least of B1 flammability class (difficult to ignite). So, this value is taken as minimum.

Fatalities related to product use: While investing the fatalities related to product use, application phase is also included. So, this indicator requires fire reports and insulation material usages and fatalities that have occurred during insulation action.

Findings of product safety tests (incl. any awards, labels): This indicator includes any positive labels, awards or product safety test results related to any health and safety hazard that is mentioned in indicator number 3.1.1.

User – Consumer Transparency

Increasing and irresponsible consumption directly leads to negative ecologic and social impacts. It is important to inform the user about hazards related to product use to promote responsible consumption and sustainable development (Norris *et al.*, 2013). Transparency is defied in ISO 26000 directive (2008) as; "openness about decisions and activities that impact on society and the environment". Reporting guideline of GRI is one of the tools that companies use to communicate with public on how their activities influence sustainable development outcomes (OECD, 2008). Transparency indicators for this impact category are composed according to methodological sheets of UNEP for S-LCA (Norris *et al.*, 2013)

Consumers' ability to reach full ingredient information: According to Turkish Consumer Protection Act, it is the responsibility of the producer to provide understandable information about product's advertisement, usage, installation, maintenance and repair in Turkish and also with international symbols in form of labels. Furthermore, if any health and safety risks are in question, these risks and protective measures must be legibly written on product's label and user manual (Tüketicinin Korunması Hakkında Kanun, 2013: clause 55). Company websites of each product are investigated to see if there is complete information about full ingredient list on product declarations and labels.

Publication of a sustainability report: Company websites of each product are investigated to see if there is a sustainability report, environmental product declaration or lifecycle assessment study.

Precise and readily understandable information about safe use and maintenance: User manuals are acquired and evaluated to see if required information about health and safety risks is complete and understandable for each product. Health and safety measures are also expected. Risk categories in indicators 3.1.1 and 3.1.2 are used.

User – Feedback Accessibility

User manuals are evaluated for this impact category.

Company's commitment to allow user feedbacks: To understand company's sensitivity on the subject, an interview question is prepared to ask company executives.

System to respond user feedbacks: For a successful sustainable development, a company should develop a system to respond to user feedbacks. To understand how current feedback system works, an interview question is prepared to ask company executives.

Society – Anti-corruption & no improper involvement in political activities

Enhancing accounting and auditing standards and providing effective, proportionate and dissuasive civil, administrative or criminal penalties for failure to comply with such measures is promoted in United Nations' Convention Against Corruption (2004: article 12) Corruption results with unrecorded money flow within the official economic system that has a huge impact on sustainable economic development (Norris *et al.*, 2013). This impact category evaluates corruption in corporate scale as well as in national level.

Evidence of corrupt and / or extortionate business practices: Corrupt practices include; bribery, money laundering, or other illicit activities (Caux Round Table, 2010). Executive interview and desktop screening are performed according to these examples.

Risk of corruption in the country and/or sub-region: This indicator item measures the company's risk of corruption depending on national sensitiveness. Corruption Perceptions Index of company's location is measured to grade this indicator.

Corporate measures to combat corrupt business practices: UN Global Compact (2014) explains possible measures companies take to fight against corruption on principle 10 as; internal measures, (introducing anti-corruption policies within the organization) external measures, (reporting corporate measures and sharing experiences through case studies) collective action (create or participate in a hub with industry peers and propose projects) and call government to action (to address corruption and foster effective governance for a sustainable and inclusive global economy). Executive interview and desktop screening are performed according to these examples.

Society – Contribution to the national economy and stable economic development

A company's economic development level leads to sufficient wealth of both individuals and the state to satisfy basic material needs which then leads to a more socially sustainable community (Norris *et al.,* 2013). There are many ways that companies can contribute to national economy that are not limited with selected indicators. Still, this impact category aims to measure the company's contribution to national economic development.

Contribution to the national budget (taxes paid minus subsidies received): There are many ways to measure a company's contribution to national budget like revenues, paid wages, R&D costs, *etc.* (Norris *et al.*, 2013). The most straight-forward method is to calculate the yearly gap between taxes and revenues.

Contribution to the foreign trade balance: Foreign trade balance is the balance between a country's imports and exports in a given period (Piana, 2006). By its definition, it is directly related to sustainable development since it measures if a country consumes more than it produces. To calculate company's contribution to foreign trade balance, ratio between company's export and import shares are calculated.

The sector stability during market crisis: To evaluate insulation sector's stability during market crisis, an executive interview is conducted and results are verified through desktop screening about expert and executive interviews.

Society – Prevention of Armed Conflicts

Peace and security is one of the core prerequisites for sustainable development (Norris *et al.,* 2013). This impact category measures company's influences on conflicts on regional level.

Link between economic activities and armed conflicts / Risk of conflict: To assess company's contribution to regional conflicts, executive interview and desktop screening methods are used. If the company's location is listed among "no conflict” zones in Heidelberg Institute’s (2016) Conflict Barometer for the latest year, this indicator is irrelevant.

Society - Contribution to national technology / R&D

There is a need for supportive measures to promote and fund environmental technology cooperation and experience sharing for enterprises and governments especially in developing countries (UN, 1992). The funding mechanism shall have an equitable and balanced representation within a transparent system of governance (Bodansky, 2016).

R&D Program participation: Organizations’ contribution to technologic development in cooperation with other organizations (universities, laboratories, institutions, centers) is a social concern (UNEP, 2013). To measure the level of technological contribution of the company, research and development activities are evaluated through executive interview and desktop screening.

Development of innovative products and services: Technologic effort are originated from the organizational activities within the company. This indicator evaluates company’s sensibility to develop innovative products and services.

Society – Public commitment to sustainability issues

Public commitment is a relevant indicator to understand company’s sustainability sensibility not only in organizational level but also in community level (Norris *et al.,* 2013). There are many ways a company can contribute to national sustainability including; reducing energy and resource usage within the whole supply chain, using recycled packaging and establishing a more efficient transportation fleet (Campbell, 2010). Ethic and social issues like basic human rights, working conditions, health and safety issues are also relevant (Social Accountability International, 1997). Sustainability issues covers all subjects that are evaluated within the context of this study; including, participating in the study. Measurable criteria are used within the scope of the context of the study.

Awards for engagement in social and / or environmental sustainability issues: To evaluate company’s commitment in national sustainability issues, awards related to engagement in sustainability investigated through interview and desktop screening.

Membership in alliances and programs to support and promote sustainable business practices: Company's membership in programs and alliances that promote sustainable business practices and their relevance is evaluated through interview and desktop screening.

Supply Chain Actors - Fair Competition

Conflicting acts of companies to fair competitive behavior are identified as; fixing prices, making rigged bills, establishing output restrictions or quotas or sharing or dividing markets by allocating customers, suppliers, territories or lines of commerce (UN, 2008). This impact category aims to measure the company's voluntary commitment to fair competitive attitude towards supply chain actors.

Presence of anti-competitive behavior or violation of anti-trust and monopoly legislation: Monopolization is an act of restrictive business practice that depends on dominant position of market power abuse which refers to an organization's controlling state of the relevant market for a particular good or service by itself or together with a few other enterprises (UN, 2008; Singh, 1989). This indicator evaluates company's anti-competitive behavior through interview and desktop screening.

Presence of policies to prevent anti-competitive behavior: This indicator evaluates company's commitment to prevent anti-competitive behavior in the supply chain by looking at relevant corporate policies through interview and desktop screening.

Supply Chain Actors - Promoting social responsibility among partners

Complication and importance of promoting social responsibility in the supply chain gets more important as the company becomes more globalized (Norris *et al.*, 2013). Promoting sustainability in the supply chain is a way to develop social sustainability guidelines by confirming them according to priorities of the suppliers and partners (OECD, 2008). This impact category evaluates if company's corporate understanding of sustainability covers its supply chain as well.

Presence of codes of conduct that protect human rights of workers among suppliers: This impact category checks if the company has any codes of conduct to promote human rights of its suppliers' and partners' workers as well as its own through interview and desktop screening.

Membership in an initiative that promotes social responsibility along the supply chain: This impact category evaluates company's corporate understanding of sustainability by looking for memberships in any initiative that promotes sustainability long the supply chain through interview and desktop screening.

Supply Chain Actors - Supplier relationships

Carrying company's relationship to suppliers beyond simple transaction relationship improves social conditions of supply chain (Norris *et al.,* 2013). This impact category evaluates company's relationship with suppliers to understand sustainability of its supply chain. Note that interviews with suppliers are important tools of verification to use in this impact category if the suppliers are accessible.

Interactions: payment on time: Delaying payments according to the contracted duration shake the confidence along the supply chain. This indicator evaluates how reliable does the supply chain operate through frequency of occurrence of delays on payment.

Interactions: sufficient lead time: Delays on procurement may occur if contracted lead time is not sufficient. This indicator evaluates how reliable does the supply chain operate through evaluating if the contracted lead time is sufficient?

3.2.6. LCC Study

Economic savings via decreased heating bills is a major motivation for property owners to apply exterior insulation. To measure financial sustainability of each insulation material, life cycle cost (LCC) analysis method was applied with goal and scope definitions that are specific for this study. The assessment structure is mainly based on economic cost of sheathing application during the construction phase and economic gain due to decreased energy demand during the usage phase. Since target energy demand was fixed to the same maximum value, total sheathing cost would be the determining factor on economic sustainability.

- **Goal and Scope Definition**

Scope of life cycle cost assessment depends on which stakeholder of the product's lifecycle benefits from it financially. The assessment was done with respect to the property owners as the decision-making body. So, economic inputs and outputs are calculated according to the "user" stakeholder category. Supposing that sheathing application does not require any maintenance during usage period, money outflow occurs during construction phase only with respect to the property owners. The outflow is balanced with the money gain due to decreased energy bills during the usage phase until payback time when the sheathing application pays its own expenditure. After that breaking point, every passing month brings profit in comparison to the baseline scenario. Therefore, the assessment only covers the time interval that includes the construction phase and the usage phase (Figure 3.15).

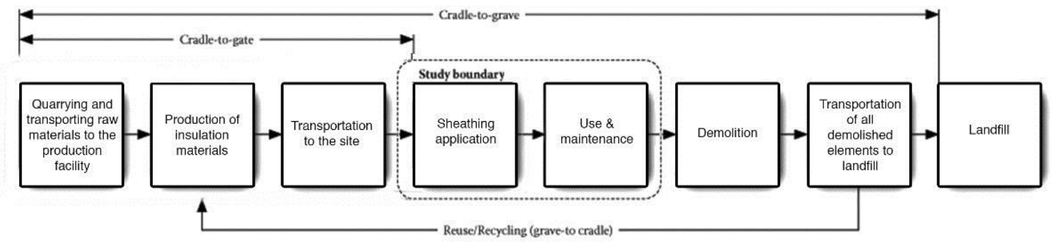


Figure 3.15 LCC phases and system boundary for insulation materials

To compare the difference between economic benefit that is generated by insulation and total sheathing cost, assessment was conducted on the time basis. Since it was presumed that no maintenance or expenditure is required within the payback period or after the payback period that causes an economic loss for property owners within the total usage period of the thermal renovation application, the assessment was not carried out within a defined lifetime period. Payback period of the renovation was specified as the unit of comparison. Aim of this assessment was to calculate this payback period as the method of comparison.

- **LCC Assessment**

To calculate the balance between money outflow and money gain due to insulation, cost items were specified one by one. Firstly, cost items were divided into two categories as materials and workmanship. Since sheathing applications are similar and insulation thicknesses are not significantly different, material quantities except insulation materials were calculated as identical for each insulation scenario (Increase in surface area due to material thickness was omitted since all material quantity calculations include sufficient margin of error). However, total cost of the application was calculated to find out payback period for each scenario. The material items and calculations are shown on Table 3.82. Cost and quantity data was collected from unit prices that have been given by Ministry of Environment and Urbanization of Turkey (2016) and leaflets of İzocam. Glass wool sheathing product is not available in Turkey. So, an equivalent glass wool insulation material with same density, thickness and thermal resistance value was taken as a reference from URSA Insulation, S.A. Application costs were calculated for 1 m^2 of sheathing application as well as for total surface area of the building. While total values were being added up, a single insulation material was selected for each scenario. All material quantities were obtained from BIM directly.

Table 3.21 Cost calculation of sheathing materials

Material		sheathing application for 1 m2				sheathing application for 810 m2						Unit price			Total
		area	volume	count	mass	sack	count	mass	length	area	volume				
		m2	m3	#	kg	#	#	kg	m	m2	m3	₺	definition	ref no	₺
adhesive mortar					4	162		3240				0,35	1 kg	4480	1.134
Insulation Material	Rock wool (7cm)	1,1								891		26,10	1 m2	izocam	23.255
	Glass wool (8cm)	1,1								891				izocam	-
	XPS (6cm)	1,1								891		26,80	1 m2	izocam	23.879
9-15 cm steel insulation pins				6			4860					0,40	1 piece	04.274/2A1	1.944
sheathing plaster					5	162		4050				0,45	1 kg	4.481	1.823
glass-fiber mesh		1,10								891		1,50	1 m2	4.479	1.337
rough plaster (workmanship incl.)			0,02								16,2	90,00	1 m3	10.004/MK	1.458
decorative plaster (workmanship incl.)			0,01								8,1	90,00	1 m3	10.006/MK	729
water			0,013								10,13	5,60	1 m3	4.031	57
angle trim									180			0,44	1 m	04.457/4B	79

After material cost calculation, workmanship was calculated. During this calculation, processes that have been defined in the unit prices inventory of Ministry of Environment and Urbanization of Turkey were taken as a reference. The results are given on Table 3.83.

Table 3.22 Cost calculation of workmanship

Workmanship	Quantity for 1 m2	Quantity for 810 m2	Unit price			Total
	person*hour	person*hour	₺	definition	ref no	₺
sheathing foreman	1,2	972	10,10	1 person*hour	1.010	9.817
sheathing apprentice	0,6	486	7,55	1 person*hour	1.210	3.669
construction worker	2	1620	7,4	1 person*hour	1.501	11.988

To obtain total cost of each design option, workmanship cost was added to material costs. According to that calculation, total costs of each design option are given on Table 3.84 along with unit area cost and costs per flat.

Table 3.23 Total application cost of each design option in TL

	Total	Unit m2	Per flat
Rock wool	57.289,50	70,73	5.728,95
Glass wool	50.796,34	62,71	5.079,63
XPS	57.913,20	71,50	5.791,32

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, results of previously mentioned assessment methods are presented with their final calculations. Weighted values of E-LCA and S-LCA studies are presented as single score results. “Interpretation of results” phase that is suggested for LCA studies in ISO 14040 (2006) directive is performed in this section all together. Still, interpretation phase requires a peer review in the end. First three sections share distinct results of the assessment. Last section reveals the overall result and evaluation.

4.1. E-LCA Results

According to the given impact categories in chapter 3, total environmental impacts of three insulation materials within the given scope were calculated and results are given on Table 4.1 and Figure 4.1. Each material was evaluated with respect to minimum material quantity (kg) that is required to achieve maximum yearly energy demand (21 kWh) for the case building which is the selected functional unit.

Table 4.1 Total environmental impact comparison

Abbreviation		Mass	AP	EP	GWP	ODP	SFP	PED	NRE	RE
Impact Category		**Mass**	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Depletion Potential**	**Smog Formation Potential**	**Primary Energy Demand**	**Non Renewable Energy**	**Renewable Energy**
Unit		kg	$kgSO_2eq$	kgNeq	$kgCO_2eq$	CFC-11eq	O_3eq	MJ	MJ	MJ
Options	**Rock wool**	8.502,900	105,00	2,215	15.248,0	4,005E-04	471,7	180.677	172.521	8.156
	Glass wool	3.115,776	67,83	3,188	11.566,0	7,567E-04	734,7	193.223	176.180	16.043
	XPS	1.457,460	9,13	4,663	3.892,0	2,64E-07	145,2	123.679	120.513	3.165

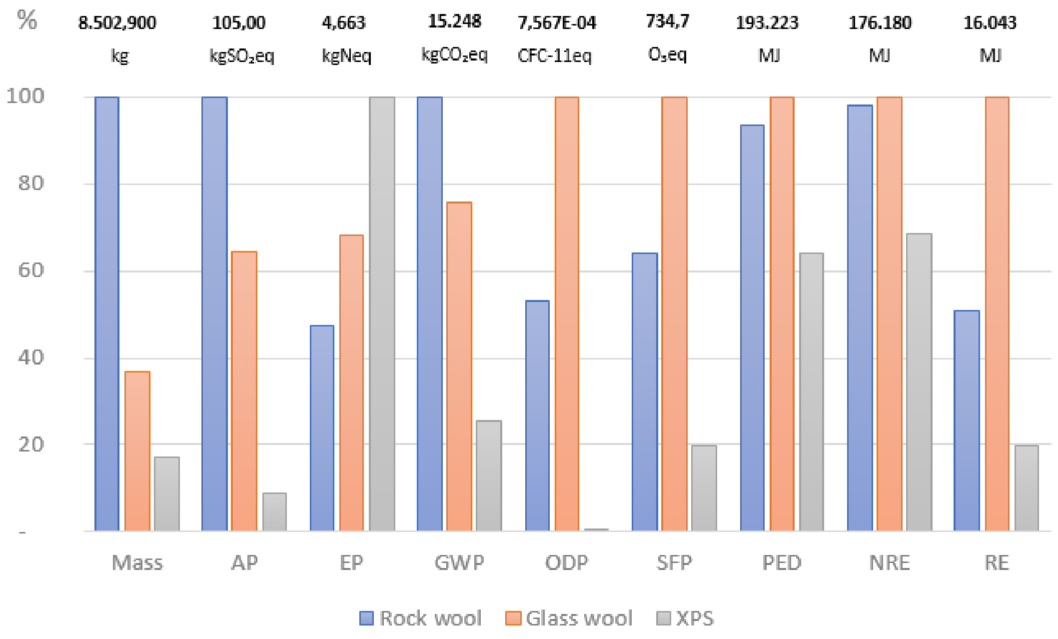


Figure 4.1 Total environmental impact comparison

Although environmental impacts of each material were calculated with respect to the functional unit, unit mass based (1kg) impact calculation was also conducted to see the dependence on material quantity. Results of second assessment are given on Table 4.2 and Figure 4.2. Due to its high density and thickness, rockwool has by far the highest impact on AP and GWP but when calculated according to unit mass, glass wool has a higher impact on both.

Table 4.2 Environmental impact comparison for 1 kg

Abbreviation		AP	EP	GWP	ODP	SFP	PED	NRE	RE
Impact Category		**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Depletion Potential**	**Smog Formation Potential**	**Primary Energy Demand**	**Non Renewable Energy**	**Renewable Energy**
Unit		$kgSO_2eq$	kgNeq	$kgCO_2eq$	CFC-11eq	O_3eq	MJ	MJ	MJ
Options	**Rock wool**	1,23E-02	2,60E-04	1,7933	4,71E-08	5,55E-02	21,2489	20,2897	0,9592
	Glass wool	2,18E-02	1,02E-03	3,7121	2,43E-07	2,36E-01	62,0144	56,5445	5,1490
	XPS	6,26E-03	3,20E-03	2,67E+00	1,81E-10	9,96E-02	84,8593	82,6870	2,1716

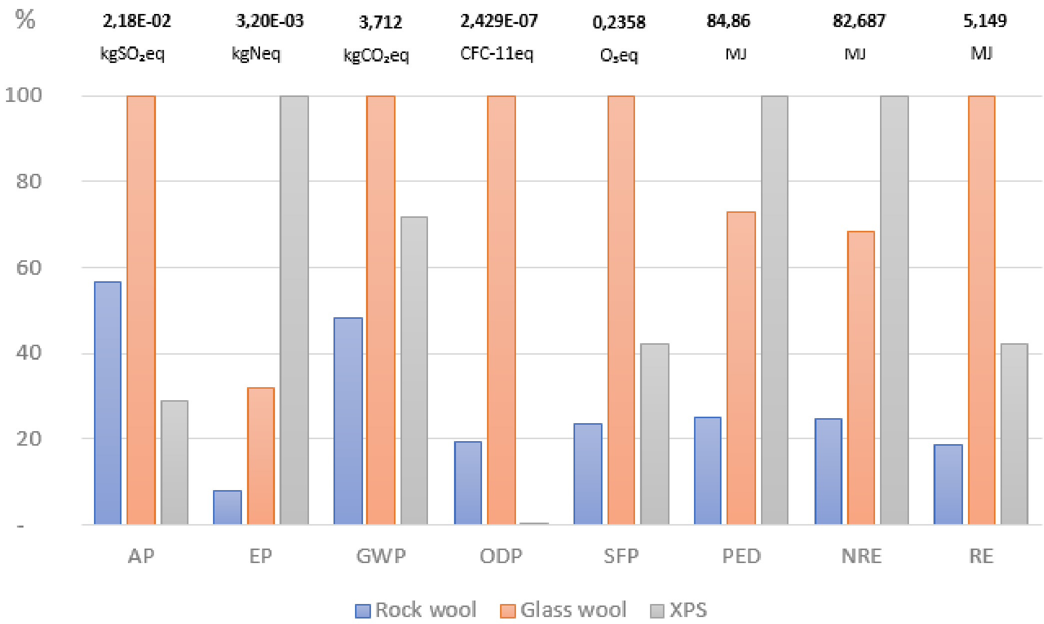


Figure 4.2 Environmental impact comparison for 1 kg

Acquired data needs to be translated into single score assessment data to be used in sustainability assessment. To render comparison of categories possible, each impact data needs to be demonstrated in a chart with a common unit. Normalization operation was applied for this reason. Normalization provides a ratio of each impact data to a reference country's related total impact. Total impact per capita was also used for normalization. This reference country data is called "normalization factor". Preferably, normalization factors are acquired from local data where assessment takes place. Although there have been some attempts to create such a database for Turkey, (Öztaş & Tanaçan, 2015) there is not sufficient data for each impact category. For this reason, TRACI 2.1 database that has been used for impact assessment was used for normalization as well. Values that were used in this normalization process are reference values of US-Canada for 2008.

After normalization, weighting was performed to compare impact values among themselves and come up with a single environmental impact score for each material. Weighting values are available for Turkey in YDED-TR model (Öztaş & Tanaçan, 2015). Normalization and weighting were performed by using Equation 3.13 where each impact potential value (IP) was divided to related normalization factor (NF), multiplied with related weighting factor (W) and summed up for each material to eventually obtain total impact value (TIV). In this equation, i set is composed of insulation materials which are rock wool (1), glass wool (2) and XPS (3) and j set is composed of impact categories which are AP (1), EP (2), GWP (3), ODP (4) and SFP (5).

$$\mathrm{TIV}_k = \sum_{1}^{5} \frac{IP_{ij} \times W_j}{NF_j} \qquad \begin{matrix}(i=1,2,3)\\(j=1,2,3,4,5)\end{matrix} \qquad \text{Equation 3.13}$$

Normalized values of environmental impact categories are show in Table 4.3 and Figure 4.3. According to the normalized values, acidification potential of mineral wools has a significant impact over XPS. Specifically, rockwool's acidification potential is above average country acidification potential per capita. Except that specific value, it is possible to state that all other impact categories for each insulation material are below average for US-Canada per capita values. Ozone depletion potential is insignificant for insulation materials when compared to overall country impact.

Table 4.3 Comparison of normalized and total environmental impacts

Normalization Factor (TRACI 2.1, US-CA 2008 - per capita)		94,60	20,4	24000	0,146	1450
Abbreviation		AP	EP	GWP	ODP	SFP
Impact Category		**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Depletion Potential**	**Smog Formation Potential**
Options	**Rock wool**	1,11	0,11	6,35E-01	2,74E-03	0,33
	Glass wool	0,72	0,16	4,82E-01	5,18E-03	0,51
	XPS	0,10	0,23	1,62E-01	1,81E-06	0,10

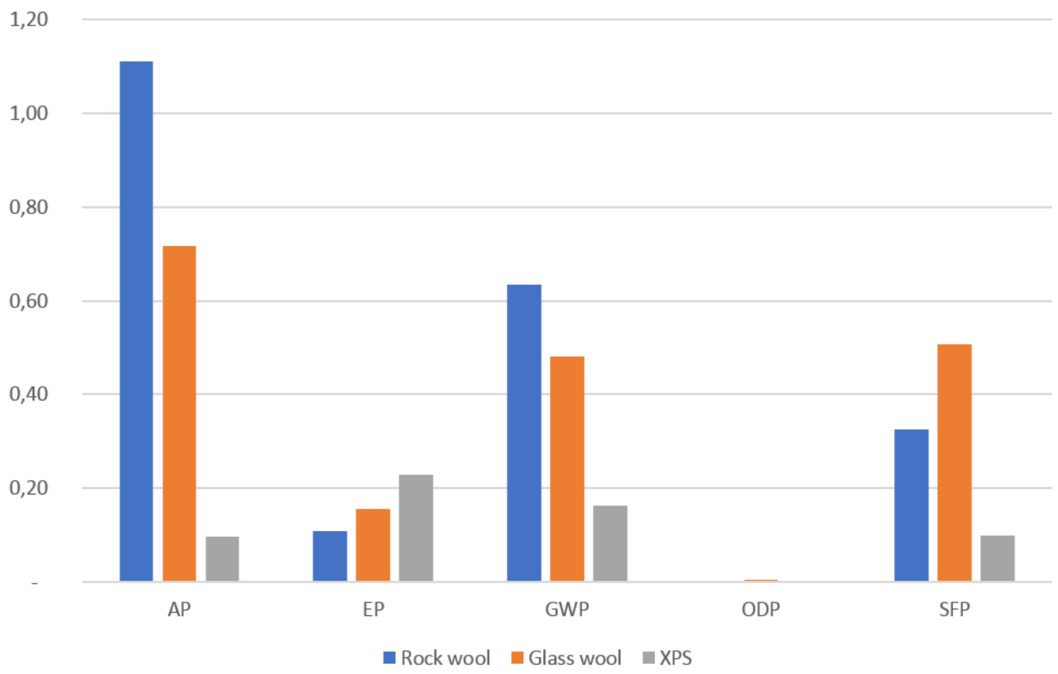


Figure 4.3 Comparison of normalized and total environmental impacts

Weighting is applied according to YDED-TR model which had been created according to a risk assessment study of selected 11 impact categories for Turkey (Tanaçan & Öztaş, 2015). Comparative results after weighting are shown on Table 4.4 and Figure 4.4. According to single score evaluation results, XPS has significantly lower environmental impact in overall. Rock wool, on the other hand, has the highest impact among all three materials. Considering high transportation measure difference between glass wool and rock wool, (where glass wool has the highest impact caused by transportation while rock wool has the lowest) in another study where transportation impacts of these two materials had similar values; difference between rock wool's and glass wool's total environmental impact values would increase and this difference would occur especially in EP and SFP values since transportation has the highest share in these categories.

Table 4.4 Comparison of weighted and single score values

Weighting		0,03	0,05	0,15	0,03	0,03	
Abbreviation		AP	EP	GWP	ODP	SFP	**TOTAL**
Impact Category		**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Depletion Potential**	**Smog Formation Potential**	
Options	**Rock wool**	3,33E-02	5,43E-03	9,53E-02	8,23E-05	9,76E-03	**0,14**
	Glass wool	2,15E-02	7,81E-03	7,23E-02	1,55E-04	1,52E-02	**0,12**
	XPS	2,90E-03	1,14E-02	2,43E-02	5,42E-08	3,00E-03	**0,04**

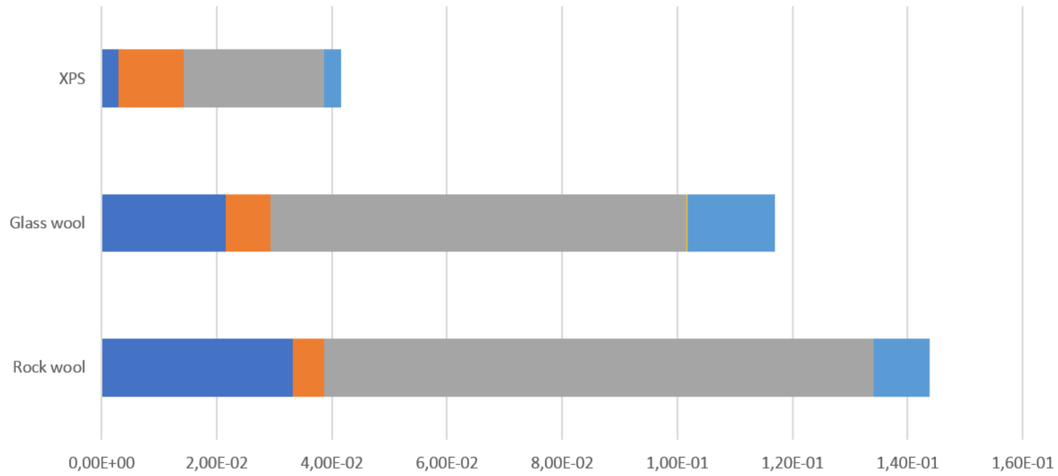


Figure 4.4 Comparison total single score environmental impacts

As it is shown in Table 4.4, GWP has the highest weighting value which means it is the most sensitive impact category for Turkey. Due to XPS's significantly low GWP value, difference between mineral wools and XPS increases after weighting. Only impact category where XPS has a higher environmental impact than mineral wools is EP but difference in other impact categories comprise a higher impact difference. Another impact category where XPS has significant advantage over mineral wools is ODP but since insulation materials' contribution to ozone depletion is too insignificant compared to average reference values, this impact category loses its influence on final results after normalization.

4.2. S-LCA Results

The research structure that has been explained on previous pages was utilized to compare three design options. Firstly, company and facility information were gathered according to the designed scheme (Table 4.4). In the beginning of the survey, number of workers and working hours were learned to calculate yearly person*hour of each facility. This value also acts as a weighting constant between facilities to conduct a fair comparison between facilities with different sizes. Also, raw material mass distribution data through the production process is collected as an optional step for S-LCA. This data is used to determine a weighting value when S-LCA is also conducted on raw material extraction and production phases one by one. Since this study is only conducted on a single production phase, mass distribution data is used for LCA only. Some confidential company data could not be acquired for this individual study.

Table 4.5 “Facility Information” indicators

<table>
<tr><th>ID</th><th>Question</th><th>Equation</th><th>min</th><th>max</th><th>Evaluation</th><th>Stakeholder</th></tr>
<tr><td>0</td><td>How many workers are there in the facility? (for yearly person*hour calculation)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0</td><td>What is the working routine? (for yearly person*hour calculation)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>0</td><td>What is the material mass distribution through the supply chain? (kg)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.1.1</td><td>What is the number of reported occupational accidents in one year?</td><td>OAFR=(#OA/YPH)x1000000</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.1.2</td><td>What is the number of reported occupational diseases in one year?</td><td>ODFR=(#OD/YPH)x1000000</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.1.3</td><td>Sum of Risk Values on the Risk Analysis table for safety items (Risk Analysis Required).</td><td>Sum(RV=P x I)</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.1.4</td><td>Sum of Risk Values on the Risk Analysis table for health items (Risk Analysis Required).</td><td>Sum(RV=P x I)</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.2.1</td><td>Total number of reports on compensation appeals based on discrimination</td><td>Number/YPH</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.2.2</td><td>Absolute value of the difference between male percentage and female percentage on executive board.</td><td>|m%-w%|</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.2.3</td><td>Absolute value of the difference between male and female salaries on same department with same specifications.</td><td>|Sm-Sf|</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.2.4</td><td>Ratio of disabled employees to total number of employees in the working environment.</td><td>D/total number of workers</td><td>0</td><td>max</td><td>HIB</td><td>W</td></tr>
<tr><td>1.3.2</td><td>Rate of minimum full-time worker wages.</td><td>MWW-LPT</td><td>min</td><td>max</td><td>HIB</td><td>W</td></tr>
<tr><td>1.5.3</td><td>Ratio of workers with a contract to total number of workers.</td><td>#CW/#TW</td><td>min</td><td>max</td><td>HIB</td><td>W</td></tr>
<tr><td rowspan="2">1.6.1</td><td>Ratio of workers who are younger than 18 years.</td><td>#MW/#TW</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>Ratio of workers who are younger than 15 years.</td><td>#MW/#TW</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>1.7.3</td><td>Number of unionized workers</td><td>#UW/#TW</td><td>min</td><td>1</td><td>HIB</td><td>W</td></tr>
<tr><td>1.8.1</td><td>Rate of adequate working time</td><td>WTW >WTmax => WTW – WTmax</td><td>0</td><td>max</td><td>LIB</td><td>W</td></tr>
<tr><td>2.1.1</td><td>Location of each supplier in the supply chain. (Local: 1; National: 0,5; Foreign: 0)</td><td>Sum(S1g x S1w) / Sum(1xS1w)</td><td>min</td><td>1</td><td>HIB</td><td>LC</td></tr>
<tr><td>2.1.2</td><td>Ratio of workers who reside out of local community borders.</td><td>#NLW/#TW</td><td>min</td><td>1</td><td>LIB</td><td>LC</td></tr>
<tr><td>2.2.1</td><td>What is the number of reported local accidents connected to company’s activities?</td><td>OAFR=(#OA/YPH)x100</td><td>0</td><td>max</td><td>LIB</td><td>LC</td></tr>
<tr><td>2.2.2</td><td>What is the number of reported local negative health impacts connected to company’s activit</td><td>ODFR=(#OD/YPH) x 1000000</td><td>0</td><td>max</td><td>LIB</td><td>LC</td></tr>
<tr><td>4.2.1</td><td>What is the gap between taxes and revenues according to last year’s results.</td><td>Taxes - subsidies</td><td>min</td><td>max</td><td>HIB</td><td>S</td></tr>
<tr><td>4.2.2</td><td>What is the corporate ratio of company’s export and import shares?</td><td>Export share/import share</td><td>min</td><td>max</td><td>HIB</td><td>S</td></tr>
</table>

For semi-qualitative indicators, interviews with company representatives and facility managers have been conducted. The questions were prepared as interview questions. For indicators that are related to workers and local community, the questions can be designed as survey questions to conduct a survey on a selected group of parties. This would return more reliable results. For this study, answers are collected via interviews with related individual responsibles (Table 4.6).

Table 4.6. “Interview” indicators

ID	Question	Choices					Evaluation	Stakeholder
	Are there any corporate policies or programs to combat occupational health and safety issues?	1,00	0,00				HIB	W
1.1.5	What is your assessment about corporate policy and programs to combat occupational health and safety issues?	1,00	0,75	0,50	0,25		HIB	W
	Is there a performance measurement system applied?	1,00	0,00				HIB	W
	Does the performance related incentive system meet workers’ demands?	1,00	0,66	0,33			HIB	W
	Are performance criteria clearly defined?	1,00	0,66	0,33			HIB	W
	Are performance criteria and rewarding methods clearly explained to the workers?	1,00	0,66	0,33			HIB	W
1.3.1	Are expectations from performance outcomes corresponds to incentives?	1,00	0,75	0,50	0,25		HIB	W
1.3.2	Rate of minimum full-time worker wages.	1,00	0,75	0,50	0,25	0,00	HIB	W
1.3.3	Are your salaries always paid on due time completely?	1,00	0,75	0,50	0,25	0,00	HIB	W
1.4.1	Does the company take corporate measures against forced labor?	1,00	0,75	0,50	0,25	0,00	HIB	W
1.4.2	Do you experience or witness forced labor in your workplace?	1,00	0,75	0,50	0,25	0,00	LIB	W
1.5.1	Have you ever experienced or witnessed a breach of any obligatory social contributions?	1,00	0,75	0,50	0,25	0,00	LIB	W
1.5.2	In case of a health problem with a medical report, have you experienced or witnessed any wage deduction or dismissal?	1,00	0,66	0,33	0,00		LIB	W
1.6.1	Have you witnessed making use of child labors in the workplace who are younger than 15 years old?	1,00	0,75	0,50	0,25	0,00	LIB	W
1.7.1	According to your own observations, does the company support workers' association and collective bargaining rights?	1,00	0,75	0,50	0,25	0,00	HIB	W
1.7.2	Have you ever experienced or witnessed any hindering action on worker organizational activities or any inequality to member workers by the company?	1,00	0,66	0,33	0,00		LIB	W
	Are there any awareness campaigns on hygiene and sanitation in the workplace?	1,00	0,66	0,33	0,00		HIB	LC
	Are there enough measures to avoid possible community exposure of hazardous materials from transportation vehicles?	1,00	0,75	0,50	0,25	0,00	HIB	LC
	Are there registered sites for waste disposal and is it certain that only these sites are used for disposal?	1,00	0,75	0,50	0,25	0,00	HIB	LC
	Is it ensured that haul trucks are never overloaded and speed limits are never exceeded?	1,00	0,75	0,50	0,25	0,00	HIB	LC
2.2.3	In case of any emergency, is there a backup communication system with off-site resources like fire department?	1,00	0,00				HIB	LC
	Does the facility show due diligence on protecting local cultural values and ethnic identities?	1,00	0,75	0,50	0,25	0,00	HIB	LC
	Does the company show due diligence on not invading local lands, territories and resources?	1,00	0,75	0,50	0,25	0,00	HIB	LC
2.3.1	Does the facility show due diligence on avoiding forced population transfers or migrations?	1,00	0,75	0,50	0,25	0,00	HIB	LC
	Are there any occurrences of violation of local community’s right to protect local cultural values and ethnic identities caused by the facility’s activities?	1,00	0,75	0,50	0,25	0,00	LIB	LC
	Are there any occurrences of invasion of local lands, territories and resources by the facility?	1,00	0,75	0,50	0,25	0,00	LIB	LC
2.3.2	Are there any occurrences of forced population transfers, or migrations caused by company’s activities?	1,00	0,75	0,50	0,25	0,00	LIB	LC
2.3.3	Is there any specific education program for employees (especially for security staff) on human rights?	1,00	0,00				HIB	LC
2.4.1	Do you think the facility gives enough importance to local community informing through formal trainings, project level reports and community dialogues?	1,00	0,66	0,33	0,00		HIB	LC
2.4.2	Do you think the facility gives enough importance to developing a system to respond community grievances?	1,00	0,75	0,50	0,25	0,00	HIB	LC
2.5.1	Is there any delocalization eviction or migration resulted from company’s establishment or organizational activities?	1,00	0,00				LIB	LC
2.5.2	Are there any forced eviction or resettlement case resulted from facility’s establishment or organization activities?	1,00	0,00				LIB	LC
3.3.1	Do you think the facility gives due diligence to allow and evaluate feedbacks from users?	1,00	0,75	0,50	0,25	0,00	HIB	U
3.3.2	Do you think the facility gives enough importance to developing a system to respond user grievances?	1,00	0,75	0,50	0,25	0,00	HIB	U
4.1.1	Do you agree that the company has involved in corrupt or extortionate business practices?	1,00	0,75	0,50	0,25	0,00	LIB	S
4.1.3	Do you agree that the company takes corporate measures to combat corrupt business practices?	1,00	0,75	0,50	0,25	0,00	HIB	S
4.2.3	How much was the sector affected from the latest economic crisis?	1,00	0,75	0,50	0,25	0,00	LIB	S
4.3.1	Do you think that the company’s corporate activities contribute to regional conflicts?	1,00	0,75	0,50	0,25	0,00	LIB	S
4.4.1	Does the company contribute to national technologic development by participating in research and development projects?	1,00	0,66	0,33	0,00		HIB	S
4.4.2	Does the company display due diligence to develop innovative products and services?	1,00	0,66	0,33	0,00		HIB	S
5.1.1	Does the company perform any anti-competitive behavior or violation of anti-trust and monopoly legislation?	1,00	0,75	0,50	0,25	0,00	LIB	SCA
5.1.2	Is there any corporate policy to prevent anti-competitive behavior in the supply chain?	1,00	0,50	0,00			HIB	SCA
5.2.1	Are there any corporate codes of conduct to protect human rights of workers among suppliers?	1,00	0,50	0,00			HIB	SCA
5.2.2	Are there any membership in an initiative that promotes social responsibility along the supply chain?	1,00	0,50	0,00			HIB	SCA
5.3.1	How often do delays on payments occur to suppliers and partners?	1,00	0,75	0,50	0,25	0,00	LIB	SCA
5.3.2	Does the company provide sufficient lead time to suppliers?	1,00	0,75	0,50	0,25	0,00	HIB	SCA

Remaining data is collected via desktop screening where the data is available to public (Table 4.7). These questions are mostly qualitative and require literature review or expert revision to understand related terms and design evaluation parameters.

Table 4.7. “Desktop screening” indicators

ID	Question	Scale					Evaluation	Stakeholder
	Material’s toxicity / irritation potential	1,00	0,50	0,00			LIB	U
3.1.1	Material’s carcinogenic potential	1,00	0,50	0,00			LIB	U
3.1.2	Material’s flammability class	1,00	0,50	0,00			HIB	U
3.1.3	Reports of fatalities occurred during insulation process and fire reports related to insulation materials.	# of fatalities					LIB	U
3.1.4	Number of awards, labels and positive product safety results related to health and safety risks of the product	Product safety test results					HIB	U
3.2.1	Is there complete available information about full ingredient list of the product?	1,00	0,50	0,00			HIB	U
3.2.2	Is there a sustainability report, environmental product declaration or lifecycle assessment study published on	1,00	0,50	0,00			HIB	U
3.2.3	Is there complete information on all health and safety risks of product’s installation, use and maintenance phases. Is there complete information about protective measures on all health and safety risks of product’s installation, use and maintenance phases.	1,00	0,50	0,00			HIB	U
4.1.2	What is the corruption perceptions index of the company’s location?	Corruption perceptions score					LIB	S
4.5.1	Are there any awards of the company for engagement in social or environmental sustainability issues?	1,00	0,50	0,00			HIB	S
4.5.2	Are there any membership in alliances and programs to support and promote sustainable business practices?	1,00	0,50	0,00			HIB	S

Factory information, desktop screening and interview results were collected in one unified table and semi-qualitative data was translated into quantitative data by using the formulas and evaluation parameters for each indicator item. While translating fully-qualitative data to quantitative score, interpretation of LCA performer was involved. The results were not collected in a common rating scheme but they give information about their related indicators only. To form a common rating language, the values were normalized.

The primary results were evaluated without categorizing them as "impact" or "benefit". Categorization was done during normalization. Normalization was performed with Equation 3.14 for "lower is better" (LIB) items and with Equation 3.15 for "higher is better" (HIB) items to classify all the results as "impacts". Higher score for LIB items means more social impact. A lower score is desired for them. Higher score for HIB items on the other hand, means less social impact (or more social benefit). A higher score is desired for them. To classify them as "benefit", equations and items must be matched the other way around. In the equations below, I_n is normalized impact value, I is primary result of the indicator item and I_{min} and I_{max} are specified minimum and maximum values for each indicator.

$$I_n = \frac{I - I_{min}}{I_{max} - I_{min}} \qquad \text{Equation 3.14}$$

$$I_n = \frac{I_{max} - I}{I_{max} - I_{min}} \qquad \text{Equation 3.15}$$

By using equations, results were rescaled to fit between 0 and 1 where 0 means "no impact" and 1 means "maximum impact". Some normalization calculations return indeterminate (0/0) result when they represent the maximum or minimum value for their set. These results were fixed to 0 if they are interpreted as "minimum impact" or to 1 if they are interpreted as "maximum impact" Some confidential data about companies was not applicable (NA) and for these indicators, overall normalized value of their own impact category was used. Then, normalized values were multiplied with their related weight values to create a single score. Sum of weighted results of all indicators in each impact category became the impact value for that category. Similarly, sum of all impact values in a stakeholder category became the total impact to that stakeholder. Weighted values were also expanded by multiplying with 100 to see the results as percentages. Results are given on Table 4.8.

Table 4.8 Overall results of S-LCA study

STAKEHOLDERS / ID NO	overall weight	weight	IMPACT CATEGORIES / INDICATORS	Rock wool	Glass wool	XPS	min	max	Evaluation	N-rock wool	N-glass wool	N-XPS	W-rock wool	W-glass wool	W-XPS
WORKERS	0,26		WORKERS										7,694	5,638	7,858
1.1	0,04	0,174	HEALTH AND SAFETY										2,10E-02	2,00E-03	2,05E-02
1.1.1	0,01		Number of accidents at work	3333	444	0,00	0,00	3333	LIB	1,00	0,13	0,00	9,00E-03	1,20E-03	0,00E+00
1.1.2	0,01		Number of recognized occupational diseases and reports on elevated health risks	0,00	0,00	0,00	0,00	0,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.1.3	0,01		Basic measures and arrangements to maintain and increase safety at work	NA	NA	NA	0,00	NA	LIB	NA	NA	NA	6,00E-03	4,00E-04	1,00E-02
1.1.4	0,01		Measures and arrangements to maintain and increase health at work	NA	NA	NA	0,00	NA	LIB	NA	NA	NA	6,00E-03	4,00E-04	8,25E-03
1.1.5	0,01		Policies and programmes to combat HIV/AIDS and/or other locally important health issues (dengue, malaria, alcoholism etc.)	1,00	1,00	0,75	0,00	1,00	HIB	0,00	0,00	0,25	0,00E+00	0,00E+00	2,25E-03
1.2	0,04	0,147	DISCRIMINATION										1,58E-02	1,35E-02	9,47E-03
1.2.1	0,01		Reports on discriminatory practices of the company	0,00	0,00	0,00	0,00	0,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.2.2	0,01		Proportion of women in management positions	0,84	0,73	1,00	0,00	1,00	LIB	0,84	0,73	1,00	7,96E-03	6,91E-03	9,47E-03
1.2.3	0,01		Ratio of salary of women wages to men	0,00	0,00	0,00	0,00	0,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.2.4	0,01		Proportion of disabled employees	0,02	0,03	0,10	0,00	0,10	HIB	0,83	0,70	0,00	7,89E-03	6,63E-03	0,00E+00
1.3	0,04	0,138	REMUNERATION										1,41E-02	1,48E-02	1,53E-02
1.3.1	0,01		Average level of performance-related incentives	0,81	0,75	0,71	0,00	1,00	HIB	0,19	0,25	0,29	2,22E-03	2,96E-03	3,46E-03
1.3.2	0,01		Ratio of corporate minimum wages to local costs of living	0,00	0,00	0,00	0,00	0,00	HIB	1,00	1,00	1,00	1,18E-02	1,18E-02	1,18E-02
1.3.3	0,01		Payment of wages in due time	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.4	0,03	0,128	FORCED LABOUR										0,00E+00	0,00E+00	4,14E-03
1.4.1	0,02		Voluntary commitments by the company on abolition of forced labour	1,00	1,00	0,75	0,00	1,00	HIB	0,00	0,00	0,25	0,00E+00	0,00E+00	4,14E-03
1.4.2	0,02		Reports on cases of forced labour	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.5	0,03	0,11	SOCIAL SECURITY										0,00E+00	0,00E+00	3,13E-03
1.5.1	0,01		Evidence of breaches of obligatory social contributions	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.5.2	0,01		Duration and level of wage continuation in the case of illness	0,00	0,00	0,33	0,00	1,00	LIB	0,00	0,00	0,33	0,00E+00	0,00E+00	3,13E-03
1.5.3	0,01		# of workers with a contract	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.6	0,03	0,101	CHILD LABOUR										0,00E+00	0,00E+00	0,00E+00
1.6.1	0,01		Reports on cases of child labour	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.6.2	0,01		Reports on cases of young labour	0,00	0,00	0,00	0,00	0,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
1.7	0,03	0,11	FREEDOM OF ASSOCIATION										2,60E-02	2,60E-02	2,60E-02
1.7.1	0,01		Voluntary commitments by the company in the field of freedom of association & right to collective bargaining	0,25	0,25	0,25	0,00	1,00	HIB	0,75	0,75	0,75	7,10E-03	7,10E-03	7,10E-03
1.7.2	0,01		Reports on hindering workers' organizations and their activities	1,00	1,00	1,00	0,00	1,00	LIB	1,00	1,00	1,00	9,47E-03	9,47E-03	9,47E-03
1.7.3	0,01		Rate of unionization	0,00	0,00	0,00	0,00	1,00	HIB	1,00	1,00	1,00	9,47E-03	9,47E-03	9,47E-03
1.8	0,02	0,092	ADEQUATE WORKING TIME										0,00E+00	0,00E+00	0,00E+00
1.8.1	0,02		Weekly working hours	0,00	0,00	0,00	0,00	0,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
LOCAL COMMUNITY	0,24		LOCAL COMMUNITY										8,949	4,867	9,338
2.1	0,06	0,228	LOCAL EMPLOYMENT										3,59E-02	2,76E-02	4,32E-02
2.1.1	0,03		Percentage of spending on locally based suppliers	0,67	0,45	0,52	0,45	1,00	HIB	0,61	1,00	0,87	1,68E-02	2,76E-02	2,40E-02
2.1.2	0,03		Work force hired locally	0,70	0,02	0,70	0,02	1,00	LIB	0,69	0,00	0,69	1,91E-02	0,00E+00	1,91E-02
2.2	0,06	0,228	HEALTH AND SAFETY										3,39E-02	1,38E-03	2,41E-02
2.2.1	0,02		Accidents connected to the company's activities	3,33	0,00	5,00	0,00	5,00	LIB	0,67	0,00	1,00	1,23E-02	0,00E+00	1,84E-02
2.2.2	0,02		Negative and positive health impacts for the local population	1,67	0,00	0,00	0,00	1,67	LIB	1,00	0,00	0,00	1,84E-02	0,00E+00	0,00E+00
2.2.3	0,02		Measures and arrangements to maintain and improve safe and healthy living conditions	0,825	0,925	0,69	0,00	1,00	HIB	0,18	0,08	0,31	3,22E-03	1,38E-03	5,68E-03
2.3	0,06	0,246	HUMAN RIGHTS										1,32E-02	1,32E-02	1,49E-02
2.3.1	0,02		Voluntary commitments by the company in the field of human rights	0,83	0,83	0,75	0,00	1,00	HIB	0,17	0,17	0,25	3,30E-03	3,30E-03	4,95E-03
2.3.2	0,02		Reports on human rights violations related to the company's activities	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
2.3.3	0,02		Human rights training for employees, particularly for security staff	0,50	0,50	0,50	0,00	1,00	HIB	0,50	0,50	0,50	9,90E-03	9,90E-03	9,90E-03
2.4	0,04	0,158	COMMUNITY ENGAGEMENT										6,49E-03	6,49E-03	1,13E-02
2.4.1	0,02		Information possibilities for residents	0,66	0,66	0,66	0,00	1,00	HIB	0,34	0,34	0,34	6,49E-03	6,49E-03	6,49E-03
2.4.2	0,02		System to respond to community grievances	1,00	1,00	0,75	0,00	1,00	HIB	0,00	0,00	0,25	0,00E+00	0,00E+00	4,78E-03
2.5	0,03	0,14	DELOCALIZATION										0,00E+00	0,00E+00	0,00E+00
2.5.1	0,02		Delocalization or Migration resulted from company's activities.	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
2.5.2	0,02		Forced evictions / resettlements related to the company's activities	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
CONSUMER/USER	0,23		USERS										0,651	1,954	5,573
3.1	0,1	0,462	HEALTH AND SAFETY										0,00E+00	1,30E-02	2,61E-02
3.1.1	0,03		Health opportunities / risks related to product use	0,00	0,50	0,50	0,00	1,00	LIB	0,00	0,50	0,50	0,00E+00	1,30E-02	1,30E-02
3.1.2	0,03		Accidents related to product use	1,00	1,00	0,50	0,00	1,00	HIB	0,00	0,00	0,50	0,00E+00	0,00E+00	1,30E-02
3.1.3	0,03		Fatalities related to product use	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
3.1.4	0,03		Findings of product safety tests (incl. any awards, labels)	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
3.2	0,07	0,308	TRANSPARENCY										0,00E+00	0,00E+00	2,32E-02
3.2.1	0,02		Consumers' ability to reach full ingredient information	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
3.2.2	0,02		Publication of a sustainability report	1,00	1,00	0,00	0,00	1,00	HIB	0,00	0,00	1,00	0,00E+00	0,00E+00	2,32E-02
3.2.3	0,02		Precise and readily understandable information about safe use and maintenance	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
3.3	0,05	0,231	FEEDBACK ACCESSIBILITY										6,51E-03	6,51E-03	6,51E-03
3.3.1	0,03		Company's commitment to allow user feedbacks	0,75	0,75	0,75	0,00	1,00	HIB	0,25	0,25	0,25	6,51E-03	6,51E-03	6,51E-03
3.3.2	0,03		System to respond user feedbacks	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
SOCIETY	0,15		SOCIETY										3,665	3,665	3,665
4.1	0,04	0,244	CORRUPTION										1,02E-02	1,02E-02	1,02E-02
4.1.1	0,01		Evidence of corrupt and / or extortionate business practices	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
4.1.2	0,01		Risk of corruption in the country and/or sub-region	41	41	41	90	10	LIB	0,61	0,61	0,61	7,24E-03	7,24E-03	7,24E-03
4.1.3	0,01		Corporate measures to combat corrupt business practices	0,75	0,75	0,75	0,00	1,00	HIB	0,25	0,25	0,25	2,96E-03	2,96E-03	2,96E-03
4.2	0,03	0,222	CONTRIBUTION TO ECONOMY										1,61E-02	1,61E-02	1,61E-02
4.2.1	0,01		Contribution to the national budget (taxes paid minus subsidies received)	NA	NA	NA	NA	NA	HIB	NA	NA	NA	5,38E-03	5,38E-03	5,38E-03
4.2.2	0,01		Contribution to the foreign trade balance	NA	NA	NA	NA	NA	HIB	NA	NA	NA	5,38E-03	5,38E-03	5,38E-03
4.2.3	0,01		Company's economic stability during market crisis	0,50	0,50	0,50	0,00	1,00	LIB	0,50	0,50	0,50	5,38E-03	5,38E-03	5,38E-03
4.3	0,03	0,178	CONFLICTS										0,00E+00	0,00E+00	0,00E+00
4.3.1	0,03		Link between economic activities and armed conflicts / Risk of conflict	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
4.4	0,03	0,178	CONTRIBUTION TO NATIONAL TECHNOLOGY										1,03E-02	1,03E-02	1,03E-02
4.4.1	0,01		R&D Program participation	0,60	0,60	0,60	0,00	1,00	HIB	0,40	0,40	0,40	5,16E-03	5,16E-03	5,16E-03
4.4.2	0,01		Development of innovative products and services	0,60	0,60	0,60	0,00	1,00	HIB	0,40	0,40	0,40	5,16E-03	5,16E-03	5,16E-03
4.5	0,03	0,178	NATIONAL COMMITMENT TO SUSTAINABILITY										0,00E+00	0,00E+00	0,00E+00
4.5.1	0,01		Awards for engagement in social and / or sustainability issues	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
4.5.2	0,01		Membership in alliances and programmes to support and promote sustainable business practices	1,00	1,00	1,00	0,00	1,00	HIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
SUPPLY CHAIN ACTORS	0,13		SUPPLY CHAIN ACTORS										4,912	4,912	6,305
5.1	0,05	0,409	FAIR COMPETITION										2,64E-02	2,64E-02	2,64E-02
5.1.1	0,03		Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation	0,00	0,00	0,00	0,00	1,00	LIB	0,00	0,00	0,00	0,00E+00	0,00E+00	0,00E+00
5.1.2	0,03		Presence of policies to prevent anti-competitive behaviour Y/N	0,00	0,00	0,00	0,00	1,00	HIB	1,00	1,00	1,00	2,64E-02	2,64E-02	2,64E-02
5.2	0,04	0,273	SOCIAL RESPONSIBILITY										1,76E-02	1,76E-02	2,64E-02
5.2.1	0,02		Presence of codes of conduct that protect human rights of workers among suppliers	0,00	0,00	0,00	0,00	1,00	HIB	1,00	1,00	1,00	1,76E-02	1,76E-02	1,76E-02
5.2.2	0,02		Membership in an initiative that promotes social responsibility along the supply chain	1,00	1,00	0,50	0,00	1,00	HIB	0,00	0,00	0,50	0,00E+00	0,00E+00	8,80E-03
5.3	0,04	0,318	SUPPLIER RELATIONSHIPS										5,13E-03	5,13E-03	1,03E-02
5.3.1	0,02		Interactions: payment on time	0,00	0,00	0,25	0,00	1,00	LIB	0,00	0,00	0,25	0,00E+00	0,00E+00	5,13E-03
5.3.2	0,02		Interactions: sufficient lead time	0,75	0,75	0,75	0,00	1,00	HIB	0,25	0,25	0,25	5,13E-03	5,13E-03	5,13E-03

According to the total stakeholder impact scores, chart on the Figure 4.5 has been drawn. The chart shows total social impacts of each design option with contributions of each stakeholder category within them. The values on the chart are also their percentage values with respect to possible maximum social impact score which is 100.

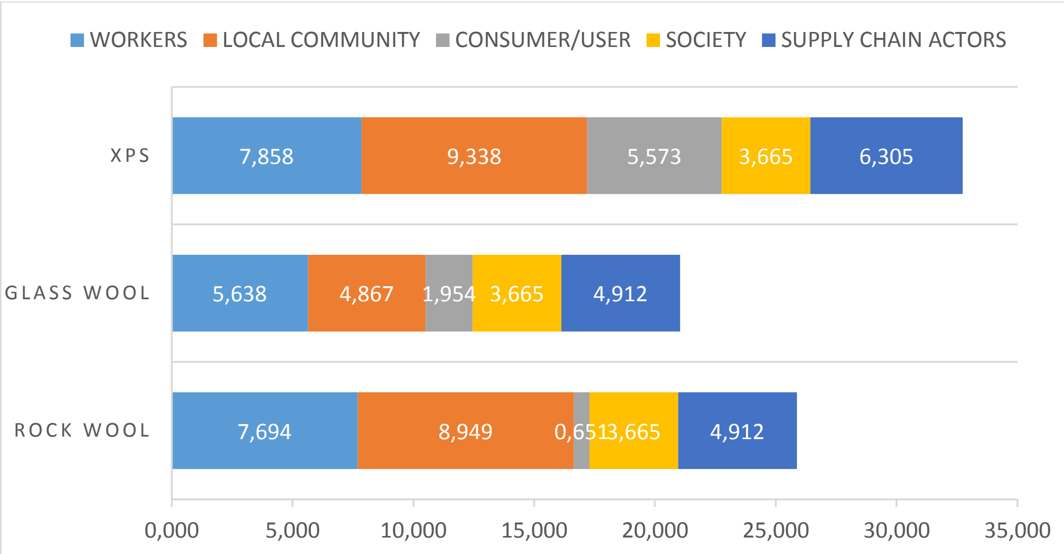


Figure 4.5 Overall results of S-LCA study.

The most significant social impacts were detected on "supply chain actors" category for all three materials. This hot-spot reveals that companies do not consider developing policies that could protect their suppliers' and their workers' rights besides their other policies about their own workers' rights, environmental protection, local people's rights and customer satisfaction. Also, there are some significant hot-spots on certain impact categories that are essential to improve. Firstly, it was detected that worker salaries are below the national poverty threshold for a family of four people. Secondly, it can be understood that female executive rates are quite low in the sector. Lastly, unionization and collective bargaining system is not applicable and it should be developed for the sector. Risk analysis, national economy contribution and foreign trade balance were non-applicable data which are valuable points and could have been used to detect more hot-spots. For a more sustainable thermal insulation industry, these problems should be addressed.

4.3. LCC Results

As it was stated in chapter 3, cost comparison was performed according to payback periods by utilizing the calculation results in chapter 3. For this reason, yearly heating cost was calculated for baseline scenario as well as three design scenarios by dividing natural gas unit cubic meter price for Ankara to one cubic meter natural gas kWh heating potential and multiplying the result with monthly heating demand. This calculation was performed for three design options as well and cumulative cost data of each month was compared on a graph (Figure 4.6). Annual inflation was omitted. Also, since these insulation materials does not require any maintenance within at least 10 years, maintenance scenario is omitted.

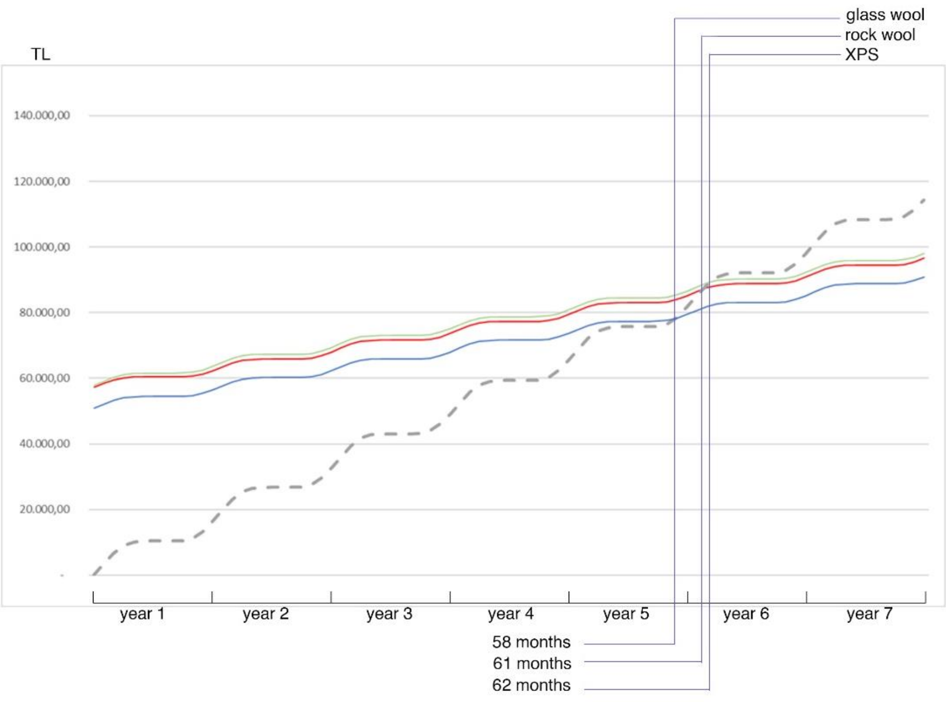


Figure 4.6 Payback period comparison of design options

The results show that payback period of rock wool and XPS scenarios are very close to each other. Although price of glass wool product was a reference value, the results can be used in feasibility studies to define the unit price of glass wool batting for sheathing purposes. Total payback time results in moths were accepted as impact scores of the comparative LCC study.

4.4. Overall LCSA Results

Since the framework can be based on an overall renovation process, sheathing application has been defined as a single step of building renovation process within that overall framework as it is visualized in Figure 4.7.

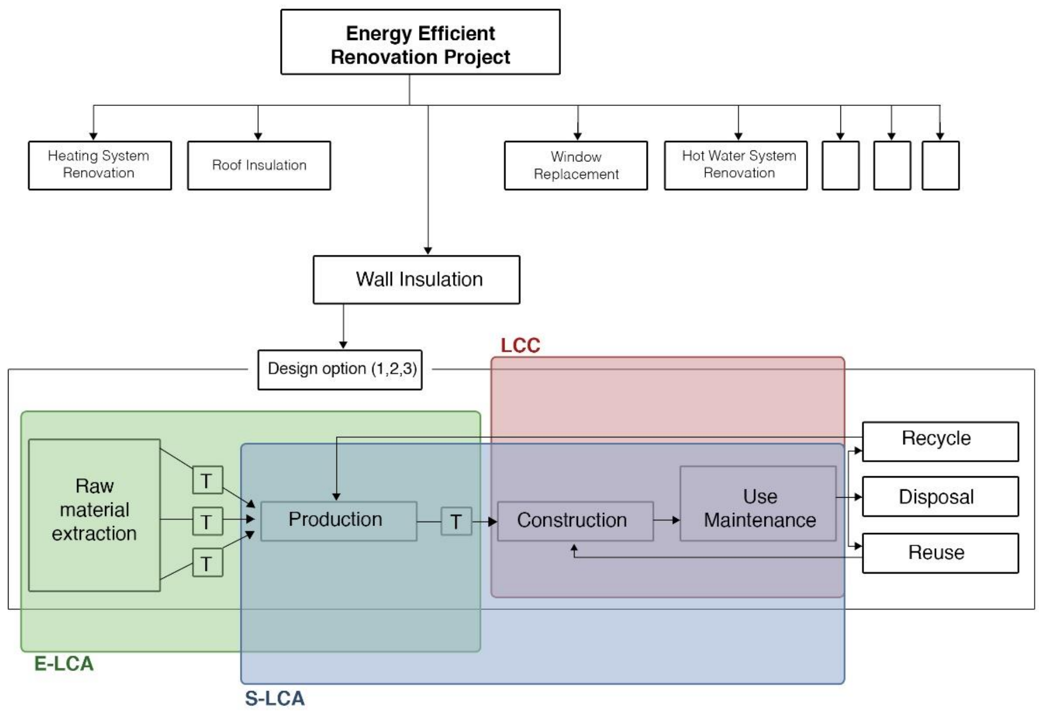
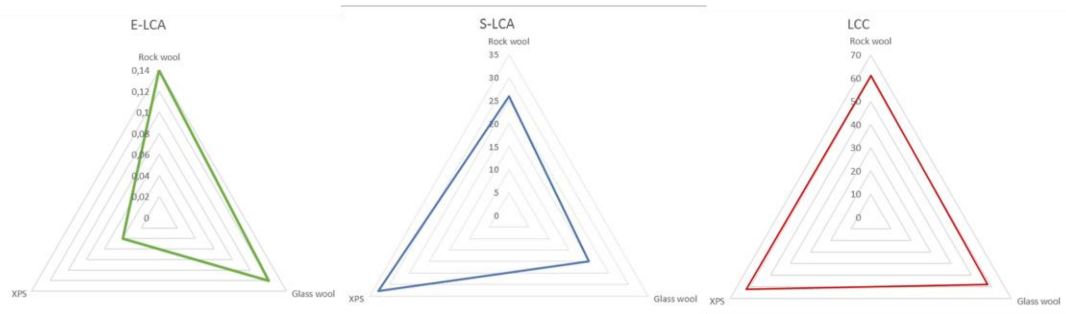


Figure 4.7 Overall framework and system boundaries

Due to define functional unit for the study, LCC and E-LCA studies were performed for the same amount of material. However, S-LCA study works with information about processes which are irrelevant to express per unit of process output (Manik *et al.*, 2013). Still, the functional unit can be used to calculate fraction of each process and weight impacts accordingly when the study is performed for more than one processes within the life cycle. For example, raw material extraction processes of each insulation material can be evaluated as well and results can be multiplied with fractions of each process according to the functional unit (i.e. mass fraction or financial cost). In this case, only upstream (up to usage phase) process categories should be evaluated for each process and downstream (usage phase) process categories should be added to the system after calculating total impact of upstream categories. For example, working hours should be calculated for each process individually and multiplied with their weight value and only then total value can be evaluated along with downstream impact categories such as user safety.

According to UNEP/SETAC LCI (2011) guidelines on SLCA, performing normalization, aggregation and weighting for three assessment studies together is not recommended due to early stage of LCSA implementation. Also, during literature review, no examples of such an application could be found in recent sources. Thus, three assessment results are compared within themselves and the best and worst options for each option are represented on Figure 4.8.



	Rock wool	Glass wool	XPS
E-LCA	0,14	0,12	0,04
S-LCA	25,87	21,04	32,74
LCC	61,00	58,00	62,00

best option
middle option
worst option

Figure 4.8. Overall sustainability score comparison of insulation materials

It is important to state that some company references were used in LCC and E-LCA but it does not mean that the same companies were involved in S-LCA study. Company names that are involved in S-LCA were kept confidential and they are not shared in this study.

Although there is no significant difference, glass wool scored the best among other insulation materials in LCC. LCC study was based on end-users but other parameters for economic comparison in nation level were included in S-LCA study (Indicators 4.2.1 and 4.2.2). Unfortunately, data could not be acquired for these indicators which could have changed the results significantly. Other missing data was on worker health and safety category (Indicators 1.1.3 and 1.1.4) which have high category weights.

According to the results and scores, decision making body (in this case: end user) can evaluate the importance of each assessment category among themselves since there is no suggested weighting for assessment results. The decision maker may not find 2 or 3 months of difference in payback time worthy of notice and evaluate all materials identical in terms of economic impacts. In that case, glass wool can be evaluated as the most sustainable option since it does not score the highest on social or environmental impacts. Results show that glass wool sheathing application is a sustainable alternative over other options and its production as sheathing material in Turkey is recommended. On the other hand, although its highest score on social impacts, XPS can also be selected as a more sustainable option than rockwool due to its remarkable low score on environmental impacts.

To further develop the suggested S-LCA approach and really understand the lifecycle social impacts of insulation materials, the study should be expanded to cover raw material extraction and demolition phases by dividing upstream and downstream processes as well. Also, impact categories that were objectively selected from literature should be reviewed by experts to create a national framework for S-LCA. The national framework for the method should be developed for both E-LCA and S-LCA. Generally, the S-LCA framework is created for each study specifically but if a national framework is created, it can be utilized as a base model to build on. To create that framework, methods on how valid measurements can be performed for each indicator should be developed by expert review separately, by supporting a broad literature review in distinct disciplines where possible. Similarly, reliability of E-LCA will continue to raise doubts as long as it depends on foreign process databases. Also, there was some missing information in S-LCA study that was not shared by companies. If a national framework is created and the S-LCA is performed nationally, this information can be acquired and it may help the researchers detect hot-spots both nationally and on company basis.

CHAPTER 5

CONCLUSION

Countries develop environmental sustainability goals and to deal with environmental problems and energy crisis. To be able to promote usage of sustainable products and limit usage of risky ones, they should be assessed and distinguished properly. Life cycle assessment is a commonly used global method with a mature database to calculate environmental risks related to a product, service or process. Enhancing this method to include other aspects of sustainability would help the researchers to calculate a products overall impact on sustainable development of a country.

Building industry is one of the areas that LCA is commonly used due to the industry's significant impact on environment. On the other hand, its socio-economic impact is as significant as its environment impact. However, assessment framework on these areas are not as mature as environmental assessment framework. Like environmental product declarations, companies could be encouraged to publish social and economic declarations as well to promote usage of sustainable products. Developing assessment parameters of a holistic sustainability assessment is a pre-requirement of such a standardization system.

In this study, a life cycle sustainability assessment method was presented and tested to compare sustainability performances of three insulation materials that are used as exterior sheathing applications in building renovation projects. Although the method is still under development in the literature, its utilization is recommended to both benefit from it by being able to conduct a holistic sustainability assessment and to develop it. The study is focused on social sustainability assessment via S-LCA method. This study can be utilized to generate a set of social criteria to assess insulation materials. The method can also be adapted to other building materials with proper modifications. To fully conclude the LCSA framework and use it for standardization process, expert review is required. The study also provides a weighting system and multi-criteria assessment framework with normalization method for S-LCA studies on building materials.

Case study results show the potential of LCSA method on a sample assessment. The case study was conducted on rock wool, glass wool and XPS options. Among them. Overall, glass wool does not score the highest on any of the assessments. With given fiber glass batting specifications, glass wool can be an alternative sustainable mineral wool application on exterior walls. Although it has a much higher environmental impact than XPS, when compared with rock wool, its production as a sheathing material seems feasible and recommended.

5.1. Evaluation of the Proposed S-LCA Methodology

During the development of S-LCA method in this study, many challenges and potentials were experienced. Also, there are some key points to consider when conducting a similar S-LCA study. First of all, conducting a sensitivity analysis is recommended since there are many indicators in the literature about often referred impact categories. Framework of this study is based on determining importance of impact categories according to their usage frequency in the literature. However, number of indicators related to an impact category can determine an indicator's individual weight within the overall scheme. Thus, some important indicators may appear to be too insignificant whereas some indicators may affect the results significantly. To avoid these outlines, proper indicator weight boundaries should be defined and a sensitivity analysis should be carried out.

Deciding social sustainability parameters is a challenging step. To minimize subjective interpretation at that step, systematic literature survey was conducted to see the most relevant concerns in the literature on that subject. However, subjective interpretation of literature is required to design survey questions out of indicators. Employing a group of experts on the subject would minimize subjective interpretation. Experts should be selected according to the scope of the study.

While carrying out the assessment, only production facilities of products were considered. However, raw material extraction facilities and transportation phases should be considered within the S-LCA scope as well. While indicator in user stakeholder category are mostly related with usage phase, worker stakeholder category does not include sheathing application workers. Also, raw material supply phase finds a place in this method as a stakeholder category but it mostly focuses on production facility and supplier relationships. Workers on the raw material extraction facilities and local communities at those sites were not included This exclusion of some phases was done to be able to deal with complex parameters of a holistic assessment and build the S-LCA framework within the scope of a thesis study. Main aim of the study was to build an assessment framework. Case study was performed as an objective to be able to demonstrate how the method can be applied. In case of a whole life cycle assessment, upstream processes (raw material extraction and production) and downstream processes (usage and disposal) should be evaluated individually and results should be combined afterwards by keeping in mind functional unit as a common ground to combine these results.

It is important to state that this method does not show its full potential on the designated case study. Since all production facilities are in the same country, indicator items belonging to "society" stakeholder category returned similar results. If raw material extraction facilities are included, the impact results of that category would affect the overall comparison. Local community results would also vary significantly when surveys are conducted in raw material extraction locations as well.

For more reliable results, surveys should be conducted instead of interviews. Most of the semi-quantitative indicators depend on interview questionnaires. These questions should be translated into survey questions and carried out on a group of individuals for more reliable results. Same scoring method should be used for survey questions and resulting average score should be used for each indicator.

Among many S-LCA methods, UNEP/SETAC guidelines were selected as the most promising method that is open to development. This study also follows a similar pattern and suggests considering it as a baseline method to further develop it.

5.2. Holistic Sustainability Assessment Methodology

Carrying out three assessment studies together rendered detection of potentials and manifestation of the key concerns possible. First of all, if functional unit is not defined in the beginning of the assessment, a common ground between different assessment studies cannot be created. Furthermore, if the assessments are performed on more than one building materials, products and services, functional unit should be defined for each of them according to their product utility. While defining the functional unit, it is important to keep in mind that LCC study is also within the assessment framework. Thus, product quantity for the same amount of financial gain cannot be a functional unit.

It is important to state that defining a social subject of the assessment is necessary for holistic evaluation. Subject is the decision-making group or individual that most probably get the assessment conducted as well. It can be a user that wants to compare products in terms of sustainability, a national entity that inspects sustainability of products, a local union that the product facility is located in the vicinity and so on. Scope of the assessment should be defined according to the subject of the assessment.

Financial parameters that are related to national economy, worker salaries and supplier renumeration are covered within S-LCA scope and LCC only performed with respect to users to avoid category intersections between assessment frameworks. LCC was kept simple and based on one decision maker stakeholder category. Because financial parameters within S-LCA study are related with social sustainable development. If the study would be conducted by a company to compare sustainability of its products, LCC should be based on company's incomes and expenses. Such a change in LCC context does not affect S-LCA framework.

The case study was conducted on a certain product but method can be enhanced to include all applications and materials of an energy efficient renovation project. Suggestions for further development of the method are listed on the following section.

5.3. Recommendations for Further Development

Results are finalized with recommendations to develop the methodology further. This chapter aims to inspire future studies as well.

The study should be conducted on a larger scope with various energy efficient renovation applications in the context. In such a study, either design scenarios with specified materials, products and services can be designated and compared or each one of them can be assessed individually to find best overall design scenario. First method would require overall scores for each scenario whereas for the second method, products, materials and services should be compared within their own context and highest scoring options should be combined for the best overall scenario. Since there are three assessment studies for scoring, the results should be interpreted in the end to see the best individual options socially, environmentally and economically.

Scope of all life cycle assessments should be extended to include all relevant life cycle phases of products to see the full potential of the method. Also, reliability of LCA results is an important issue that needs development. Data that is used for LCA impact results as well as normalization process is not local data. Local database needed for more reliable LCA results. On the other hand, to obtain more reliable S-LCA results, interview questions should be converted to survey questions and the survey should be conducted on relevant bodies like facility workers and individuals from local community. For this study, such an extensive survey could not be possible due to academic scope of this study. To apply this method on a real scenario, same indicators should include survey questions that can be asked more than one individuals for more reliable results.

Finally, it is obvious that each holistic sustainability study in any industry puts a building block to future fully developed sustainability assessment standards. For this reason, each study would most probably fill a gap in the literature and shape the future framework.

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APPENDIX A

BUILDING DRAWINGS

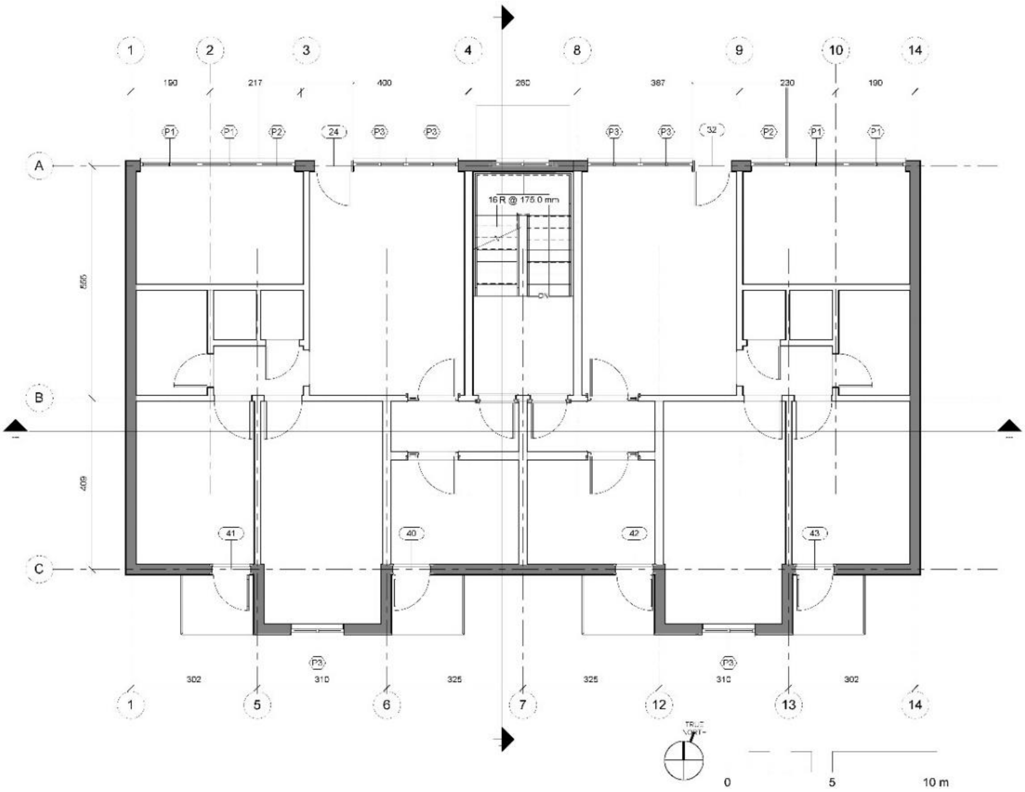

Figure A.1. Plan drawing of the case building

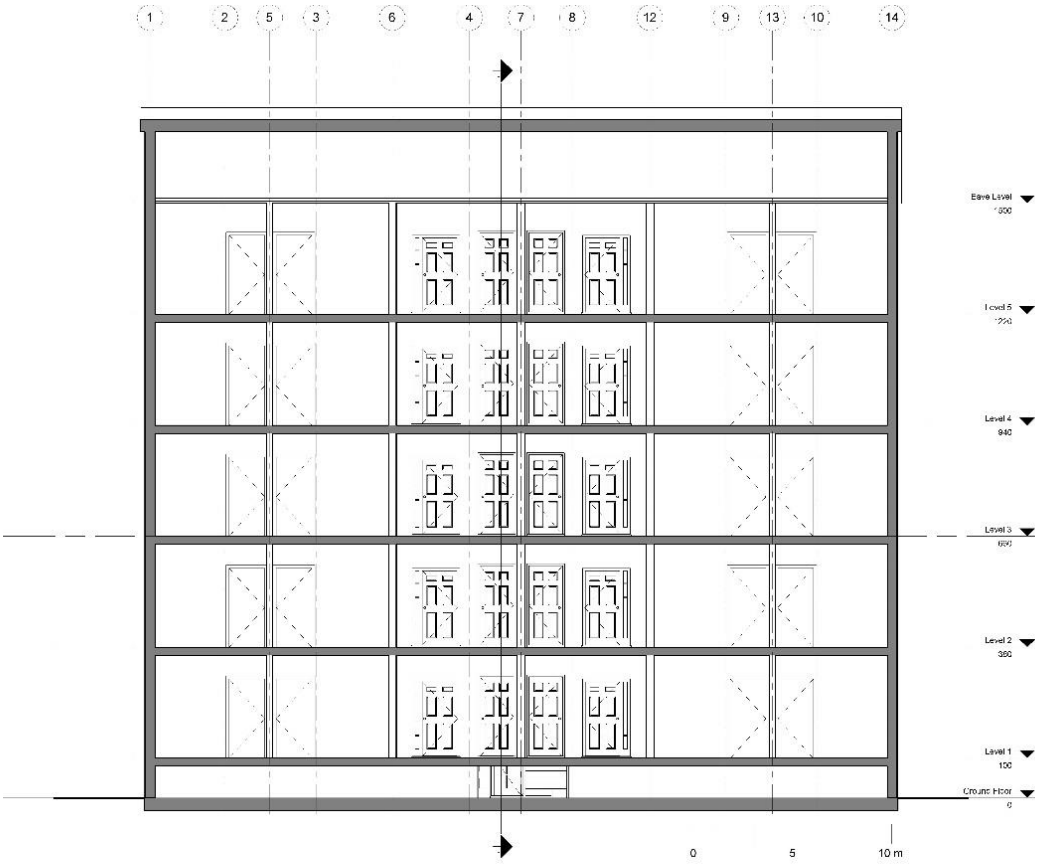

Figure A.2. Longitudinal section of the case building

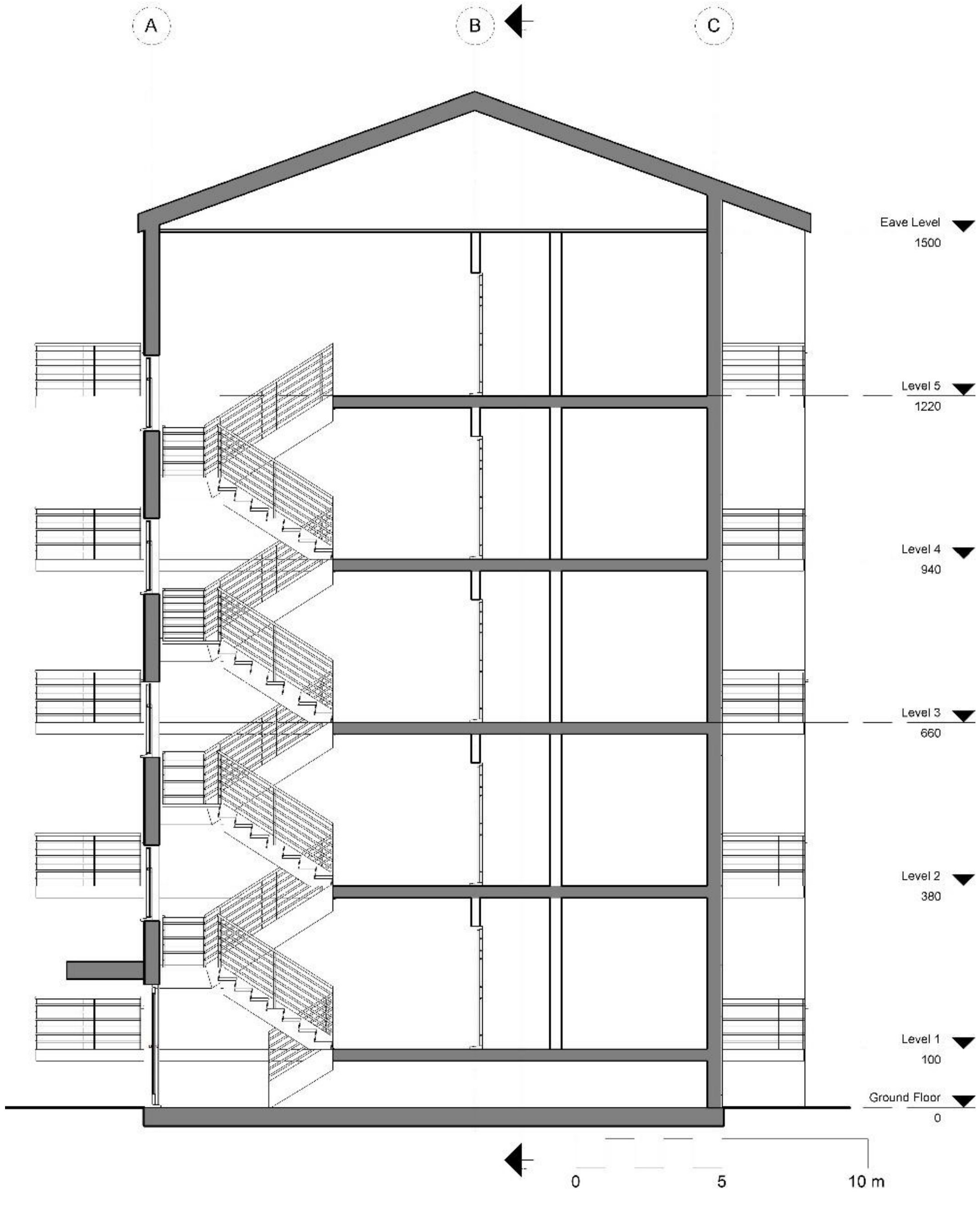

Figure A.3. Cross section of the case building

APPENDIX B

SPECIFICATIONS OF THE S-LCA INDICATORS

Table B.1 Indicator - Number of reported accidents at work

Facility Information	1.1.1 What is the number of reported occupational accidents in one year?
Evaluation	Lower is better
Equation	OAFR=(#OA/YPH)x1000000

Abbreviations	OAFR=Occupational Accident Occurrence Rate
	#OA=Occupational Accident Number in a Year
	YPH=Total Yearly Person*Hour

Reference Values	Max: max value Min: 0 (never)

Table B.2 Indicator - Number of occupational diseases

Facility Information	1.1.2. What is the number of reported occupational diseases in one year?
Evaluation	Lower is better
Equation	ODFR=(#OD/YPH)x1000000

Abbreviations	ODFR=Occupational Disease Occurrence Rate
	#OD=Occupational Disease Number in a Year
	YPH=Total Yearly Person*Hour

Reference Values	Max: max value Min: 0 (never)

Table B.3 Indicator – Occupational safety risks

Facility Information	1.1.3. Sum of Risk Values on the Risk Analysis table for safety items (Risk Analysis Required).
Evaluation	Lower is better
Equation	Sum(RV=P x I)
Abbreviations	RV= Risk Value P= Probability I= Impact
Reference Values	Max: max value Min: 0

Table B.4 Indicator – Occupational health risks

Facility Information	1.1.4. Sum of Risk Values on the Risk Analysis table for health items (Risk Analysis Required).
Evaluation	Lower is better
Equation	Sum(RV=P x I)
Abbreviations	RV= Risk Value P= Probability I= Impact
Reference Values	Max: max value Min: 0

Table B.5 Indicator – Occupational health and safety measures

Interview Question 1	1.1.5. Are there any corporate policies or programs to combat occupational health and safety issues?			
Answers 1	Yes (1,00)		No (0,00)	
Interview Question 2	What is your assessment about corporate policy and programs to combat occupational health and safety issues?			
Answers 2	They are adequate (1,00)	They are adequate but not executed properly (0,75)	They are inadequate (0,50)	They have no positive effect on worker health and safety (0,25)
Evaluation	Higher is better			
Reference Values	Max:1		Min: 0	

Table B.6 Indicator – Compensation appeals based on discrimination

Facility Information	1.2.1 Total number of reports on compensation appeals based on discrimination (Discriminatory practices are defined based on race, color, sex, religion, political opinion, national extraction or social origin, *etc.*).
Evaluation	Lower is better
Equation	Number/YPH
Reference Values	Max: max value Min: 0

Table B.7 Indicator – Difference of male & female percentage on executive board

Facility Information	1.2.2 Absolute value of the difference between male percentage and female percentage on executive board.
Evaluation	Lower is better
Equation	|m%-w%|
Reference Values	Max: max value Min: 0

Table B.8 Indicator – Difference of male & female salaries

Facility Information	1.2.3 Absolute value of the difference between male and female salaries on same department with same specifications.
Evaluation	Lower is better
Equation	|Sm-Sf|
Abbreviations	Sm= male salary (TL) Sf= female salary (TL)
Reference Values	Max: max value Min: 0

Table B.9 Indicator – Ratio of disabled employees

Facility Information	1.2.4 Ratio of disabled employees to total number of employees in the working environment.
Evaluation	Higher is better
Equation	Disabled/total number of workers
Reference Values	Max: max value Min: 0

Table B.10 Indicator – Performance related incentives

Interview Question 1	1.3.1.1 Is there a performance measurement system applied?			
Answer 1	Yes		No (0,00)	
Interview Question 2	1.3.1.2 Does the performance related incentive system meet workers' demands?			
Answer 2	More than expected (1,00)	As expected (0,66)	Underachieving (0,33)	
Interview Question 3	1.3.1.3 Are performance criteria clearly defined?			
Answer 3	Clearly defined (1,00)	Defined but can be better (0,66)	Not defined (0,33)	
Interview Question 4	1.3.1.4 Are performance criteria and rewarding methods clearly explained to the workers?			
Answer 4	Clearly explained (1,00)	Explained but can be better (0,66)	Not explained (0,33)	
Interview Question 5	1.3.1.5 Are expectations from performance outcomes corresponds to incentives?			
Answer 5	More than expected (1,00)	As expected (0,75)	Underachieving (0,50)	No positive effect (0,25)
Evaluation	Higher is better			
Equation	checklist grading (multiply each answer with 0,25)			
Reference Values	Max: 1 Min: 0			

Table B.11 Indicator – Remuneration rate

Facility Information	1.3.2 Rate of minimum full-time worker wages.
Evaluation	Higher is better
Equation	MWW-LPT
Abbreviations	MWW= minimum wage of full-time workers LPT= local poverty threshold
Reference Values	Max: max value Min: min value

Table B.12 Indicator – Payment of wages in due time

Survey Question	1.3.3 Are your salaries always paid on due time completely?				
Likert Scale	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Higher is better				

Table B.13 Indicator – Corporate commitments on abolition of forced labor

Interview Question	1.4.1 Does the company take corporate measures against forced labor?				
Answers	Yes, and it has a special sensitivity on that subject (1,00)	Yes, and the measures are adequate (0,75)	Yes, but the measures are not executed well (0,50)	Yes, but the measures have no positive effect (0,25)	There are no corporate measures (0,00)
Evaluation	Higher is better				

Table B.14 Indicator – Evidence of forced labor

Interview Question	1.4.2 Do you experience or witness forced labor in your workplace? (Forced labor includes doing anything that is not defined in job definition in compulsion, being forced to adapt to radical changes without your consent, being forced to work apart from your working hours, being forced to work in inhuman conditions as a punishment to a strike, *etc.*)				
Likert Scale	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Lower is better				

Table B.15 Indicator – Breaches of obligatory social contributions

Interview Question	1.5.1 Have you ever experienced or witnessed a breach of any obligatory social contributions including health, disability or pension schemes?				
Likert Scale	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Lower is better				

Table B.16 Indicator – Duration and level of wage continuation in case of illness

Interview Question	1.5.2 In case of a health problem that is authenticated by a medical report, have you experienced or witnessed any wage deduction or dismissal?			
Likert Scale	Most of the time (1,00)	Sometimes (0,66)	Rarely (0,33)	Never (0,00)
Evaluation	Lower is better			

Table B.17 Indicator – Number of workers with a contract

Facility Information	1.5.3 Ratio of workers with a contract to total number of workers.
Evaluation	Higher is better
Equation	#CW/#TW
Abbreviations	#CW = number of workers with a contract #TW = total number of workers
Reference Values	Max: 1 Min: 0

Table B.18 Indicator – Reports on cases of child labor

Interview Question	1.6.1 Have you witnessed making use of child labors in the workplace who are younger than 15 years old?				
Likert Scale	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Lower is better				

Table B.19 Indicator – Total child labor rates

Facility Information	1.6.2.1 Ratio of workers who are younger than 18 years. 1.6.2.2 Ratio of workers who are younger than 15 years.
Evaluation	Lower is better
Equation	#MW/#TW
Abbreviations	#MW = number of minor workers (child or young) #TW = total number of workers
Reference Values	Max: max value Min: 0

Table B.20 Indicator – Voluntary commitments on freedom of association and right to collective bargaining

Interview Question	1.7.1 According to your own observations, does the company support workers' association and collective bargaining rights?				
Likert Scale	Yes, and it has a special sensitivity on that subject (1,00)	Yes, it does (0,75)	It does not support enough (0,50)	It does not support at all (0,25)	It violates those rights (0,00)
Evaluation	Higher is better				

Table B.21 Indicator – Reports on hindering worker organizations

Interview Question	1.7.2 Have you ever experienced or witnessed any hindering action on worker organizational activities or any inequality to member workers by the company?			
Likert Scale	Most of the time (1,00)	Sometimes (0,66)	Rarely (0,33)	Never (0,00)
Evaluation	Lower is better			

Table B.22 Indicator – Rate of unionization

Facility Information	1.7.3 Number of unionized workers
Evaluation	Higher is better
Equation	#UW/#TW
Abbreviations	#MW = number of unionized workers #TW = total number of workers
Reference Values	Max: 1 Min: min value

Table B.23 Indicator – Rate adequate working time

Facility Information	1.8.1 Rate of adequate working time
Evaluation	Lower is better
Equation	$WT_W > WT_{max}$ => $WT_W - WT_{max}$ $WT_W < WT_{max}$ => 0
Abbreviations	WT_W = weekly total working time WT_{max} = maximum weekly working time (45 hours)
Reference Values	Max: max value Min: 0

Table B.24 Indicator – Percentage of local suppliers

Facility Information	2.1.1 Location of each supplier in the supply chain. (Local: 1; National: 0,5; Foreign: 0)
Evaluation	Higher is better
Equation	Sum(S1g x S1w) / Sum(1xS1w)
Abbreviations	Sg= Supplier grade Sw=Supplier weight (kg)
Reference Values	Max: 1 Min: min value

Table B.25 Indicator – Percentage of local workers

Facility Information	2.1.2 Ratio of workers who reside out of local community borders.
Evaluation	Lower is better
Equation	#NLW/#TW
Abbreviations	#NLW= Nonlocal workers /#TW= Total number of workers
Reference Values	Max: 1 Min: min value

Table B.26 Indicator – Accidents connected to company activities

Facility Information	2.2.1 What is the number of reported local accidents connected to company's activities?
Evaluation	Lower is better
Equation	OAFR=(#OA/YPH)x100

Abbreviations	OAFR=Occupational Accident Occurrence Rate
	#OA=Occupational Accident Number in a Year
	YPH=Total Yearly Person*Hour

Reference Values	Max: max value Min: 0 (never)

Table B.27 Indicator – Negative health impacts for the local population

Facility Information	2.2.2 What is the number of reported local negative health impacts connected to company's activities?
Evaluation	Lower is better
Equation	ODFR=(#OD/YPH) x 1000000

Abbreviations	ODFR=Occupational Disease Occurence Rate
	#OD=Occupational Disease Number in a Year
	YPH=Total Yearly Person*Hour

Reference Values	Max: max value Min: 0 (never)

Table B.28 Indicator – Measures and arrangements to maintain and improve safe and healthy living condition

Interview Question 1	2.2.3.1 Are there any awareness campaigns on hygiene and sanitation in the workplace?				
Answer 1	Yes, and there is a special sensitivity on that subject (1,00)	Yes, there are (0,66)	Yes, but they are not executed enough (0,33)	No, there are not (0,00)	
Interview Question 2	2.2.3.2 Are there enough measures to avoid possible community exposure of hazardous materials from transportation vehicles?				
Answer 2	Yes, and there is a special sensitivity on that subject (1,00)	Yes, there are enough measures (0,75)	Yes, but measures are not enough (0,50)	No, there are no measures (0,25)	No, and this situation leads to serious problems (0,00)
Interview Question 3	2.2.3.3 Are there registered sites for waste disposal and is it certain that only these sites are used for disposal?				
Answer 3	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	No registered site available (0,00)
Interview Question 4	2.2.3.4 Is it ensured that haul trucks are never overloaded and speed limits are never exceeded?				
Answer 4	Yes, and there is a special sensitivity on that subject (1,00)	Yes, certainly (0,75)	Most probably (0,50)	No, and it may cause some troubles (0,25)	No, and it caused serious problems in the past (0,00)
Interview Question 5	2.2.3.5 In case of any emergency, is there a backup communication system with off-site resources like fire department?				
Answer 5	Yes (1,00)		No (0,00)		
Evaluation	Higher is better				
Equation	Checklist grading (0,2 point for each question)				
Reference Values	Max: 1 Min: 0				

Table B.29 Indicator – Voluntary commitments in the field of local rights

Interview Question 1	2.3.1.1 Does the facility show due diligence on protecting local cultural values and ethnic identities?				
Answer 1	Yes, and there is a special sensitivity on that subject (1,00)	Yes, certainly (0,75)	Most probably (0,50)	No, it does not (0,25)	No, and it causes serious problems (0,00)
Interview Question 2	2.3.1.2 Does the company show due diligence on not invading local lands, territories and resources?				
Answer 2	Yes, and there is a special sensitivity on that subject (1,00)	Yes, certainly (0,75)	Most probably (0,50)	No, it does not (0,25)	No, and it causes serious problems (0,00)
Interview Question 3	2.3.1.3 Does the facility show due diligence on avoiding forced population transfers or migrations?				
Answer 3	Yes, and there is a special sensitivity on that subject (1,00)	Yes, certainly (0,75)	Most probably (0,50)	No, it does not (0,25)	No, and it causes serious problems (0,00)
Evaluation	Higher is better				
Equation	checklist grading (average value)				
Reference Values	Max: 1 Min: 0				

Table B.30 Indicator – Reports on human rights violations related to the company's activities

Interview Question 1	2.3.2.1 Are there any occurrences of violation of local community's right to protect local cultural values and ethnic identities caused by the facility's activities?				
Answer 1	Extremely often (1,00)	Very often (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Interview Question 2	2.3.2.2 Are there any occurrences of invasion of local lands, territories and resources by the facility?				
Answer 2	Extremely often (1,00)	Very often (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Interview Question 3	2.3.2.3 Are there any occurrences of forced population transfers, or migrations caused by company's activities?				
Answer 3	Extremely often (1,00)	Very often (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Lower is better				
Equation	checklist grading (average value)				
Reference Values	Max: 1 Min: 0				

Table B.31 Indicator – Human rights training for employees

Interview Question	2.3.3 Is there any specific education program for employees (especially for security staff) on human rights?	
Answer	Yes (1,00)	No (0,00)
Evaluation	Higher is better	
Reference Values	Max: 1 Min: 0	

Table B.32 Indicator – Information possibilities for residents

Interview Question	2.4.1 Do you think the facility gives enough importance to local community informing through formal trainings, project level reports and community dialogues?			
Answer	Yes, and there is a special sensitivity on that subject (1,00)	Yes, it does (0,66)	Yes it does, but they are not adequate (0,33)	No, it does not (0,00)
Evaluation	Higher is better			

Table B.33 Indicator – System to respond to community grievances

Interview Question	2.4.2 Do you think the facility gives enough importance to developing a system to respond community grievances?				
Answer	Grievances are always evaluated and solved (1,00)	Grievances are generally evaluated and solved (0,75)	Grievances are evaluated but not solved (0,50)	Grievances are not adequately evaluated (0,25)	Grievances are never adequately evaluated (0,00)
Evaluation	Higher is better				

Table B.34 Indicator – Delocalization and migration resulted from company's activities

Interview Question	2.5.1 Is there any delocalization eviction or migration resulted from company's establishment or organizational activities?	
Likert Scale	Yes (1,00)	No (0,00)
Evaluation	Lower is better	

Table B.35 Indicator – Forced evictions / resettlements

Interview Question	2.5.2 Are there any forced eviction or resettlement case resulted from facility's establishment or organization activities?	
Answer	Yes (1,00)	No (0,00)
Evaluation	Lower is better	
Reference Values	Max: 1 Min: 0	

Table B.36 Indicator – Health opportunities / risks related to product use

Desktop Screening	3.1.1.1 Material's toxicity / irritation potential 3.1.1.2 Material's carcinogenic potential		
Scale	Significant risk (1,00)	Slight risk (0,50)	No risk (0,00)
Evaluation	Lower is better		
Reference Values	Max: 1 Min: 0		

Table B.37 Indicator – Accidents related to product use

Desktop Screening	3.1.2 Material's flammability class		
Scale	A1 (1,00)	A2 (0,50)	B1 (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.38 Indicator – Fatalities related to product use

Desktop Screening	3.1.3 Reports of fatalities occurred during insulation process and fire reports related to insulation materials.
Scale	Number of fatalities
Evaluation	Lower is better
Reference Values	Max: max value Min: 0

Table B.39 Indicator – Findings of product safety test

Desktop Screening	3.1.4 Number of awards, labels and positive product safety results related to health and safety risks of the product.
Scale	Safety evaluation
Evaluation	Higher is better
Reference Values	Max: 1 Min: 0

Table B.40 Indicator – Consumers' ability to reach full ingredient information

Desktop Screening	3.2.1 Is there complete available information about full ingredient list of the product?		
Scale	Satisfactory Information (1,00)	Unsatisfactory Information (0,50)	No Information (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.41 Indicator – Publication of a sustainability report

Desktop Screening	3.2.2 Is there a sustainability report, environmental product declaration or lifecycle assessment study published on company's website about the product?		
Scale	Satisfactory (1,00)	Unsatisfactory (0,50)	No Information (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.42 Indicator – Precise and readily understandable information about safe use and maintenance

Desktop Screening	3.2.3 Is there complete information on all health and safety risks (flammability, toxicity, irritation, carcinogenic potential) of product's installation, use and maintenance phases. Is there complete information about protective measures on all health and safety risks of product's installation, use and maintenance phases.		
Scale	Complete Information (1,00)	Incomplete Information (0,50)	No Information (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.43 Indicator – Company's commitment to allow user feedbacks

Interview Question	3.3.1 Do you think the facility gives due diligence to allow and evaluate feedbacks from users?				
Answer	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Higher is better				
Reference Values	Max: 1 Min: 0				

Table B.44 Indicator – System to respond user feedbacks

Interview Question	3.3.2 Do you think the facility gives enough importance to developing a system to respond user grievances?				
Answer	Grievances are always evaluated and solved (1,00)	Grievances are generally evaluated and solved (0,75)	Grievances are evaluated but not solved (0,50)	Grievances are not adequately evaluated (0,25)	Grievances are never adequately evaluated (0,00)
Evaluation	Higher is better				
Reference Values	Max: 1 Min: 0				

Table B.45 Indicator – Evidence of corrupt and / or extortionate business practices

Interview Question	4.1.1 Do you agree that the company has involved in corrupt or extortionate business practices? (For example; bribery, money laundering or other illicit activities)				
Likert Scale	Strongly agree (1,00)	Agree (0,75)	No idea (0,50)	Disagree (0,25)	Strongly disagree (0,00)
Evaluation	Lower is better				
Reference Values	Max: 1 Min: 0				

Table B.46 Indicator – Risk of corruption in the country and/or sub-region

Desktop Screening	4.1.2 What is the corruption perceptions index of the company's location?
Scale	Corruption perceptions index score
Evaluation	Lower is better
Reference Values	Max: max value Min: min value

Table B.47 Indicator – Corporate measures to combat corrupt business practices

Interview Question	4.1.3 Do you agree that the company takes corporate measures to combat corrupt business practices? (These measures include creating anti-corruption policies within the organization, reporting corporate measures externally, collective action with other business peers and calling government to action)				
Likert Scale	Strongly agree (1,00)	Agree (0,75)	No idea (0,50)	Disagree (0,25)	Strongly disagree (0,00)
Evaluation	Higher is better				
Reference Values	Max: 1 Min: 0				

Table B.48 Indicator – Contribution to the national budget

Company Information	4.2.1 What is the gap between taxes and revenues according to last year's results.
Evaluation	Higher is better
Equation	Taxes - subsidies
Reference Values	Max: max value Min: min value

Table B.49 Indicator – Contribution to the foreign trade balance

Company Information	4.2.2 What is the corporate ratio of company's export and import shares?
Evaluation	Higher is better
Equation	Export share/import share
Reference Values	Max: max value Min: min value

Table B.50 Indicator – The sector stability during market crisis

Interview Question	4.2.3 How much was the sector affected from the latest economic crisis?				
Answer	Heavily (1,00)	Significantly (0,75)	Same as country average (0,50)	Slightly (0,25)	Not affected (0,00)
Evaluation	Lower is better				
Reference Values	Max: 1 Min: 0				

Table B.51 Indicator – Link between economic activities and armed conflicts

Interview Question	4.3.1 Do you think that the company's corporate activities contribute to regional conflicts?				
Answer	Strongly agree (1,00)	Agree (0,75)	No idea (0,50)	Disagree (0,25)	Strongly disagree (0,00)
Evaluation	Lower is better				
Reference Values	Max: 1 Min: 0				

Table B.52 Indicator – R&D Program participation

Interview Question	4.4.1 Does the company contribute to national technologic development by participating in research and development projects in cooperation with universities, laboratories, institutions and centers?			
Answer	Yes, and there is a special sensitivity on that subject (1,00)	Yes, it does (0,66)	It rarely does (0,33)	No, it does not (0,00)
Evaluation	Higher is better			
Reference Values	Max: 1 Min: 0			

Table B.53 Indicator – Development of innovative products and services

Interview Question	4.4.2 Does the company display due diligence to develop innovative products and services?			
Answer	Yes, and there is a special sensitivity on that subject (1,00)	Yes, it does (0,66)	It rarely does (0,33)	No, it does not (0,00)
Evaluation	Higher is better			
Reference Values	Max: 1 Min: 0			

Table B.54 Indicator – Awards for engagement in social or sustainability issues

Desktop Screening	4.5.1 Are there any awards of the company for engagement in social or environmental sustainability issues?		
Scale	Satisfactory (1,00)	Unsatisfactory (0,50)	No Information (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.55 Indicator – Membership in alliances and programs to support and promote sustainable business practices

Desktop Screening	4.5.2 Are there any membership in alliances and programs to support and promote sustainable business practices?		
Scale	Satisfactory (1,00)	Unsatisfactory (0,50)	No Information (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.56 Indicator – Anti-competitive behavior or violation of anti-trust and monopoly legislation

Interview Question	5.1.1 Does the company perform any anti-competitive behavior or violation of anti-trust and monopoly legislation? (Anti-competitive behavior is identified as; fixing prices, collusive tendering, market or customer allocation arrangements, enforcing arrangements, concerted refusal of suppliers to potential importers, *etc.*)				
Answer	Always (1,00)	Most of the time (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Lower is better				
Reference Values	Max: 1 Min: 0				

Table B.57 Indicator – Presence of policies to prevent anti-competitive behavior

Interview Question	5.1.2 Is there any corporate policy to prevent anti-competitive behavior in the supply chain? (Anti-competitive behavior is identified as; fixing prices, collusive tendering, market or customer allocation arrangements, enforcing arrangements, concerted refusal of suppliers to potential importers, *etc.*)		
Answer	Yes (1,00)	No idea (0,50)	No (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.58 Indicator – Human rights of workers among suppliers

Interview Question	5.2.1 Are there any corporate codes of conduct to protect human rights of workers among suppliers?		
Answer	Yes (1,00)	No idea (0,50)	No (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.59 Indicator – Membership in an initiative that promotes social responsibility along the supply chain

Desktop Screening	5.2.2 Are there any membership in an initiative that promotes social responsibility along the supply chain?		
Scale	Satisfactory (1,00)	Unsatisfactory (0,50)	No membership (0,00)
Evaluation	Higher is better		
Reference Values	Max: 1 Min: 0		

Table B.60 Indicator – Payment on time

Interview Question	5.3.1 How often do delays on payments occur to suppliers and partners?				
Answer	Extremely often (1,00)	Very often (0,75)	Sometimes (0,50)	Rarely (0,25)	Never (0,00)
Evaluation	Lower is better				
Reference Values	Max: 1 Min: 0				

Table B.61 Indicator – Sufficient lead time

Interview Question	5.3.2 Does the company provide sufficient lead time to suppliers?				
Answer	It is more than sufficient (1,00)	It is sufficient (0,75)	I sometimes find it insufficient (0,50)	I generally find it insufficient (0,25)	I don't think it is sufficient (0,00)
Evaluation	Higher is better				
Reference Values	Max: 1 Min: 0				