LAPPENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
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DESIGNING FOR SUSTAINABILITY: A COMPARATIVE ANALYSIS OF STEEL AND WOOD BASED FURNITURE

Examiners: Professor Risto Soukka
Ph.D. Sanni Väisänen

ABSTRACT

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Designing for Sustainability: A Comparative Analysis of Steel and Wood Based Furniture

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Keywords: office furniture, eco-design, sustainability, life cycle assessment, life cycle inventory, SimaPro, particle board

Life cycle assessment (LCA) is a methodology that calculates environmental performance of product. In order words, it can be used for calculating environmental adverse effects of product. In this thesis LCA is used for three office chairs and one of them is designed eco-friendly. The system boundaries of this LCA study is cradle-to-grave. Primary data is taken from the company named Koleksiyon Mobilya and secondary data were conducted from literature and assumptions in some cases. SimaPro LCA software version 8.2.0.0 is used in this thesis study and Ecoinvent 3.0 is involved in this study. Thenceforth, two office chairs are assessed with CML IA baseline method to show the environmental adverse effects with regards to eleven environmental impact categories. such as abiotic depletion, global warming potential and so on. The common hotspots of two office chair are came from the part of back frame and mechanism. These parts are made from metals which require significant amount of energy during its life cycle particularly mining and manufacturing. Therefore, the raw material of back frame part is changed with particle board. The reason of selecting particle board is that young's modulus and compressive strength values are relatively close to the metals. Addition to that, these criteria are essential for the chair durability and comfort of user. Subsequently, the environmental impact results show that the material selection is the key point for designing eco-friendly product. The global warming potential 100a result of one office chair named as Eco-Dastan is 74.7 kgCO_2-eq. which is less than the other two office chair which are Dastan 30 and

Dastan and Dastan 30 v.2. Consequently, selection of suitable raw material is an indispensable factor for protecting the environment.

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Contents

SYMBOLS AND ABBREVIATIONS

CCl_3CH_3	1,1,1-Trichloroethane
CCl_4	Tetrachloromethane
CER	Corporate Environmental Reports
CF	Carbon Footprint
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Cleaner Production
ELCA	Environmental Life Cycle Assessment Methodology
EPD	Environmental Product Declaration
EU	European Union
FRIM	Forest Research Institute Malaysia
GAs	Generic Algorithms
GHG	Greenhouse Gases
GWP	Global Warming Potential
H_2S	Hydrogen Sulphide
H_2SO_4	Sulfuric Acid
H_3PO_4	Phosphoric Acid
HCl	Hydrogen Chloride
HF	Hydrogen Fluoride
HNO_3	Nitric Acid
ISO	International Standard Organization
LCA	Life Cycle Assessment
LCE	Life Cycle Engineering
LCI	Life Cycle Inventory
LCSA	Life Cycle Sustainability Assessment
LEED	Leadership Energy and Environmental Design
N_2O	Nitrous Oxides
NGO	Non-Governmental Organization

NH3	Ammonia
NOK	Norwegian Krone
NOx	Nitrogen Oxides
OECD	Organisation for Economic Co-operation and Development
OPT	Oil Palm Trunk
OPTL	Oil Palm Trunk Lumber
PCR	Product Category Rule
POCP	Photochemical Ozone Creation Potential
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
SD	Sustainable Development
SETAC	Society of Environmental Toxicology and Chemistry
SME	Small-Medium Enterprise
SO2	Sulphur Dioxide
SO3	Sulphur Trioxide
SWOT	Strengths, Weaknesses, Opportunities, Threats
TOBB	The Union of Chambers of Commerce and Commodity Exchanges of Turkey
TurkStat	Turkish Statistical Institute
UNEP	United Nations Environment Programme
UNEP-IE	The United Nations Environment Programme-Industry and Environment Centre
WBCSD	World Business Council for Sustainable Development

1. Introduction

Throughout a couple of decades understanding of environmental loads occurring from products' life cycle, and consumption of natural resources have been recognized and became an essential topic in daily basis (New South Wales Environmental Protection Authority, 1997, p. 1-16). Even though adverse effects of human being on the environment have been mention since early 1800s, however, the Anthropocene term is proposed recently. The Anthropocene term is a new epoch including the actions and results of humanity started at around 1800s which is related to the Industrial Revolution. During between 1800 and 2000, the world population rose to six billion whilst energy consumption increased by approximately 40-fold and economic production grew by 50-fold (McNeill, 2000). As the result of these increases, greenhouse gases (GHG) has been rapidly grown. Especially these gases are resulted from fossil fuel consumption during industrial processes. During the Great Acceleration (after World War 2), the concentration of CO_2 in atmosphere rose from 311 ppm to 369 ppm between 1950 and 2000. This contribution came from mostly OECD countries (J. T. Houghton et al, 2001, p. 11-21). Related to this unstoppable increase, Rockstörm analysis published and defined nine planetary boundaries and their safe operating space regarding to humanity (Rockström et al. 2009, p. 472-475). Finally, according to this analysis, climate change, rate of biodiversity loss and the nitrogen cycle have already been exceeded the safe operating limit. In order to combat with these challenges, solving environmental problems has become quite urgent and this concept can be emerged with economic and social welfare. Thereupon, the sustainability must be the key concern in this issue in order to cover these three obstacles.

In the global market, the significant demand on preferring wood materials in furniture products has been rising due to its low level of environmental impact loads and economic viability. Koleksiyon Mobilya is one of the leader furniture manufacturer that is sensitive to the environmental issues with the high level of concern. Besides, highly demanded environmental friendly products are the new criteria regarding to the customers while purchasing a new stuff. Due to this behaviour change on the customer side, the sustainability has been a new trade barrier for whom does not put these issues in their business model.

A comprehensive tool to assess the environmental load of product or service is life cycle assessment (LCA). This is organized, and detailed methodology defined by the International

Organization for Standardization (ISO, 2006) with the standards of 14040 and 14044 particularly. ISO 14040 standard is published for identifying principles and framework of LCA (Technical Committee 2006, p 1-28) and other standard ISO 14044 is specially for the practitioners who apply the LCA, with the purpose of explaining requirements of LCA and LCI studies (Technical Committee, 2006, p 1-28).

In this thesis study, LCA is conducted to cradle-to-grave approach since related Product Category Rule (PCR) require (The International EPD System, 2015, p. 1-17). PCR is the guideline for preparing ISO 14025 Environmental Product Declaration document based on LCA study. Ultimately, the biggest motivation of this thesis study is the sustainability vision of Koleksiyon Mobilya and to find alternative materials for non-renewable materials.

1.1. Organization of the thesis

The structure of thesis consists of literature review, case study, discussion of the result, and conclusion. Literature review starts with Sustainability Aspects of Furniture Sector, and continues to Design for Sustainability. Besides, the case study based on evaluating environmental performance of two office chairs involves in the section of A comparative analysis of steel and wood-based furniture. After that, Discussion part is explained in the Section 5 and ultimately the last section of this thesis study is Conclusion.

1.2. Statement of Problem

The business-as-usual approach is a business model that aims at consuming resources without concerning neither environmental nor social issues. On the contrary that, the circular business model based on sustainability requires less material, alternative materials to non-renewable resource, and provides recycle, reuse application in the business.

Furniture industry uses considerable volume of raw material particularly metals and plastics which demand high volume of energy. Additionally, the hotspots of office chair generally come from upstream processes of chair life cycle which means that the raw material is needed to be focused on. According to this perspective, Koleksiyon Mobilya decides to determine their office chairs' environmental performance and update their performance through using alternative materials instead of using raw materials having adverse environmental effect. Therefore, the life cycle assessment is desired to calculate impact assessment of two office chairs and design more environmental friendly product.

2. Sustainability Aspects of Furniture Sector

From the beginning of the world the mankind always has been consuming any type of source in the earth. Related to rapid increase of human population, amount of consumption per person has been dramatically scaled up. After decades, the scientists have concerned about situation of source of energy and raw materials. Since, incredible rise of consumption on natural sources is more likely be a threat for the world through triggering global warming, climate changes, deforestation, extinction of animal species and so on. Based on these problems, at the first-time sustainability or sustainable development has been commonly defined by R. H. Cassen as "Economic and social development that meets the needs of the current generation without undermining the ability of future generations to meet their own needs" (Hinrichsen, 1987, p. 11-21). Upon this description, the goal of sustainability is to give a unique inspiration to business and industry in order to measure, evaluate and control their pollution levels, and then create new sustainable business models to reach desired sustainability conditions (Cakar et al. 2009, p. 49-67). There is no doubt that the sustainability point of view is the most powerful approach in terms of mitigating human adverse effect on environment (Chen et al. 2013, p. 85-90). Additionally, the mounting attention to sustainability has caused a dilemma on in which way the sustainability approach can be taught to the worldwide. In order to solve this problem, companies and NGOs must take the responsibilities to get the sustainable world. the company image, competitiveness, quality of product or service are not only reason to buy anything from company, nowadays, the sustainability approach and CSR of the company has more crucial criterion to go for particular company among its competitors in the market (Länsiluoto et. al, 2010, p. 385-395). With customers being more conscious of environmental issues, the organizations have realized that the sustainability is vital for their business. It is said that the sustainability involves in three main issue such as environmental, economic, and social. Each organization in the market including NGOs and profit companies strive to understand sustainability and apply into their organizations as a strategic management tool (Danchev, 2006, p. 953-965).

When the definition of sustainability is formed, number of obstacles occurred. For instance, demanding on elevated level of pellet consumption for household heating might influence on deforestation. Essential points from this type of example is that the sustainability have complicated and different type of systems inside. In order to deal with these kind of systems, a new technique is needed which is called systems thinking (Fiksel, 2009). Organisation for

Economic Co-operation and Development (OECD) launched the business model for this purposed called Triple Value Model (Fiksel, 2006, p. 15-22). It includes stock and flow model and supports decision making mechanism for having better know-how on environmental, economy and social linkage. the first system is environmental systems including all type of materials and energy resource. It includes renewable energy resources such as bioenergy, non-renewable sources, and limited environmental media namely air, land, water. Secondly, industrial systems are for accomplishing societal needs through using environmental resources as mentioned before. Extracting a raw material and utilization of energy is used for this system with adding a value to the product throughout its supply chain. Then, it is called economical capital. The finally system is societal systems. The human consumes product, service or energy generated by industrial systems. And, the human can extinguish natural sources by reformation. Through industrial and environmental systems, human being might be affected either positively or negatively. Moreover, this system arranges hierarchy mechanism that leads human behaviour. With this 3V model, system modelling might be easier through simulation methods to analyse different options occurred with alternative interference (Fiksel, 2006, p. 15-22).

In order to analyse or calculate which methodology works as desired, assessment techniques must be used for this purpose. In recent times, importance of assessment tools for sustainability is known. A tool only serving for environmental impact assessment which is called Environmental Life Cycle Assessment Methodology (ELCA) is newly combined with one the other environmental sustainability tool for product and service such as Life Cycle Sustainability Assessment (LCSA) (UNEP et. al, 2011). UNEP and SETAC has launched LCSA as a combination of Life Cycle Assessment, Life Cycle Costing (Swarr et al. 2011, p. 389-391) and Social Life Cycle Assessment (UNEP et. al, 2009). Notwithstanding, complete LCSA still is not enough in order to assess each pillar of sustainability (Ostermeyer et. al, 2013, p. 1762-1779) and suffering from methodological limitations (Guinée, (Ed.) et. al, 2002). well organized literature review on sustainability assessment tools shows that there is not sufficient tool containing three pillars of sustainability at the same time (Linke et al. 2013, p. 556–563). Moreover, according to global trends, developed countries are leading to sustainability assessments studies compared to developing countries (Hansmann, 2012, p. 451-459; Graymore, et. al, 2014, p. 3145-3170). On the other hand, for improving efficiency of assessment tools, performance indicators must be placed (Staniskis et. al, 2009, p. 42–50)

However, using effective and appropriate indicator to show up sustainability level needs agreement with indicators and assessment tool (Bork et. al, 2014, p. 1–13).

In the face of detailed literature review on sustainability point of view in Turkey, there is limited number of articles and research on this issue. In Turkey, sustainability has been generally approached in terms of sustainable consumption and production since 90s (Ulutas et al., 2012, p. 203-209). Turkey situation is explained in the report written by Republic of Turkey Ministry of Environment and Urbanization. This report includes six strategies such as (1) creating awareness, (2) generating capacities, (3) forming partnerships, (4) information sharing mechanisms, (5) financial mechanisms and (6) political reforms conducted with United Nation Environment Programme (UNEP, 2002). Because of sustainable consumption and production in Turkey can be explained in this order:

- Despite the sustainability is mentioned in the law as it is needed, unfortunately there is no legislation or rule for Turkey's sustainability action plan.
- Because of inadequate infrastructure of industrial plants and organizations, on-going projects driven by universities and public institutions have not been carried out in the order of national framework.
- For the sustainable consumption and production, there is few amounts of incentives given by the government. Unfortunately, these incentives fall behind European incentives.

The companies in Turkey address sustainability issues mainly in terms of economic pillar. They apply this approach into process design, product design, then optimization of logistical processes respectively. During designing and application phase of sustainability into the business model, the problem occurs because of lack of knowledge on environmental awareness. Nonetheless, ISO 14001 certificate in Turkey have been dramatically known and used among companies in the market (Türk, 2009, p. 559-569).

From this point, the furniture industry in Turkey and its application in terms of sustainability will be mentioned. First, the meaning of furniture is an object to be used for comfort at shared areas such as living room, office, hospital and so on (Serin et al., 2009, p. 108-116). The furniture has a functional value, that makes places usable, and its design and aesthetics are criteria for being chosen by a customer. Despite of industrialization of furniture making has started 70s of Turkey, however, manufacturing of furniture in Anatolia has been seen in Mesopotamia and Hittite civilization since ancient age (Taner, 2000). From the first time of furniture manufacturing, the wood has been always selected even metal, plastics, and glass has been used recently. There are vital advantages to use wood. For instance, it is easy to mobilize, and its ability of dye absorption is one of the most important reason to be selected for the furniture industry.

Forest area in Turkey covers 21.2 million ha which is 27.2 percent of Turkey's total land area. Related to this land area, in order to supply wood to the Middle East countries which do not have enough source of wood manufacturing industry Turkey is the first place to provide this service. Additionally, Turkey can be effective supplier in terms of semi-processed wood products for the European market because of low labour cost. In Table 2-1, it is shown that wood trade between Turkey and major markets in the Middle East and Europe.

Table 2-1: Export Markets in Wood and Forestry Products Industry (TurkStat - Turkish Statistical Institute)

Countries	2013	2014	2015	2015-2014 % Growth
Iran	129.624	209.103	169.140	-19,1
Iraq	114.256	104.190	75.556	-27,5
Turkmenistan	67.071	64.887	56.688	-12,6
Azerbaijan	77.869	70.467	42.396	-39,8
Georgia	44.717	54.280	32.809	-39,6
Albania	11.152	19.813	16.964	-14,4
Saudi Arabia	7.245	14.092	15.809	12,2
Algeria	7.547	10.299	15.099	46,6
Cyprus	14.868	15.490	15.079	-2,7
Jordan	16.065	16.234	14.508	-10,6
Russian Federation	35.959	28.783	12.428	-56,8
Germany	12.279	11.751	11.601	-1,3
Libya	17.857	17.163	11.399	-33,6
Bulgaria	9.304	12.222	11.395	-6,8
Italy	7.397	11.725	10.097	-13,9
Romania	5.151	8.363	9.689	15,8
Lebanon	5.642	7.551	9.287	23,0

Production of furniture in Turkey is held in both workshops and big facilities. Among these types of production unit, small workshops play crucial role in the market due to hand made furniture demand. On the other hand, workshops enable to expend their production capacity in quickly when demand is higher than usual one. Since the labour cost is relatively low and the owner of workshop can hire more worker. On the contrary, big manufacturing companies have standard type of furniture produced by automated systems and they produce generally for foreign markets.

Data taken from TurkStat shows that in 2012 furniture production in Turkey was accounted 10.3 million TRY. After General Census of Industry and Business Establishments in 2002, 151.904 people were hired, and the industry includes 33.924 companies manufacturing in different type of product (TÜİK, 2002). Besides, The Union of Chambers of Commerce and Commodity Exchanges of Turkey (TOBB) publishes 40 companies which have more than 250 employees, and 155 companies who have over 100 employees. According to Istanbul Chamber of Industry’s list six furniture company involve the top 500 industrial establishments of Turkey.

Table 2-2: Number of Furniture Facility and Their Employment Level in Turkey (TurkStat)

Cities	Number of Establishment	%	Level of Employment	%
Istanbul	3874	26.4	21653	22.1
Ankara	1971	13.4	10637	10.9
Izmir	1474	10	8947	9.1
Bursa	1329	9	13994	14.3
Kayseri	647	4.4	11390	11.6
Antalya	551	3.8	2134	2.2
Samsun	287	2	1201	1.2
Kocaeli	273	1.9	2716	2.8
Other	4286	29.1	25215	25.8
Total	**14692**	**100**	**97887**	**100**

Location for manufacturing places of furniture industry is generally held in big cities in Turkey such as İstanbul, Ankara, Bursa (İnegöl), Kayseri, İzmir and Adana. In Ankara, the place named “Siteler” is known as one of the biggest furniture manufacturer places in Turkey. There are more than 10,000 registered companies in small and medium size. Moreover, approximately 10 most known companies which is operating in big scale of production are in Siteler area. Additionally, Bursa İnegöl is rapidly growing and became the third most important production region in Turkey. Especially Bursa is mostly covered by forest lands which means that the facilities are close enough to raw material. Ultimately, “Karabağlar and Kısıkköy” which supply furniture to the Aegean Region belongs to city of İzmir.
Based on materials used throughout the production process in Turkey, manufacturing process can be divided in three main part like wooden furniture (massive and veneered), metal furniture and others. Among these three, the wooden furniture is the most common way in turkey. Because of good quality of wood, it is preferred in major share in total demand of furniture industry (Republic of Turkey Ministry of Economy, 2016).

Recently, almost all furniture facility has the latest technological updates and machinery in their production area. From the late 90s using high-tech and CNC machines in this industry have dramatically raised. In accordance with quality control mechanism, the process starts from even raw material extraction to the packaging process. Besides, large scale mass production facilities have specific packaging material as a necessity of European trade rules. These are such as PE, PP, foam, poly-urethane and cardboard boxes. Finally, the substantial number of companies have ISO 9000 certificates and other relevant documents.

One of the most criterion for buying furniture from customer point of view is to ensure the latest fashion taste. For this reason, designers must update their collection and keep close to any changes in the market. The designers must meet consumers’ demands in both foreign and domestic markets. Moreover, Turkish designers and furniture companies have an advantage to follow up customer demands due to Turkey has one of the biggest textile industry in the world. So that, adaptation to another type of fabric or colour based on contemporary trends is easy for Turkish manufacturers.

Export activities in Turkey have accelerated in last ten years. Related to this increase, exports in furniture industry is accounted from US $ 684,5 million in 2005 to US $ 2,2 billion in 2015. This amount of increment in 10 years is caused by expansion of facility' volume, design and quality of raw materials. The export products include wooden furniture for bedroom, office and kitchen and seats for motor vehicles mainly.

As it can be seen in Table 2-3**Hata! Başvuru kaynağı bulunamadı.**, the major share in export markets belongs to Iraq, Saudi Arabia Germany, and Libya. The total share of first three country has more than 30 percent of major export markets in Turkey furniture sector. In Europe, showrooms and warehouses are playing crucial role for increasing export business. Another reason related to increase of export furniture is Turkish contracting sector. This sector is responsible for construction of housing, tourism projects and hospital in abroad. These are mainly buildings and decorated by furniture made in Turkey.

Table 2-3: Major Export Markets in Furniture Industry Value: US$ 1,000 (Trademap)

Countries	2013	2014	2015	Share of Countries (%) 2015
Iraq	451.531	477.153	425.981	19,4
Saudi Arabia	81.248	113.246	159.752	7,3
Germany	135.302	141.424	146.934	6,7
Libya	234.417	187.240	136.225	6,2
France	103.844	117.152	123.173	5,6
Azerbaijan	165.270	176.781	100.718	4,6
U.S.A.	37.656	63.563	90.582	4,1
Turkmenistan	86.958	98.922	82.653	3,8
U.K.	55.971	60.478	60.708	2,8
U.A.E.	39.438	39.622	57.302	2,6
Holland	45.390	45.778	42.769	1,9
Iran	30.182	35.116	38.547	1,8
Romania	26.242	43.138	37.545	1,7
Italy	33.059	34.667	36.741	1,7
Israel	30.015	32.584	36.419	1,7
Algeria	16.343	29.056	36.363	1,7
Russian Federation	96.893	76.121	31.254	1,4
Georgia	30.149	42.990	30.062	1,4
Egypt	22.748	27.176	27.834	1,3
Cyprus	23.361	22.839	24.046	1,1
Spain	21.976	24.334	23.375	1,1
Belgium	21.237	24.626	22.853	1,0
Qatar	18.473	16.640	21.402	1,0
Kazakhstan	27.851	28.101	21.126	1,0

Greece	17.190	21.431	18.949	0,9
Austria	24.644	21.488	18.778	0,9
Morocco	12.232	15.998	18.084	0,8
Others	290.348	342.895	323.592	14,8
Total	**2.179.968**	**2.360.561**	**2.193.768**	**100**

The beginning of 2005, the export value was 684.552 thousand US Dollar. During the following year, it has been rapidly growing without any decrement. Ultimately it has picked up in 2015 with 2.193.768 value.

Table 2-4 : Export Activities in Turkey by year (TurkStat)

Years	Value in US$ 1.000
2005	684.552
2006	764.715
2007	1.032.658
2008	1.332.922
2009	1.153.520
2010	1.363.062
2011	1.606.993
2012	1.849.065
2013	2.179.967
2014	2.360.560
2015	**2.193.768**

In order to face with market threats, and weaknesses of furniture industry, and also see opportunities in this market, the SWOT analysis is beneficial for companies in this sector. This analysis is made by companies and their stakeholders with interviews and surveys. First, the strengths of the furniture industry can be explained in this way: the market has significant amount of company having big scale mass-production systems. This means that the market is dominated by powerful companies and they can play vital role in export activities. Second strength is high volume of labour force. In accordance with socioeconomic situations in

Turkey, most people are willing to work in any condition despite worker's salary for furniture industry in small and medium enterprises is not sufficient. So that, the industry is easily to hire people with low labour cost. Thirdly, the history of wood industry ensures wood working skills. Besides the mass-production, handmade and hand-crafted work is so popular, and it drives both domestic and abroad customer to buy unique and stylish wood furniture.

On the contrary, there are several weaknesses for furniture industry in Turkey. It can be said that there is lack of information about how to deal with networking problems and organization. Except for big scale companies, there are numerous family companies in the sector. So that, they have traditional way to run the business, however, the novel approaches for staying in the business differ from the old ones. The other problem is that there is not enough incentives or financial aids from government. Lack of information on support mechanism such as Kosgeb (Small and Medium Enterprises Development Organization) and Igeme (Export Development Centre) causes to miscommunication between SMEs which need to be well organized. Unfortunately, there are couple of issues related to environment such as lacking raw materials, using high volume of energy and its cost. The furniture sector in Turkey for production of bedrooms, offices generally depends on wood based. So that, the raw materials for this type product creates scarcity for forests in the long term. The finally, weaknesses are related to lack of knowledge about international standards. Recently, European markets claims such documentation on environmental performance of the product and quality certification. This makes a barrier between Turkish and European markets. In order to cope with this problem, European markets generally request environmental product declaration documents (EPD), Nordic Swan and similar kind of certification which shows environmental performance of the product or services.

The opportunities for furniture sector can be listed as strategic location of Turkey which is very close to European and Middle East markets, globalization, high quality and branded products, increase of marketing activities, effective usage of social media, being close to latest trends and fashion. However, China threats are adverse effect on Turkish exports. Since, its price is relatively lower than each product made in Turkey, so that the customer is more likely to prefer low cost product due to economic recessions in global scale. Because of mass-production companies in global market, SMEs strive to enter the global market which is not easy. Since they cannot contribute any value to the exports.

In order to deal with all threats and weaknesses and make real contribution to Turkey’s economy, the furniture sector must create an action plan. This plan should generally mention these topics (Doğan et al., 2016):

- Urgent elimination of problems related to raw materials and energy of the sector
- Producing original collections with original designs, quality and world standards
- Support for design competitions
- R & D and patenting studies that will benefit industry development
- To comply with international standards and quality requirements, harmonization of the health and environmental conditions within the framework of international rules, establishment of laboratories for the production and measurement of these criteria
- Organizing activities for the promotion of the Turkish furniture sector abroad
- Supporting the departments of the universities related to furniture design, is required.

In order to ensure desires for sustainability in the industries number of settings must be organized and followed (Krajnc et al.,2003, p. 279–288; Lowell Center for Sustainable Production, 2015). These are to reduce materials and energy used in production system (Krajnc et al.,2003, p. 279–288; Herva et al., 2011, p. 1687–1699); to condense waste, to recycle imperfect products or product at the end of its life; the packaging of products must be durable as much as being environmental friendly; discarding of non-recyclable products; besides these environmental aspects continues learning and self-improvement for employee, safe work environment are the other critical issues for sustainability. (Lowell Center for Sustainable Production, 2015). In the following chapter, clean production issues will be mentioned deeply.

As a first step eliminating negative effects on environment helps to identify which cause triggers not sufficient production system. After realizing the bottlenecks, it leads to set up sustainability strategies for the product. Besides, in this thesis study, the furniture industry is the main focus due to the sector has been leading as a pioneer sector in respect of the global economy (Grael et al., 2010, p. 30–41; Gabiati et al., 2014). The sector has a significant number of adverse effects on environment. It can be said that volume of waste during production process and destruction of the nature is the most known drawbacks for the earth (Grael et al., 2010, p. 30–41). For these reasons, the furniture companies through being creative and innovative must be good example to other sectors and their competitors in the same market. whereby eco-design and ecolabels such as Carbon Footprint (CF), Forest Stewardship Council, Nordic Swan, EU Ecolabels the companies in furniture industry has advantage for creating different value compared to their competitors (Bovea et al., 2004, p. 111–116; Morris et alç, 2004, p. 251–266; Parikka Ahola et al, 2008, p. 472–485; Veisten, 2007, p. 29–48).

Based on significant number of case study held in the literature, in order to provide sustainable development and sustainability vision in this sector, the action plan should include these priorities: sustainable design, clean production, waste management, optimization of transportation, workplace safety, selection of wood coating material, and so on.

3. Design for Sustainability

In this chapter, Design for Sustainability topic is explained with these titles respectively: Clean production methods and their application in furniture industry, eco-efficiency, and the last but not least one is the material and its sustainability including raw materials used in furniture industry, decision behind selection process of materials, ultimately substitute materials for furniture sector.

3.1. Clean Production Methods and Its Applications in Furniture Industry

It has been rapidly mentioned that sustainable development tools and techniques such as cleaner production (CP), green supply chain applications in order to reduce greenhouse gas emissions (GHG), resource consumption are recently the key methods. It is not only related with increase of awareness about adverse effects on the environment, but also to significant pressure on limited natural resources exposed by several industries. Besides, costs of extraction of raw materials and energy consumption are the other reasons to develop this type of sustainable development tool (CETESB/UNEP, 2002).

Because of decision made by UNEP Growing Council in 1989, Cleaner Production Program was launched by UNEP-IE (The United Nations Environment Programme-Industry and Environment Centre). The definition of CP is an incessant application for preventing negative impacts on environment occurred in throughout its production processes. This method can be applied for product, process and service as well. Through using it, minimization of waste and emissions, and usage of natural resources can be controlled in easier way. Additionally, it can be classified such as optimization of whole processes of product instead of end-of-pipe solutions which are used for at the end of production processes.

In 2001, CP was linked between production sector and sustainability, in accordance with CP ensures achieving sustainable development (SD) goals by defining implementation steps (Geiser, 2001, p. 3-6). This is helpful approach for responsible people to meet SD goals such as reducing unwanted results of processes inside of the facility.

In the process point of view, CP is responsible for raw materials and energy, decreasing toxic content form raw material, and reduction of emission and waste. On the other hand, CP works for products with reducing adverse effect throughout its life-cycle which means that it starts from extraction of raw material to the end of life including such options: recycle, reuse or landfill. Ultimately, for the services the method includes designing and delivering application linked with environmental concerns.

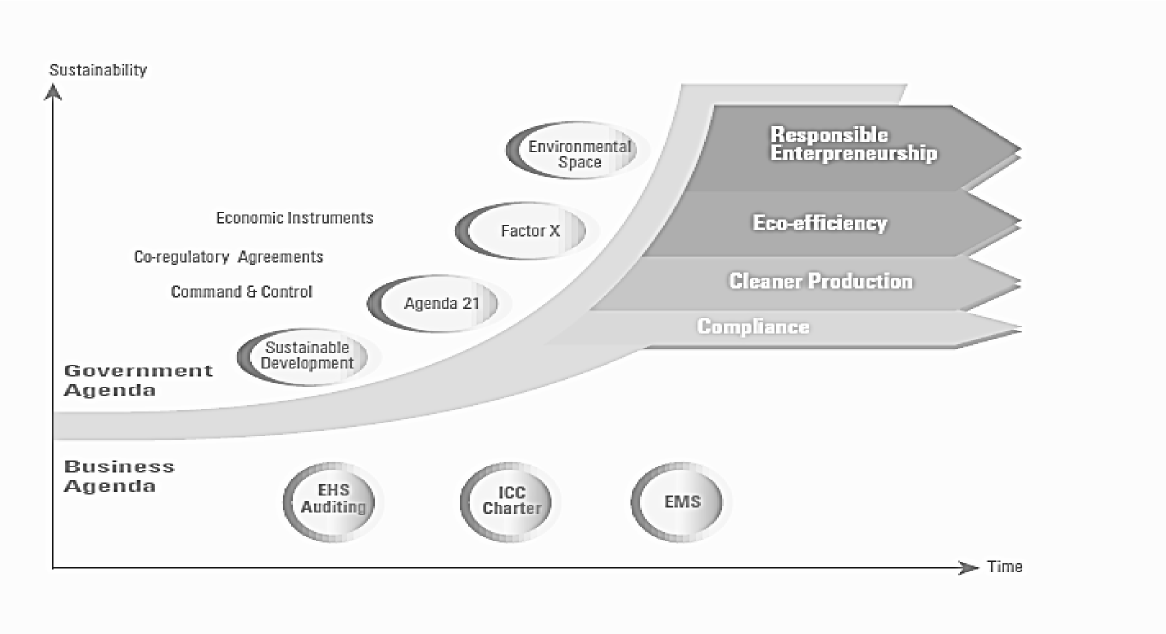

Figure 3-1: Developing relation between various SD application in years (UNEP et. al, 1998)

Each CP activities must obtain 5 stages: planning and organization; pre-evaluation; evaluation; feasibility studies and implementation respectively. These steps include specific steps individually (Staniskis et al., 2003, p. 619-628; Stasiskiene, 1999). It can be said that:

- Planning and organization:
  - to develop CP objectives
  - to agree with company's manager
  - to arrange project management team
- Pre-evaluation:
  - To organize flow charts based on budget and time
  - To measure output and input (of product)
  - To decide assessment focus
- Evaluation
  - To calculate mass and energy balance

    - To create alternatives for CP
    - To decide CP options for next step
- Feasibility
    - To perform technical, environmental, financial evaluations
    - To identify ultimate option
- Implementation
    - To apply selected options
    - To monitor progress and based on result improve CP action plan
    - To create new CP plan

Cleaner Production can be used as a tool for answering three important questions which are where, why, and how. Where and why questions refer to a company suffer from losing resources as a waste and pollution. How can be related to the way of solving minimization problem of waste and pollution. Besides, cleaner production can be defined as a combination of these applications: energy conservation; design for environment; source reduction; risk minimization and so on. With respect to this, CP must be implemented into the process with great know-how. The methods can be listed (The Institute of Environmental Engineering, APINI):

- Good Housekeeping
- Input Substitution
- Better process control
- Equipment Modification
- Technology change
- Recovery or reuse
- Product modification
- reducing energy consumption

First of all, good housekeeping is meant to control mechanism must be well organized for both managerial and operational actions. It can be truly said that good housekeeping involves preventing emissions and waste, and to administer operations inside of the facility. it includes also training and incentives program in order to improve workers skills. Ultimately, it is more likely to be low cost application and provides moderate benefits. As a particular example for housekeeping, in Norway a company having 60-70 workers produces foam in hard and soft form used in furniture industry. This company aims to reduce production losses and optimize use of energy. In accordance with this aim, project team reduces the number of different products. Then, the foam blocs are organized in terms of their types. Through this change, larger order series can be controlled in efficient way. reduction of material loss equals to a 360,000 NOK per year savings in reduced raw material costs. Finally, ecological and financial benefits are gained at the same time (Høgevold, 2011, p. 392-400). Secondly, input substitution is to be replaced materials with if there are better options for raw materials. This can be less toxic, renewable material or have a longer product life time in production process. However, input substitution is needed to be assessed for analysing the quality of product will not change after replacing application. Third one is to make better process throughout the production phase. Operational procedures and equipment instructions might be needed to be modified. As some consequences of this action, saving of time and resource, and improving efficiency should be resulted. It can be moderately costly; however, the benefits are more likely to be high. Additionally, equipment modification is about to change existing one to the new one which has better process efficiency and less emissions. Fifth method for CP is to update the technology used for production process. The technology has been changing continuously without any break. For that reason, there is always new solution for eliminating waste and emission whilst improving process efficiency. although installation cost of modern technologies has substantially high, the benefit is quite high. Another method is to use materials on-site as a raw material for another application. It is linked to both recovery and reuse activities. It means that the wasted material can be used in the same process for another item inside of the facility. In this way, it is not possible to pollute the environment. In order to maintain this, recycle and reuse applications, installation of waste separation and storage is needed. Moreover, one of important application is to modify product. It is needed for when a product has critical impacts on environment throughout its production and use phase. In order to minimize these impacts redesign of product could be a possible solution. This change can be led to improve product recyclability, and to reduce toxic materials inside of product. Feasibility analysis for latest design ideas, market research is needed in order to manage product redesign. However, the supply chain of any product is recently too much complicated then, it could be costly application due to product’s supply chain might be needed to change in order to get new components from different retailers. The last application is to use energy in efficient way. Consumption of natural resource for producing energy or use of energy is key factors for product life cycle. In order to meet the energy requirement, renewable energy resource could be the best sustainable option (WBCSD, 1998).

In fact, there are some external and internal struggles within the period of implement this sustainable production approach into the production facility. First of all, if the CEO of company has no knowledge, awareness or even interest on sustainability, it would be difficult to pursuit him to adapt this new technique. Secondly, if there is any information for waste and emission recorded, making measurement of these emissions and waste would take significant amount of time at the start. Third one is to focus on end of pipe solution instead of creating permanent application. End of pipe solution give a benefit for the brief time unlikely cleaner production applications have long term benefits. Besides, the company might not have enough capital to build up updated technology. On the other hand, there are couple external issues. The most known one is that there is no available cleaner production technology to implement for specific business activity. Each solution is not applicable for every production facility. So that, R&D activities, which are the costliest action inside of the facility, might be need.

3.2. Eco-Efficiency

The first-time eco-efficiency was announced in when Earth Summit was organized in Rio de Janeiro in 1992. However, it was written in “Changing Course” the book of Stephan Schmidheiny in 1992. The definition of eco-efficiency is “The delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the Earth’s estimated carrying capacity.” (WBCSD, 1998). As a recommendation of World Business Council for Sustainable Development (WBCSD), eco-efficiency has seven steps in order to meet sustainable development:

- to decrease material intensity of good and services
- to minimize energy consumption of goods and services
- to reduce waste and emissions
- to provide material recycle
- to increase use of renewable energy resources
- to extend durability of product
- to increase service intensity (WBCSD, 1998)

It can be said that eco-efficiency is a comprehensive approach in order to detect each impact throughout the product or service life time, i.e. cradle-to-grave approach in lifecycle assessment methodology. It means that customer is included at the end of supply chain. It can be used for both product and services as being both step by step continuous improvement and dramatic innovation process. Therefore, companies having straight business strategy on eco-efficiency have started to take advantages of customer attention through designing product using less energy and material whilst meeting customers' needs at acceptable price. Companies have had growing attention on how to measure eco-efficiency. The measures of eco-efficiency have focused on beyond industry. Recently, it covers whole supply chain of product or service. It might say that the importance of supply chain has been increasing. However, to calculate of eco-efficiency is not easy whilst unwanted items at the end of production, i.e. waste, are not always defined in the same way. Among different type of business, each emission or waste are varied, so that, it makes hard to compare two industries in terms of emissions.

WBCSD focused on developing measuring metrics and principles as a first step by conducting a survey 32 corporate environmental reports (CERs) with participation of seven companies from different industry. It aims to show how pioneer firms apply eco-efficient approach on their business and how they measure it through using CERs. These companies create relation between cost saving, risk reduction, and market opportunities through decreasing adverse environmental effects and resource consumption for product and service. It makes a difference among their competitors. Since some of them only focus on environmental side instead of combination of three sustainability pillars. Moreover, the key issue on measures for eco-efficiency is that there is neither standardized method nor common set of indicators. As companies have diverse business strategy and are in different industries. It can be said that the collaboration and standardization is needed among industries.
According to WBCSD, members of this organization should apply these metrics principles and reporting system (WBCSD, 1998):

- to be involved in protecting environmental and human life quality
- to create decision making process to accelerate organization's performance
- to understand natural diversity of business
- to involve benchmark and monitoring activities
- to be able to define, measure organizational activities

- to clarify all activities to stakeholders
- to be based on a comprehensive evaluation of the organization

On the other hand, in most cases eco-efficiency can be measured by this ratio (Verfaillie, et al., 2000):

Equation 1: Eco-efficiency

$$\text{Eco} - \text{efficiency} = \frac{\text{Product or service value}}{\text{Environmental influence}} \qquad (1)$$

Common issues between eco-efficiency and cleaner production are that they ensure company's continuous improvement in reducing consumption of resources, and delimitation risk and emissions. Secondly, these two concepts require companies to apply action plan to build environmental management concept through combining three sustainability pillars with collaboration of diverse departments such as R&D, manufacturing, transport etc. Although cleaner production may specify on that it particularly focuses on manufacturing processes, it is recently known to apply for whole life cycle. Besides, eco-efficiency comprises both products and services. With this different focus, both concepts lead companies to recognize market opportunities and threats along the supply chain. Implementation of eco-efficiency and cleaner production methods into company provides economic value by improving efficiency of entire production system. Moreover, economical saving comes from reduction of emissions and waste as well. Because, investment expenses have relatively short pay-back period. Even though both concepts have common attitude which is actions toward sustainable development, eco-efficiency most especially focuses on resource consumption, and pollution. It is for creating a value and a link between environmental and business perfection. Ultimately, cleaner production and eco-efficiency can apply into various type of company from different sectors, and their size.

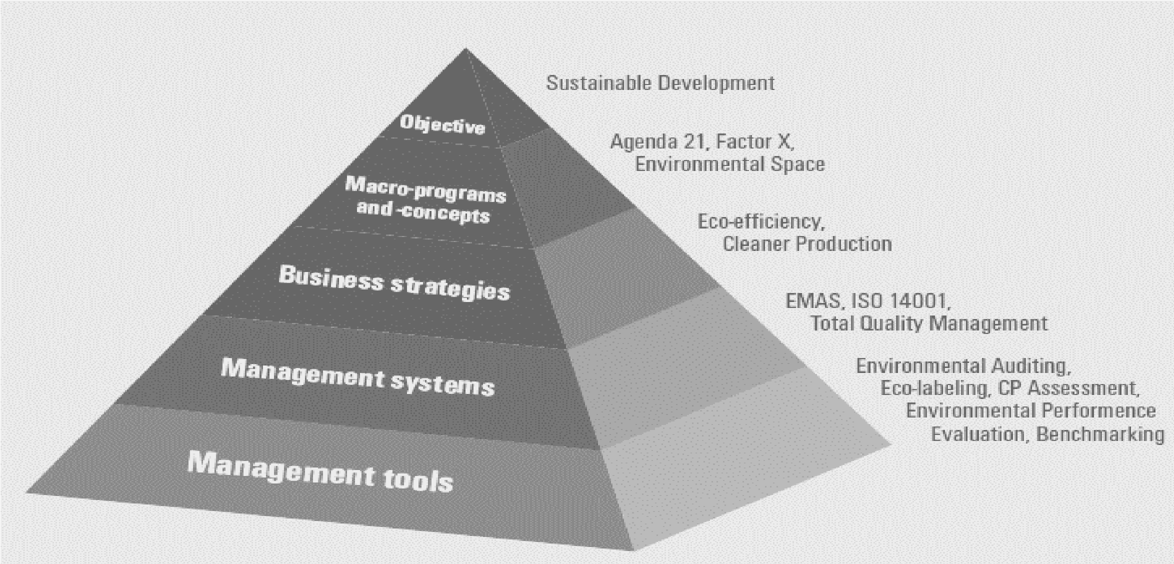

Figure 3- 2*:* The Pyramid of Business Transition Towards to Sustainability (UNEP et. al, 1998*)*

3.3. Material and Its Sustainability

3.3.1. Raw materials

Based on literature review, the common materials used in furniture production can be listed such as wood, metal, plastic, textile, and other (European Commission Joint Research Centre 2013). First, the wood is mainly used for production of table, desks, and cupboards. It can be detailed in three main sections which are particleboard, fibreboard, and plywood. Particleboard is produced under heat and pressure, after this application adhesive is applied on particles. The production of fibreboard is like particleboard except of glue fibres are used for the adhesive. This material contains three types of material in terms of increasing density such as particle board, medium-density fibreboard and hardboard respectively. Medium-density board called as MDF has wider using area in the furniture industry. the plywood is produced through under heat and pressure like particleboard and fibreboard, however, there is addition of an adhesive material to wood sheets. The second common material used in furniture production is metal. It is essential for cupboards, tables and legs of chair. As the metal have strong strength toward to strong sunlight, wind, snow, rain etc, chairs and tables made from metal have longer durability. Since, they can be used for exterior purpose. Generally, metals can be classified in four main parts i.e. aluminium, steel, iron, and others. The advantage of using aluminium is that it does not oxidise at the same time its weight is relatively lighter. For that reason, it can be used for furniture’s cast. Moreover, stainless steel is being used recently for legs of chair, supports, since it has high tensile strength which can lead to be used for hollow tubes and reduction of product weight. Iron because of its hardness, weight, and tough structure leads to be used for outdoor purpose such as bench legs. When the pure iron is used, and it is aerated, it ultimately oxidises. Finally, other metals are bronze, magnesium, chrome applied for fittings in furniture industry. The third most used material is plastics which have wider variety inside of it. In accordance with environment friendly point of view, this plastic applications are not as good as neither steel nor aluminium. Even though, it has detrimental components, it is cheap, lighter and its strength is much higher compared to other materials. As it can be recycled, it has a terrific opportunity to be used in furniture industry. plastics can be determined as two main polymers which are thermoplastics and thermosetting ones. Thermoplastic has distinctive characterization when they are treated with heat. When the heat is applied, it becomes soft and flexible. After it becomes cooler, it turns into a fragile material. On the other hand, thermosetting polymers ensure that they are durable materials, so that it is more likely be used for padding in furniture industry. especially, polyurethane foams (PUR) are selected for sofas, chair seats and backs. Additionally, the most used textile components are cotton, polyester, leather, polyamide so on. Particularly, polyamides are used for again padding purpose like thermosetting polymers do. Ultimately, glass, stone, bamboo, cane are used. However, among these materials glass needs to attention because of existence of dangerous substances for instance cupper or lead applied in mirrors where coating material is silver, aluminium, gold or chrome.

3.3.2. Material selection process and creating sustainable products

In the literature numerous research have been done by number of researchers. Holloway, focused on only one approach for selection of materials in mechanical design, and pointed out the steps of this material can consider environmental factors as well (Holloway, 1998, p. 133–143). It considers environmental performances of materials whilst conventional product selection mechanism does not focus on these issues particularly. Giudice recommends an approach for selection purpose that ensures detailed data on the environmental performance of materials and processes (Giudice et al., 2005, p. 9-20). Related to this function, it can calculate environmental impacts throughout life cycle and determine the cost of selected material. Besides, Ribeiro contributes sustainability vision into material selection process which can be called as life cycle engineering (LCE) (Ribeiro et al., 2008, p. 1887–1899). It concerns ensuring materials having better environmental, economic, and social performance during its life-time. In addition to that, this approach allows to make a comparison among diverse materials and industries by using "best material domains" method for creating different material selection scenarios. Similar to Ribeiro, Jahan examines the literature about reviewing and selection of material methodologies (Jahan et al. 2010, p. 696–705). It can be said that life cycle engineering can be assumed one of the best method for material selection of sustainable production. LCE means that activities of engineering including these: applying technological and scientific methodologies in order to create product or service whilst concerning environment and natural resources at the same time meeting sustainable development progress (Jeswiet, 2003, p. 17-20). Wherefore, LCA can be determined decision making tool which contributes to environmental production and cost saving activities. Furthermore, LCA is not only a tool for traditional tool serving for technical or chemical specification, but also tool for analysing life cycle cost, environmental effects likely LCA. In diverse research on automotive, construction, and electronic sectors, LCE is ideal for this purpose.

To optimise multi-objective decision making process for material selection approach, Zhou creates sustainability indicators of materials and recommends a combination of artificial neural networks with generic algorithms (GAs) (Zhou et al., 2009, 1209–1215). Moreover, Feng designed a methodology for selection of green materials in accordance with its toxicity (Feng, 2006). It shows that this price competition approach controls alternatives materials in different life cycle stages in view of customer satisfaction and environmental tax policy enhanced a chart about material selection process for a purpose of reduce adverse environmental impacts (Weaver et al., 1996, p. 11-17). It includes basically mechanical specification of material and its environmental performance. Additionally, Lacouture creates a model for optimisation for building material selection process as a purpose of being used for Leadership Energy and Environmental Design (LEED) in Colombia (Lacouture et al., 2009, p. 1162–1170; Bovea et al., 2006, p. 209–215). Yuan and Dornfeld designed a systematic method for classification materials regarding to toxicity of materials on human health which connects to sustainable material selection having effect on design and manufacturing of products (Yuan et al., 2010, 2009; Yuan et al., 2009, p. 18–20). Moreover, Ashby builds a structure for selection methodology of materials which is essential factor in terms of sustainable production (Ashby, 1999). Figure 3-3**Hata! Başvuru kaynağı bulunamadı.** shows phases of material selection process. One can be said that first step translation design requirement includes function, constraints, objective of this selection, and free variables. Second step is to screen using constraints which remove the material that cannot serve for its purpose. Thirdly, ranking using objectives is to find the material left after screening step. Ultimately, to seek supporting information is led to make a research the background history of top-selected candidate materials. After deciding which selection method would be proper for sustainable production system, the material selection must be handled. A sustainable product definition presents that the product has an insignificant impact on the environment throughout its life-time. Therefore, selection of material is essential due to it is related to consumption of natural resources and energy for production and use stages (Mohamed et al., 1998, p. 329–339; Tretheweya et al., 1998, p. 39–56; Jahan et al., 2010, p. 696–705). Apart from the fact that, to settle upon using renewable materials such as wood instead of plastics is crucial decision for sustainable production approach.

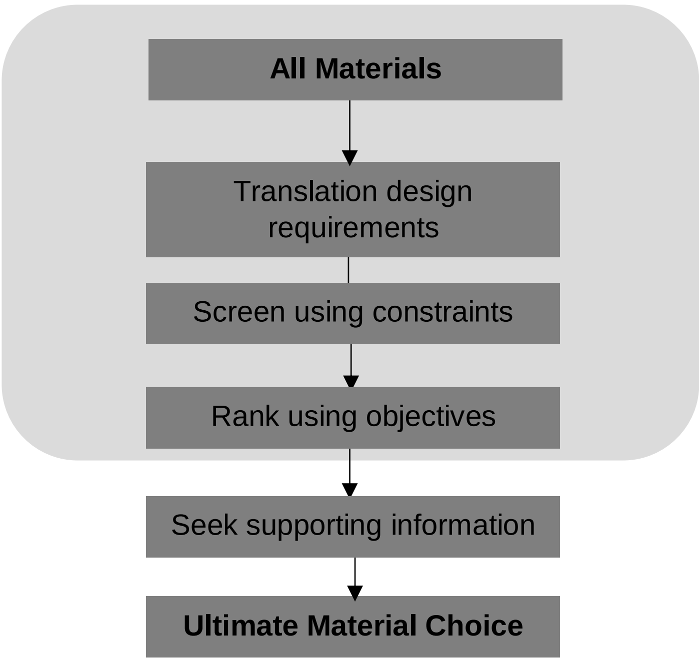

Figure 3-3*:* Phases of material selection process (Ashby, 1999)

Traditional way of selection materials for production depends on material’s price, strength, density, quality, hardness etc (Brechet et al, 2001, p. 407–428; Mangonon, 1999). Nevertheless, design of product, cultural considerations etc. are other criteria that must be considered while sustainable production occurs. Under any circumstances, the selection procedures for sustainable production stands on effect on environment likewise customer demands fiscal criteria.

Table 3-5 is situated mainly six categories for structural materials that can be considerable for production of sustainable products (Ljungberg, 2007, p. 466-479). This includes almost 99 percent of all materials used for mechanical, civil, and electrical engineering applications. As an exception, chemical substances are not included in this table. The sustainability score is estimated from 1 to 3. Score of 3 represents the highest or best value for this criterion.

Table 3-5 : The six material groups for sustainable product (Ljungberg, 2007, p. 466-479)

Materials	Examples	Sustainability score
Metal	Steel Aluminium Bronze	2-3
Ceramics	Porcelain (clay) Mineral glass Al2O3, Si3N4, SiC, etc.	2-3
Synthetic polymers	Thermoplastics (e.g., PE, PS, PC, PP) Two component polymers (e.g., epoxy) Rubber (e.g., Isopren)	1-3
Natural organic materials	Wood Cotton Silk	2-3
Natural inorganic materials	Stone Minerals	3
Composites	Mixed materials, e.g.: PS + glass fibres, Cu +W-fibres, Rubber + textile fibres, asphalt (oil + stone), Wood Polymer Composites (WPC)	1-2

Metals are generally affordable to buy and easy-to-recycle through re-melting. Its durability and strength make this material the most used in diverse industries such as construction, furniture, automotive etc. Steel and copper have high level of melting point which leads to significant level of energy demand for re-melting process. Besides, corrosion factor is another issue needed to be considered for the metals. Since, the chemicals for corrosion protection is needed. Ultimately, its sustainability score is 2-3 corresponding to high melting temperature and its toxicity during extraction process.

Ceramics is a material having non-toxic ingredients and light weight. For conventional ceramics application clay is used whilst pure oxides, nitrides, and carbides are better option for advanced ceramics. Even though ceramics are brittle, they are corrosion resistant, durable and hard. It can be seldom recycled to new products due to it demand crushing, grinding and re-burning. These processes require cost and energy demand.

Synthetic polymers mostly known as plastics and rubbers are made by raw oil. However, some of polymers is made by natural organic materials such as wood. When polymers made of raw oil are recycled, the material cannot be determined as renewable due to oil used in material inside is limited amount and new oil reserves would not be formed in short period of time. Because of re-burning polymers such as polyethylene creates carbon dioxide which leads to increase greenhouse gas (GHG) emission into air. Additionally, polymers containing halogens such Teflon® (PTFE) and polyvinyl chloride (PVC) have significant amount of adverse effect on environment when they are burnt since the fumes release into the air. Hereby, the re-melting can be determined as a better option. Whereas polymers have low re-melting point (approximately 200 °C) compared to metals, the energy consumption for this operation is relatively low. Furthermore, if exhaust cleaning can be arranged for combustion reaction of burning polymers, the recycle of these materials can be done. Finally, sustainability score of polymers depends on toxic chemicals inside of material, and non-renewable materials, so that, it varies on from 1 to 3.

Natural organic materials such as wood, cotton, and silk are used in variety forms and industry. during recycling process carbon dioxide is released to the air and captured by plants and trees. Since, the carbon dioxide level in the atmosphere would not increase when natural organic materials are burnt. On the contrary, adhesive materials and colouring contents used in natural organic materials can be toxic for the environment. Thus, sustainability score varies on from 2-3.

Natural inorganic materials such as stone, rock have common points with ceramics. Due to, natural inorganic materials' sustainability score is 3. Composites are combination of two different materials. Recently it has been known from form of ceramic fibres composed with plastic resin. If these materials are burnt as a purpose of recycling with no toxic formation, the sustainability score could be 3 when materials are renewable. Generally, composite materials are non-renewable, so that the separation of components is needed to special process. Thus, this makes composite unsustainable.

To sum up, these materials can be defined as a sustainable for clean manufacturing purposes in the future. Nonetheless, demanding on wood and cotton too much is likely to cause on deforestation and adverse environmental issues such as water problems, carbon utilization, and so forth. Because of that, the material can be considered as it is sustainable, however, the processes of materials' utilization are needed to be determined for ensuring sustainability concept for throughout materials' life-cycle. Ultimately, polymers and plastics need a special attention because of there is a chance that they can be recycled or re-used.

3.3.3. Alternatives materials on sustainable manufacturing applications

In this section, alternative and eco-friendly raw materials are described to be substituted to conventional supplies in the office furniture industry. Basically, some wood types such as rubberwood, and plastics have alternative options for more eco-friendly products.

In many researches show that bamboo, coconut wood, and oil palm trunk (OPT) are mentioned as an alternative raw material for wood-based furniture production. Besides hemp, flax and leaf fibres can be used as a raw material in furniture industry. Firstly, Bamboo has various subfamilies and there are more than thousand species to bamboo herb. Each bamboo species has different type of specification and qualifications (Mohd et al., 2012). The locations of bamboo plantation are held majorly in Southeast Asia with 64 percent, and South America having 33 percent bamboo plantation is the second biggest region in the world. The rest of bamboo plantation belongs to Africa and Oceania (Bonilla et al., 2010, p. 83-91). As a result of detailed research on developing alternative raw materials to wood-based furniture industry, the bamboo-based bio composite materials are found (Liansheng et al., 2002, p. 55-58). Bamboo is related to not only environmental friendly concept but also has unique form for the designer through its flexibility. This means that the bamboo has significant importance both for designers and manufacturers to provide clean production requirements. Regarding to this, many governments have started to make research groups and centres based on providing sustainable furniture industry. For instance, Malaysian government has an agency named as Forest Research Institute Malaysia (FRIM). Similar to this example, the Chinese Association Eco-materials was established by the Chinese government to support scientists who search on how to design, produce, reuse and recycle materials in environmental friendly way. Innovations in bamboo fiber leads to improve material durability (Schroder, 2012). There are numerous of awarded examples to be used for a criterion for buying bamboo-based furniture. The most known designer Anthony Marschak created Spring Chair with using bamboo instead of solid wood. He needed to use solid wood, however, he preferred more versatile material as a raw material. This chair was produced from sustainable resources and its flexibility provides easy-to-bend for the designers (Schroder, 2012). It can be said that bamboo bio composite materials have versatile applications, so that its surface is remarkably good.

Figure 3-4: Bamboo Chair (Architonic)

Secondly, oil palm biomass is the second most used raw material substituted to rubberwood materials for furniture manufacturing processes. The industries using wood-based materials have been suffering of lack of raw material such as rubberwood. Due to increase of demanding on rubberwood, there are couple of innovations ongoing to solve shortages in rubberwood supply. On the other hand, most of time, oil palm trunk quality is close to rubberwood particleboard (Yayah et al., 1995). Additionally, the oil palm biomass can be cycled up to 90 percent (Suhaily et al., 2012, p. 4400-4423). This percentage might lead to promote use of oil palm biomass as an innovative raw material by furniture manufacturers. Moreover, oil palm trunk lumber (OPTL) can be determined as alternative material for rubberwood since its thermal, mechanical and physical specifications, and resistance to pests

(Suhaily et al., 2012, p. 4400-4423). These characteristics of OPTL directly effect on being selected for furniture manufacturing process by customers due to these can provide durability, quality as rubberwood does.

The general structure of oil palm components is shown in **Hata! Başvuru kaynağı bulunamadı.**. As it can be understood that unlikely other type of wood options, each part of oil part tree can be used in various processes. Finally, this leads to ensure sustainable production mechanism through providing less waste and scraps.

The third alternative material for wood-based applications in furniture industry is to use coconut wood. It can be versatile material used in diverse manufacturing processes such as furniture, and hand made products like novelties. Since it has tremendous grain and natural looking. When the appearance is considered as a first criterion by the customer for willing to buy the product, coconut wood can be the best alternative compared to conventional wood types using in the furniture production. Therefore, through its quality level, and appearance coconut wood would be an innovative solution for deciding on which alternative raw material should be selected. Besides, coconut wood especially in South Asia might be new pioneer for export market activities. the common point between coconut wood and other type of woods is that like all untreated recent cut lumber can be affected by mould and get spots from fungi when the lumber is not appropriately preserved from extrinsic factors. Thus, protective treatment is needed if the lumber is used for production of export goods.

Another issue that should be considered is plastics. Generally, plastics are harmful to the environment specially at the its end-of-life. Incineration of plastics releases various chemicals such as carbon dioxide which leads to increase global warming potential. Besides, increasing of social awareness is the key factor for developing scientific researches on alternative materials. Therefore, the researchers have found the solution for providing environmental performance of plastics through creating bio-composites with natural fibre. Eco composites includes natural fibres which is called natural fibre reinforced plastics (Carus et al., 2008, p. 18-25). These have been rapidly preferred by the market due to increase of demanding on environmental friendly products. The reason of being selected by the market is that NFRPs have high toughness and pleasant strength properties (Khan et al., 2005, p. 1-37). Moreover, natural fibre reinforced plastic materials have low cost/low density ratio (Chiellini et al, 2006, p. 218-222). Additionally, there are mainly two types of green materials for the plastics. These are natural reinforced plastics (NFRP) and wood plastic composites (WPC). These materials are supplied by plant fibres and wood flour respectively likewise plastics i.e. polypropylene (PP), polyethylene (PE).

Figure 3-5: Office chair upholstery back manufactured by injection moulding (Carus et. al., 2008, p 18-25)

In furniture industry, injection moulding processes recently have been used for especially for office chair’s manufacturing. In Germany, WPC production level has rapidly grown to 20000 tonnes in year of 2007. Table 3-6 shows that diverse industries such as building, construction and furniture have significant interest of using natural fibres. WPC is suggested by the furniture industry which the most known suppliers recently have a numerous of chairs made from WPC in their product portfolio. The reason to be preferred is that the injection moulding system can be used WPC for production of chair. This means that the early production machinery i.e. injection moulding system for plastics does not need to be changed.

Table 3-6: Amounts of natural fibre (excluding wood and cork) injection moulding materials used in Germany (nova-Institut, 2007, p. 1-21)

Natural fibres & Process	**Amount (in tonnes)**
Biodegradable bioplastics (packaging, catering)	60 000-70 000 (tonnes) Western Europe 2007
Bioplastics (durable applications)	30 000-40 000 (tonnes) Germany 2007
Compression moulding with natural fibres (automotive industry)	29 000 (tonnes) Germany 2005

Compression moulding with wood fibres (automotive industry)	40 000 tonnes (Germany 2005)
Compression moulding (trucks)	79 000 tonnes (Germany 2003)
Injection moulding and extrusion with wood-plastic composites	80 000-105 000 tonnes (EU 2006)
Injection moulding and extrusion with natural fibre reinforced plastics (consumer durables etc)	3000-4000 tonnes (EU 2006)
Total	at least **350 000 tonnes in the EU**

Figure 3-6: Bistro chair made of wood plastic composite (IKEA)

Since the global warming and climate change effects are the most discussed topics nowadays, the companies using plastics are looking for innovative non-oil materials. One of oil-based polymer is polypropylene (PP) which is not biodegradable. However, by using thermos-sensitive catalysts as a purpose of increasing degradability, PP can transform into an eco-composite material. Moreover, there is an evidence that natural fibre reinforced materials can be replaced with glass-PP composites. (Mohanty et al. 2002, 999-1015). Eventually, polypropylene natural fibre composites (PP-NF) and WPC are interesting substitute materials for plastics.

There are significantly important number of applications for natural fibre reinforced plastics. For instance, the German Institute of Agricultural Engineering from Potsdam has shown that the developed technology is also best fit for unretted hemp, flax, and other bast fibre species for bio-composites used in the furniture production, insulation panels. (Mundera et al, 2003,

p. 19–20). Furthermore, the company Phenix ™ Biocomposites LLC in US practises to wheat straw in Biofiber ™ composites, and sunflower hulls in its Dakota Burl composites produced for furniture industry applications (Netravali et al., 2003, 22-23)

Adhesive and coating materials used for preventing unwanted species on the wood materials and protecting from external factors have several adverse effects on environment. Whilst considering alternative materials for raw materials used in furniture production such as wood, plastics etc. chemicals must be determined to substitute to another supply. Additionally, cleaner production techniques in furniture industry strives to minimize critical environmental impacts such as emissions occurred by air pollution from adhesives and coating, and waste resulted by water, material itself (ENCAP, 2012). To begin with, adhesives can be classified as synthetic and natural and they can be used for assembling applications for wooden furniture parts. It includes toxic materials such as solvents, and hot melts. These both effect on air pollution quality and worker's health. There are several mitigations plans to minimize these adverse effects. First, substitution of adhesive materials is the key action. For instance, non-petroleum adhesives are named as furfuryl alcohol resin and lignin adhesives. The changing naturally derived adhesives can lead to reduce pollution and it is more likely to be cost effective solution as well. Secondly, foam extrusion is the new way to minimize overspray of adhesives. The technique applies adhesive under pressure to the extrusion head. This provides less wasted adhesive. Moreover, to train workers and to use masks can help not to inhale more chemicals and toxic emission from adhesives. Besides, coating applications in furniture cause air emissions that effect seriously on human health. These emissions turn into emit volatile organic chemicals (VOCs). VOCs can aerosolise when the coating container filling with VOCs are open. To mitigate emissions from coating applications, firstly, using coating having less VOCs can be a good substitute option. It should contain waterborne, ultraviolet-curable, polyurethane, and polyester coatings (EPA, 1995). One can say that spray coating includes high volume low pressure technique. It can lead to avoid overspray and thereby uses less material and emits fewer VOCs. The last mitigation action for coating applications is to be sure that coating container must be closed tightly when it is not in use.

3.4. Eco design concept and tools

Sustainable development pointed out "design" issues at the beginning of 1970s (Papanek, 1971). After two decades pass, eco-efficiency term has been mentioned by industry initiatives (Cramer et al., 1995, 91-102) and to reduce companies' adverse effects on environment eco-design has been developed (Brezet et al., 1997). When millennium begins, eco-design has been broadened through adding social and economic concerns into its concept (Crul et al., 2009).

With linguistic perspective, eco design basically includes two different roots which are eco and design. In Greek, "eco"; oikos means house, home so on. In this content, eco can be understood both ecology and economy. Wherefore, the meaning of "Eco" in Eco-design can be related to nature. The interpretation is shown in Figure 3-7. Eventually, eco-design can be defined as design with a more intelligent correlation to nature (Karlsson et al., 2006, 1291-1298).

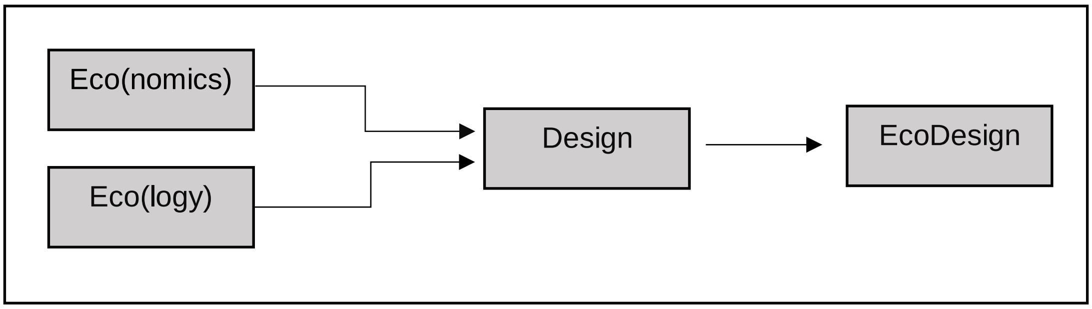

Figure 3-7: Linguistic Interpretation of Eco-Design (Karlsson et al., 2006, p. 1291-1298)

Eco-design is multi-objective aspect concerning the environmental and design issues simultaneously. Environmental concerns are assessed from external outlook and for instance such environmental laws and regulations. Despite Eco-design concept is related to environmental issues, it could be used as a guideline for internal business activities to build innovative and efficient product systems inside of the factory. Furthermore, eco-design tools should be used as a purpose of reaching sustainability vision. This leads to achieve successful product development process, for instance, the tools are based on baseline approach for the design criteria and this helps to identify relations to environmental issues. In order to synthesize design and product development process, good communication and cooperation that includes to creative, innovative, and analytic problem-solving techniques is needed. Ultimately, eco-design is great combination of design and engineering point of view which is also involved in environmental sciences (Karlsson et al., 2006, p. 1291-1298). Apart from these, the roles of designers in terms of eco-design applications can be divided in two parts such as operational and strategic. Whilst operational roles include continuous improving of product utility, however, strategic roles point out designers' capabilities in order to new product systems related to innovative sustainable lifestyles (Bakker, 1995). Additionally, responsibilities of designers' in eco-design is similar to common design projects and there is only one thing to be added into product design which is environmental concern (Lofthouse, 2004, p. 215-227). Besides, eco-design depends on accurateness of the information and the crucial success for this purpose can be described as:

- Eco-design tools made by company's own effort
- Practise with environmental reviews and roadmaps
- Good managerial engagement (Boks, 2006, p. 1346-1356)

During many years, there are numerous example of studies going on about what the roles of designers should have for reaching the sustainable development goals (Bakker, 1995; Lofthouse, 2004, p. 215-227). It is proposed four levels of industrial design application combined with sustainability:

- Redesign of existing systems regarding to environmental perspective
- Creating innovative sustainable products and services
- Designing new-fangled production-consumption systems with respect to sustainable needs
- Set up new sustainable lifestyles (Vezzoli et al., 2008)

In designer point of view, there are several tools to maintain design process in order to provide desired product development processes. One can say that essential integration between tools and product development processes leads to analyse list of tools with respect to such criteria (Byggeth et al., 2006, p. 1420-1430).

Based on literature review, there are such objectives to classify i.e., (1) analyse and evaluate, (2) select and define the priorities, (3) provide innovative ideas for design processes, (4) make a relation with other criteria (Bhamra et al., 2007). Furthermore, these tools can be categorized in terms of their scope: (1) concentrating on specific environmental objective, (2) developing new product through life cycle thinking perspective, (3) combination of design for sustainability and eco-efficiency concepts together (Vezzoli et al., 2008). Apart from these, taxonomy of eco-design tool can be described as follows: (1) Scan all techniques for evaluating the environmental concerns. Those concerns must be classified with respect to nature of its consequences such as qualitative, semi-quantitative, and quantitative.

Eventually, these are grouped based on aim of tool and difficulty of tool. (2) Each tool is grouped regarding to the method applied for various approach such as cost, safety, functionality, so on. Ultimately, these are grouped based on aim of tool and the stage of process where the design is applied.

Apart from these type of diverse categorisations, eco-design tool can be classified in six different criteria: (1) the method for environmental assessment, (2) the necessities of products addition to environmental needs, (3) whether life cycle assessment is applied for the product, (4) type of results i.e. qualitative or quantitative, (5) phases of design processes which the tool is applied, (6) the methodology considered as a baseline for such integration (Bovea, et al, 2012, p. 61-71). Ultimately, the designer can decide which eco-design tool is appropriate for the purpose based on these criteria.

Table 3-7: Objectives of Eco-design Tools (Bovea, et al, 2012, p. 61-71)

Qualitative Methods	- Checklist • AT&T • Kodak • Fast Five • VOLVO - Ten Golden Rules - MET Matrix - Matrix Element Checklist
Semi-Qualitative Methods	- Environmentally Responsible Product/Process Assessment Matrix (ERP) - Streamlined Life Cycle Assessment (SCLA) - Environmental Product Life Cycle Matrix (EPLC) - Eco-design Checklist Method (ECM) - Product Investigation, Learning and Optimization Tool (PILOT)
Quantitative Methods	- Environmental indicators Oil Point Method (OPM) - LCA - Streamlined LCA - Pre-LCA Tool - Life Cycle Phases (LCP)

It can be said that qualitative or semi-quantitative methods are relatively easy-to-use, and these methods provides such opportunities when the environmental considerations are clear to recognize. These methods can be involved in early stages of new product development; however, they cannot be considered as dependable. On the other hand, quantitative methods differ from qualitative methods in terms of where they can be applied in the product development process. Quantitative ones can be applied in the late stages of this process, if there are not significant changes needed.

Due to these diversity among those tools in order to ensure product development combined with environmental concerns and design issues, the survey including 86 tools was prepared. The biggest share of this survey is qualitative with 52 tools whilst 27 tools belong to quantitative group which 10 tools have high complexity, and 17 of it have medium complexity. On the other hand, these tools in software format cover approximately 35 percent of all tools. 44 tools take into account of product life cycle while six of these tool address sustainability criteria (Vicente et. al, 2015).

Appendix -1 (Figure 8) is prepared to express the differences between methods for assessing environmental requirements. In that figure, there are two criteria used in order to compare methods such as purpose of the method, and the degree of difficulty for methods. It can be an essential projection for decision making process of selection appropriate method of environmental evaluation. In the process of creating this table, such authors' opinions are involved for deciding how to express level of difficulty and aim of method (Knight et al., 2009, p. 549-558).

To sum up, in order to accomplish sustainable eco design processes successfully, number of steps must be completed. According to ISO Guide, trade-off between environmental impacts of product, and cost, quality, and health issues must be considered (ISO Guide 64, 2008). As a purpose of this optimization among such factors, three steps are determined for eco-design activities:

- Integration of tools into eco-design process should be involved in early stages of the process
- Life cycle thinking is the key for understanding product's impact factors into environment

- Multi-criteria decision-making approach can be used for this developing process.

In section 4, Life cycle assessment (LCA) methodology is deeply explained.

3.5 LCA, EPDs and Their Relation to Sustainability

Ensuring sustainable development procedures needs particular tools and methodology in order to point out and make impact comparison between different products or services. These products purpose satisfying customer's needs. Each product has a life time starting with extraction of its raw materials and ending up the disposal. During this period, transportations activities such as raw material transportation to the facility and transportation of final good to the customer, manufacturing of the good, and end-of-life scenarios are involved. These scenarios can be these options: recycling, reuse, energy recovery, and landfill. Moreover, life cycle assessment (LCA) models the product's life time as a system which accomplishes one or more stated functions. These functions generate the core structure of LCA study. This product system can be divided into unit process that leads to express inputs and outputs of the unit process. In such system, outputs of a unit process can be used as an input of following unit process. In Figure 3-9 LCA stages are demonstrated.

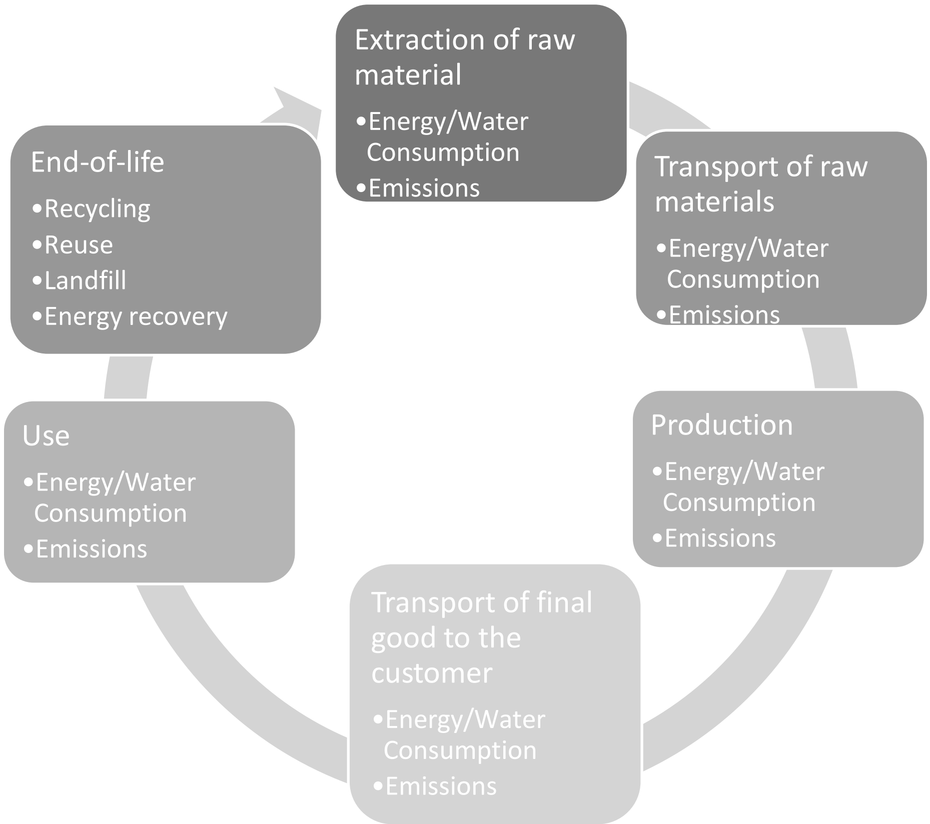

Figure 3-9: LCA Stages (Adopted from ISO 14040, 2006)

For determining impact factors and hotspots throughout life cycle of the product, LCA methodology is preferred. LCA can determine these according to:

- To identify opportunities as a purpose of improving environmental performance of product in the phase of its life cycle
- To make a decision for executives in facilities, government, or non-government organizations
- To build creative marketing campaign successfully integrated with developing eco-labels, or creating environmental product declarations (EPDs) (ISO 14040, 2006)

Through using this methodological framework, adverse impacts to the environment such as ozone depletion, climate change, eutrophication are considered and presented. ISO 14000 series are providing general structure, and framework of LCA.

The society of environmental toxicology and chemistry (SETAC) "code of practice" points out four methodological parts in LCA (Consoli et al.,1993): goal and scope; life cycle inventory analysis; life cycle impact assessment; life cycle improvement assessment respectively. On the other hand, it is stated that the life cycle improvement assessment is not be part of the component of LCA studies as separately, however, it effects on whole LCA study of product or service (ISO 14040, 2006).

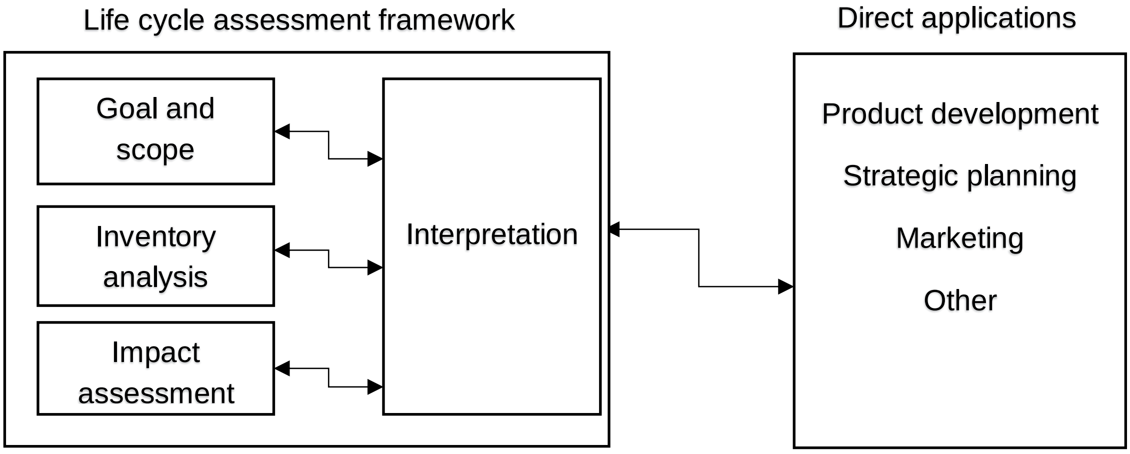

Figure 3-10: Framework of LCA

The general requirements, and principles and framework of LCA study are thoroughly mentioned and described in ISO 14040/44 standards respectively. First of all, goal and scope are defined in ISO 14040 standard. According to this standard, goal of LCA shall include such information i.e. the designed application, the purpose of LCA study, the related person who needs this study for particular purpose, and so on. Besides, the scope of study must state the production system in LCA study. The most essential parts of scope of study that shall be mentioned are functions of the system, functional unit, system boundary, allocation procedures, assumption and limitations, data quality requirements. The studied system might have a different number of functions, and one or more than one of them must be chosen in accordance with goal and scope of the study. Moreover, functional unit can be determined as a quantification factor of defined functions (performance characteristics) in the system. This functional unit purposes for being able to make a comparison among LCA studies. Furthermore, LCA study is built by defined product systems that lead to show essential points of the real system. According to this, the system boundary in LCA expresses in which unit process includes in the product system. Ultimately, if the product system is correctly designed, then inputs and outputs at its boundary represent the starting point for the flow.
System boundaries is defined due to clarify system limits when a decision is needed to be taken concerning to agree on adding a process, input, flow, or activity must be defined. Any

deletion of these items from the system should not change any significant result in system boundaries. There are different types of boundaries depending on the beginning and ending point in the system. First of all, cradle-to-gate is a boundary that starts with extraction of raw material, which is represented by cradle, and ends up with the final product before exits the facility gate. Second boundary type is cradle-to-site which associates with embodied carbon, carbon footprint, and obviously LCA studies. The ending points just differs from the cradle-to-gate approach through including final product transportation to the end user. The other type of boundary is cradle-to-grave which is most common boundary among LCA studies. It involves two more phases than cradle-to-site boundary include which are the GHG emissions associated with the in-use phase of product, and the end of life such as disposal, reuse, recycling.

The second step of LCA framework is life cycle inventory analysis (LCI). This step includes data collection processes and its calculation methodology in order to measure related inputs and outputs of the system. It refers to approximate resource consumption, and amount of emissions to air, water, and soil through collected data on energy inputs in several stages of the system, raw material inputs, and so on (ISO 14040, 2006). Apart from these, the calculation method of data is related to quality of data. Data quality has a certain link to the quality of LCA study. Data calculation should part of these processes; (1) verification of collected data, (2) creating a relation of data and unit processes, (3) creating a relation of data and functional unit. These processes are used for demonstrating result of the data inventory for each unit process, and also for the functional unit of the product system which is an imitation of the real system. During calculation processes, different type of energy resources such as electricity, fuel, and distribution of energy flow must be considered carefully. On the other hand, allocation of flows and releases are another issue in the data collection procedure. Generally, almost each production system has more than one input and output in the production system. Throughout this production system, some of products can be recycled or discarded products as a purpose of raw material for the one of next unit processes. Due to the fact that, allocation procedures must be considered when more than one product and recycling processes are involved in the product system.

The third and most important step of LCA study is life cycle impact assessment (LCIA) which purposes to demonstrate hotspots of the product system through using LCI. LCIA can be iterative approach in order to either meet or modify the goal and scope of LCA study if assessment indicators cannot be accomplished. In this stage, modelling and reasons for selection impact categories represents subjectivity of LCA study. Thus, to ensure clearly defined assumptions, transparency is essential issue to impact assessment. LCIA has three mandatory, one optional elements such as selection of impact categories, classification of the result, characterisation of result and normalisation.

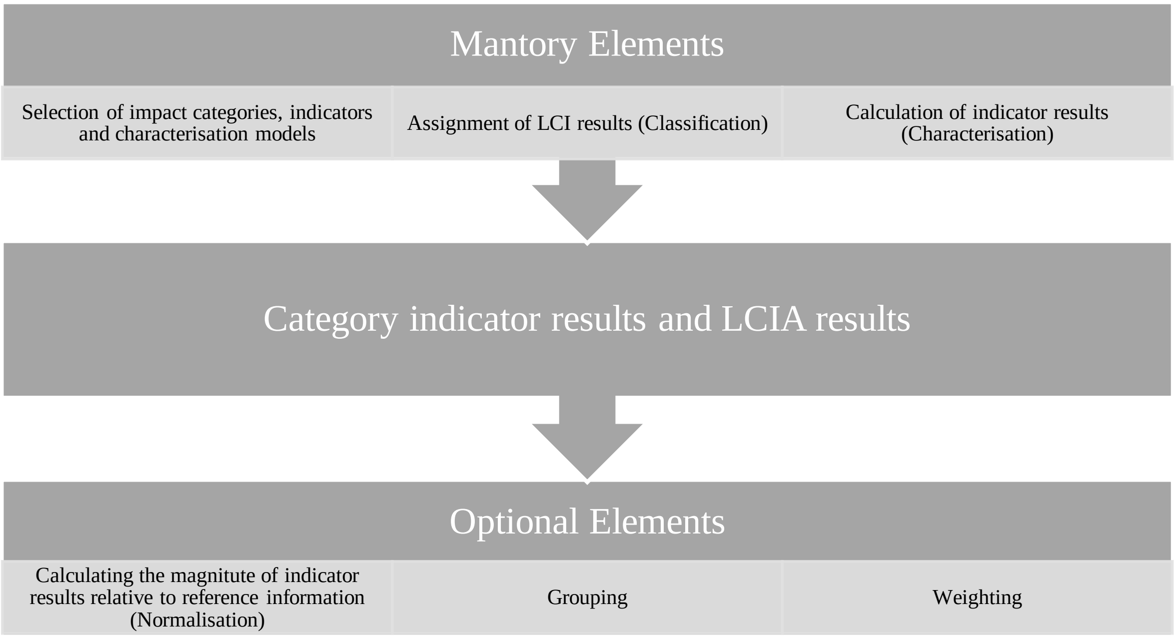

Figure 3-11: Elements of LCA Study

This structure of LCIA leads to some advantages, and also it is needed for some essential reasons. To begin with, each element separated in the LCIA phase should be clearly defined and comprehensive. One the most important thing in elements of LCIA is to use of values and subjectivity leads objective interpretation for reporting and critical review. Besides, the goal and scope have an effect on each element of LCIA which shows quality of LCA study, assumptions.

There are some barriers for LCIA that effects on representing of particular issues. This may occur when characterisation, sensitivity analysis, and uncertainty analysis is not developed as required. Additionally, either defining system boundaries or including all inputs and output of each unit process leads to affect adversely the result of LCIA stage. Ultimately, using inappropriate and unrepresentative data creates limitation of LCIA.

LCIA contains LCI results with particular environmental impact categories i.e. global warming potential, ozone depletion, eutrophication potential, acidification potential etc. and their indicators. In this thesis study, there four main impact categories used which are global warming potential, acidification potential, photochemical ozone creation potential, and eutrophication potential. These are selected based on Product Category Rules (PCR) guided for Environmental Product Declaration (EPD) documents (The International EPD System, 2015).

The one of most known impact category is global warming potential (GWP). This can be described as greenhouse effect which is related to temperature rising in the lower atmosphere. The mechanism of rising temperature in the lower atmosphere works that incoming radiation from the sun heats the lower atmosphere. Some of radiation is ideally reflected from lands and oceans. However, most specially CO_2 and greenhouse gasses i.e. methane, nitrogen dioxide, and etc. reflect infrared radiation (IR) which leads to escalate the temperature in the lower atmosphere. In this figure, energy balance is described.

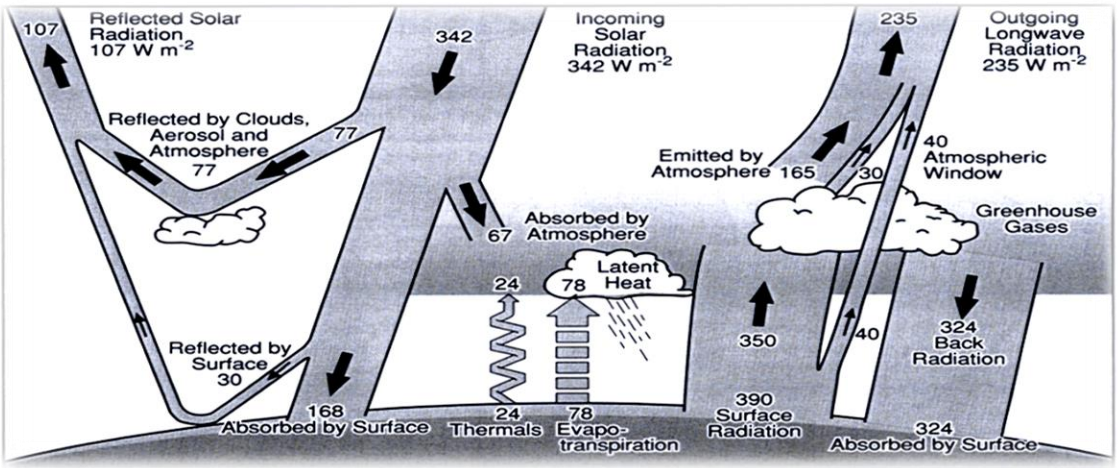

Figure 3-11: Energy Conservation in the atmosphere (Trenberth et al., 1996, p. 197-208)

One can say that the most predictable result of increasing temperature in the lower atmosphere is to effect on increasing the sea level through melting of ice caps. Besides, the main elements to global warming potential can be followed: (1) carbon dioxide (CO2), methane (CH4), nitrous oxides (N2O), CFCs (CFC-11, -12, -113, -114, -115), HCFCs (HCFC-22, -123, -124, -141b, -142b), HFCs (HFC-125, -134a, -152a), halons, tetrachloromethane (CCl4), 1,1,1-Trichloroethane (CCl3CH3), carbon monoxide (CO) (Stranddorf et al., 2003). For a special case of CO2, in order to measure global warming potential accordance with emissions, the net contribution of CO2 must be considered. For instance, as a purpose energy recovery from biomass such as wood, pellet, straw and etc causes cannot be linked to net contribution since it is assumed that these materials would degrade under all conditions. GWP is defined and measured as 20, 100 and 500 years of time period. This is settled by Intergovernmental Panel on Climate Chane (IPCC) and mentioned in several scientific articles (Houghton et al., 1996; Albritton et al., 2001). The emission of greenhouse gasses is administered by Kyoto Protocol and Climate Convention (UN 1997; UN 1992). The way of calculating greenhouse gas occurred during in any process is based on an estimation of GHG emission which depends on functional unit. The unit of GWP is showed in CO2-equivalent per kg.

$$\mathrm{GWP} = \sum_{1} GWP_{\mathrm{i}} \times m_i \qquad \lfloor kg\ CO_2 - eq. \rfloor. \qquad (1)$$

where GWP_i is the equivalent factor for the substance i,

m_i is the emission of the substance i.

The normalisation of GWP is calculated as follows (Hauschild et al., 1998):

$$\mathrm{Normref_{GWP}} = \frac{\sum_i^n m_i \times GWP_i}{\mathrm{N}} \qquad \left\lfloor kg\ CO_2 - eq. \frac{capital}{year} \right\rfloor. \qquad (2)$$

where $\mathrm{Normref_{GWP}}$ is the normalisation reference for the greenhouse effect

m_i is emitted quantity of substance i

GWP_i is the equivalence factor for the substance i

N is the number of capita in the considered area.

The second important impact factor is considered as having local and regional effect on the environment instead GWP has global effect. The reason of occurring acidification is that protons are off in the territorial and maritime ecosystems. The acidification process is held in only when anions are leaked from ecological system. If the anions can continue to stay in the system, the anions are neutralized by the natural processes. Acidification causes of heavy metals and aluminium movement. The adverse effects of increased acidification in terrestrial ecosystem are basically insufficient growth and dieback of forests. It can be monitored in middle east and north of Europe. On the contrary, in the maritime ecosystem, acid lakes can be seen in Scandinavia without existence of any species.

Acidification potential of particular items, and characteristics of nature are the key considerations to identify results of the acidification. For instance, nitrogen oxides can be stabilized through uptake in plants. This has a strong correlation between geography and plant variety.

Based on chemical structure of the substances, they can be divided into four different categories such as: strong acids, acidic anhydrides, ammonia, and organic acids. According to the literature, if either the substances provide hydrogen ions to the environment, or leaking of substituted anions from the any system, the substances are determined as having acidification potential (Hauschild et al., 1998). The substances are as follows: Sulphur Dioxide (SO2), Sulphur Trioxide (SO3), Nitrogen Oxides (NOx), Hydrogen Chloride (HCl), Nitric Acid (HNO3), Sulfuric Acid (H2SO4), Phosphoric Acid (H3PO4), Hydrogen Fluoride (HF), Hydrogen Sulphide (H2S), Ammonia (NH3). The acidification potential is calculated as SO2- equivalents:

$$\mathrm{AP} = \sum_i \mathrm{EF_i} \times m_i \qquad [SO_2 - eq.] \tag{3}$$

where EFi is the equivalency factor for the substance i,

mi is the emission of the substance i,

$$\mathrm{EF} = \frac{n}{2 \times M_W} \times 64.06 = \frac{n}{M_W} \times 32.03 \tag{4}$$

where M_W is the molecular weight of the substance emitted [g/mole],

n is the number of hydrogen ions released in the recipient as a result of conversion of the substance,

64.06 g/mole is the molecular weight of SO2.

The normalization reference for acidification is calculated with this equation (Hauschild et al., 1998):

$$Normref_{acid} = \frac{\sum_i^n m_i \times EF_{i,acid}}{\mathrm{N}} \qquad \left[kg\ SO_2 - eq.\frac{capita}{year}\right] \qquad (5)$$

where $Normref_{acid}$ is the normalisation reference for acidification,

m_i is emitted quantity of the substance i,

EFi is the equivalence factor for the substance i,

N is number of capita in the considered area.

Only sulphur dioxide, nitrogen oxides, and ammonia are the substances included in the international regulations as acidifying substances.

Third impact factor is photochemical ozone creation potential (POCP) which is determined as an individual impact category (Hauschild et al., 1998). This impact category is used for ranking purpose of VOCs content in accordance with producing ozone European zone. However, there is totally different approach used in the US which is called Incremental Reactivity (Carter et al., 1995, p. 2499-2511). POCP mainly calculates the level of ozone from VOCs emission with using series of data including complex chemical reactions in the atmosphere. As a purpose of this, the data as an input includes these substances: (1) VOCs and NOx; (2) chemical and photochemical data; (3) dry deposition rates; (4) meteorological data. Moreover, POCP presents that amount ozone from particular VOC is divided by ozone occurred from ethene:

$$POCP = \frac{ozone\ increment\ with\ the\ ith\ VOC}{ozone\ increment\ with\ ethene} \qquad (6)$$

The unit of POCP is grams of ethene equivalents per gram of gas which can be represented g C_2H_4 / g VOC. The reason of selection of ethene for the calculation is that the ethene is one the influential ozone initiator of all VOCs. The result of this equation does not show absolute values. POCP is a function which will change based on different scenarios such as from one area to another. Due to the data used for modelling is not detailed in depth, the representation of data would be a compromise (Stranddorf et al., 2003). Even though the same scenario is used for the modelling, POCP value would be resulted different. In order to avoid this variety, the input data should be more precise, and the software tools are needed to be more powerful.

The last but not least essential impact category in this LCA study is eutrophication potential. This impact category is called also “nutrient enrichment” equivalent NO3 in the literature (ISO, 1999). First of all, the adverse effects of large amount of nutrient salts are monitored generally in many lakes. The bottom of lakes has been investigated during many years, consequently, the researches show that nutrient salt and their emission have significant impact on the environment. The common reasons for this nutrient enrichment are separate industrial discharges, waste water, aquatic and territorial saltwater fish farms, and so on. Moreover, eutrophication results depletion of oxygen in the bottom of lakes and coastal waters. This is linked to which nutrient enrichment causes rapidly growth of planktonic algae and aquatic plants, due to these raises, the quality of water is going down in the long period time (Christensen et al., 1993). The steps of changing water quality are occurring as follows: firstly, the algae go to the bottom and change operation of oxygen cycle. Then, when fresh water -which means oxygen rich- cannot reach the bottom of lake, the volume of oxygen will be decreased. Ultimately, this will continue until the organism living in the bottom of lake cannot move to the depth or die.

There are mainly two macro substances contributing to the eutrophication potential impact category which are nitrogen and phosphorus. These can be determined as stopping of growth process of primary producers. Hence, both nitrogen and phosphorus contribute to nutrient enrichment. Additionally, not only nitrogen and phosphorus itself but also substances containing nitrogen and phosphorus lead to stop growth potential of primary producers. Due to the fact that, these substances can be assumed potential contributor to eutrophication potential. As a purpose of calculation of possible contributions from particular substance, there are three equivalence factors defined:

- the N potential represents nitrogen content of the substance’s,
- the P potential represents phosphorus content of the substance’s,
- the equivalence factor for the total nutrient enrichment potential, where the nitrogen and phosphorus contents are aggregated in a figure based on the assumption of an

average ratio of 16:1 between the nitrogen and phosphorus contents in aquatic organisms.

As it can be understood from above, the ratio between nitrogen and phosphorus is the order of 16. When this ratio goes up, one can say that phosphorus can be determined as a limiting nutrient or other way around. Because, the atmosphere includes free nitrogen atoms, N2, additional nitrogen gas cannot have any effect. For that reason, nitrogen gas cannot be assumed as contributor to eutrophication potential. Besides, most significant emissions from air involve NOx, that are mostly emitted from incineration activities, and ammonia, NH3, which comes from agricultural ones. In general, roots of plants in the aquatic areas ensure significant amount of nitrogen loading. This has a high correlation with using fertilisers and livestock. On the other hand, the plant running for waste water treatment, fish farms have effect on increasing of eutrophication potential. Apart from this, phosphate emitted from air is not significantly enough to be considered, so that, it is negligible. However, the momentous part of phosphorus loading of water comes from sewage water, and industrial waste water. Finally, pulp and paper, fish processing industries, and agricultural activities have great influence for phosphorus loading to surface water.

As final step of LCA study, interpretation is the stage that the data from inventory analysis and impact assessment are determined together. Particularly in LCI studies, this interpretation may include only data inventory. The ultimate goal of interpretation should explain LCIA results in accordance with selected approach. Due to the fact that, potential environmental effects can be represented in this stage. However, it should not be linked to that it must estimate the real impacts on endpoints, exceeding of threshold values, safety level of risks. The interpretation of LCA study may serve a conclusive understanding to decision-makers and managers to consider environmental issues related to the goal and scope of the study. It gives several options to make an improvement for the related study.

As a complimentary part of LCA study, reporting approach shall devote effort to different stages of LCA study. This serves a compact conclusion for the related person who needs the result of LCA or LCI study. When the LCA study includes LCIA and is forwarded to third-party verifier, the number of issues should be mentioned:

- connection between LCI results

- category endpoints to be protected
- impact category selection
- characterisation models
- indicators show profile

As LCIA does not have sufficient capability to express possible impacts on category endpoints, the content of report should include this deficiency. Besides, the references and explanation of value of choice (referred as use of value and their subjectivity) applied in the stage of LCIA should be defined in the report. After reporting of the study is completed, the critical review can be constituted, and it represents whether the requirements are met or not for each stage of LCA or LCI study such as methodology, data inventory, interpretation, ultimately reporting. Ultimately, it can be done by either internal or external expertise who have convenient knowledge and experience on LCA.

There is different type numerous LCA tools which of them is free, or includes databases, however, some of them are extensive. The Appendix – 2 (Table 1) represents various existing LCA tools and includes important features of these tools such as which language is used, business area, paid or free tool etc. one of the tools is fit for expert use whilst some of them is created for SMEs and non-specialists.

As LCA has strong relationship to other decision-making tools for making comparisons in terms of product quality, environmental performance, and so on. Environmental performance tools and declarations as an output of these tools are based on such standards established by International Standards Organization (ISO).

3.5.1. Environmental Labels: Environmental Product Declarations

Related to these environmental performance issues, ISO has published three labels which are defined as type I, II, and III separately. Each of them has particular standards as being used for the guideline in order to explain principles and procedures of the labels. These standards can be followed as ISO 14021, ISO 14024, and ISO 14025 (ISO, 1999a, b; ISO, 2006; UNOPS, 2009). First of all, the EU Ecolabel is defined within the ISO 14024 as a Type 1 environmental labelling system and is a voluntary labelling system. The criteria for eco-labelling are the cornerstones of the creation of environmental benefits. The level of environmental criteria to be applied is adjusted according to the fact that about 10-20% of the products are capable of receiving this label. The criterion is a mark of excellence that allows consumers to choose the products most sensitive to the environment, with the environmental impact of the product being developed throughout the entire life cycle. Secondly, the environmental declarations known as Type 2 are the types of labelling that firms declare in their own information and are not independently verified by third party verifier. These labels are used extensively in Turkey. However, they are not verified by third parties, due to the fact that, they do not give consumers confidence. The last but not least eco label is Environmental Product Declarations (EPD) which is key to represent environmental performance of the product (Grahl et al., 2007, p. 38-45). In order to conduct LCA to EPD documents, there are such guidelines as a basis of EPD documents including what type of data must be included, how LCA study must follow the procedures and which environmental indicators must be selected etc. These guidelines are specific for different type of product and industries, for instance, it is for organic chemical products, office furniture and so on. These guidelines are called Product Category Rules (PCR). The main consideration of PCR documents is to ensure LCA study's comparability for different scenarios of the same product. Moreover, it is necessary to generate a valid PCR to compare EPD documents. If a valid PCR is not available for the product, the PCR can be generated by submitting the document.

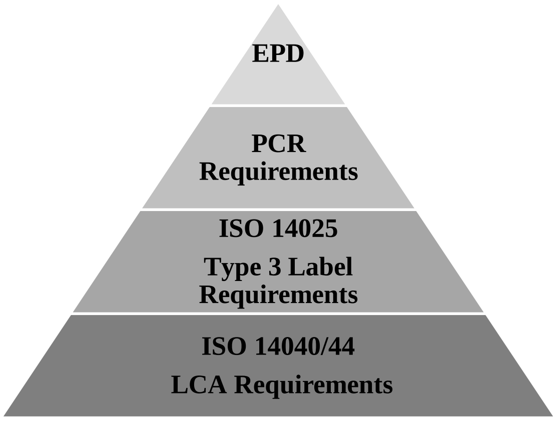

Figure 3-12: Procedures of creating EPD documents

PCR documents that are in use and in the preparation, phase can be accessed from the PCR database. The PCR documentation can also be obtained from other program operators. According to standard ISO 14025, it is stated that program operators can facilitate compliance while developing PCR for a product category, taking into account the same product category and PCR documents available in the appropriate market. Requirements and procedures for the identification of PCRs from other programs are available in the General Program Instructions.

In 2002, Directorate-General (DG) Environment, that is an organization of European Union for environmental issues, organized a study based on EPD documents in order to accelerate demanding of EPD documents which leads to represents greener products (European Commission, 2002). This study served particular purposes such as projecting national and sectoral EPD situations. Furthermore, Society of Environmental Toxicology and Chemistry (SETAC) played essential role in order to establish standardized LCA and EPD schemes (Klöpffer, 2006, p. 116–122; SETAC Europe LCA Steering Committee, 2008, p. 88-89).

In 2007, SETAC has tremendous influence on construction sector and building materials sector through organizing a conference named as 13th SETAC Europe LCA Case Study Symposium on Environmental Product Declarations. After 10 years from the first study of DG Environmental, they launched the draft document including such methodologies for calculation of environmental footprint (European Commission, 2002). This leads EPD documents to communicate among other systems and applications which is called harmonization of EPDs. Among countries, different EPD schemes are established. This may affect on creating barriers due to all of them require distinct rules.

As an essential feature of EPD documents, they can be comparable between the similar products in terms of such environmental impact categories. The results of environmental impacts lead the continuous improvement for the product and to transfer relevant information throughout the its supply chain. Due to the fact that, this information can be used in different purposes and application such as green building certification i.e. LEED, BREEAM, green procurement, environmental management systems i.e. ISO 14001 and EMAS, and ultimately eco-design which is the most important one in this thesis study. The most of all companies firstly prefer organization-related issues when environmental work inside of the company is needed. Since, this work cannot require high expenditure for installation of any system to capture such issues. For instance, it is more likely to be energy efficiency for the facility. However, if the environmental works are not easy to predict its impacts, environmental management system (EMS) can be the best fit for changing company vision from organizational issues to product related ones. In the eco design applications, EPD leads company focus to the product itself directly which is critical for decision making procedures of future priority settings (International EPD® System, 2015). EPD documents are highly focus on the product through showing environmental impacts' results such as natural resource consumption, GHG emission to the air, eutrophication potential of the product, and so on. The reason why EPD documents are the first choice as an eco-design tool is that EPD can show how stages diverse from each other. For instance, it can be resulted that production stage has more, impact than extraction of raw material in terms of carbon foot print. Thus, EPD is beneficial for eco-design applications. EPD can be basically used in two ways: benchmarking tool and communication tool for improvements. First of all, EPD documents od products lead to explain both production stages and critical environmental impacts of products. Related to that, this can be internally used as a continuous improvement scheme through developing new design options. Secondly, for new product development process, EPD should be created and used as a communication the environmental help of eco-design accomplishment. Through using same LCA method for eco-design, conducting the study of ultimate study could be more understandable.

4. A comparative analysis of steel and wood-based furniture

4.1. The goal of study

In this thesis study, two office chairs from one of the big furniture producer Koleksiyon Mobilya (hereafter called Koleksiyon) are examined regarding to their environmental performances based on LCA study. These chairs are selected on purpose due to their material types used in the manufacturing stage. Addition to this goal, the new product development study is conducted to the study. The new product is produced with eco-friendly materials in order to reduce environmental impacts of the regular office chairs. After this study, Koleksiyon might concern to reduce environmental impacts and carbon footprint of their products.

4.2. The scope of study

4.2.1. Manufacturer Company Info and Product description

Koleksiyon was found in 1972 in Ankara Industrial State as a small metal workshop by designer Faruk Malhan. Koleksiyon has great success in both domestic and foreign market due to deliver high qualified design and service experience. With this excellence, Koleksiyon has more than 40 years in market and has been leading the success. Koleksiyon can be defined as a pioneer in its sector regarding to waste treatment and be part of high level of recycling activities which effects on improving its continuous quality management. Addition to that, Koleksiyon has shown their dedication to environmental sensitivity through having ISO 14000 Environment Document, ISO 14025 Environmental Product Declaration, and other work and work place safety documents.

Environmental impacts and other adverse effects throughout two office chairs' life cycles are assessed with using Product Category Rule (PCR) document coded UN CPC 3811. This PCR can be used a framework for:

- PCR 2009:02, UN CPC 3811, Seat version 1.0
- NPCR 2015:03, UN CPC 3811, Seating revision 1
- BIFMA PCR for Seating, UN CPC 3811, version 3
- PCR 2012:19, UN CPC 3812&3814, Other furniture used in offices and other furniture not elsewhere classified, version 1.1 (International EPD® System, 2015)

PCR documents can be named as a guideline for the LCA study by ISO 14025:2006 Environmental labels and declarations - Type III environmental declarations. Due to this reason, the study has followed the principles and procedures as PCR document requires. LCA study in this thesis is analysed environmental impacts of selected two products based on upstream, core, and downstream processes as related PCR requires.

The office chairs are used as a purpose of seating in offices, schools, hospitals, banks, and so on. These chairs are produced in the facility of Koleksiyon located in Tekirdağ, Turkey. The technical specifications of products are given. The composition of materials used in production of two different office chairs is shown in Table 4-8 and Table 4-9.

Table 4-8: Material Composition of Dastan 30

Component name	Material Name	Input Amount in kg
Seat textile	Polyethylene	0,276
Seat font	Polyurethane	0,695
Gas lift	Iron-Nickel-Chromium Alloy	0,578
	Polypropylene	0,375
Wheel	Nylon 6.6 Glass Filled	0,935
Mechanism	Steel Unalloyed	3,77
Crossfoot	Polyamide	1,63
Auxiliary	Iron-Nickel-Chromium Alloy	0,227
Back textile	Polyethylene	0,181
Back frame	Iron-Nickel-Chromium Alloy	2,1275
Back Font	Polypropylene	0,928
Arm support	Cardboard	3,32
Corrugated board box	Low Density Polyethylene	0,888
Packaging film	Polyethylene	0,276

Table 4-9: Material Composition of Dastan 30 v.2

Component name	Material Name	Input Amount in kg
Seat textile	Polyethylene	0,276
Seat font	Polyurethane	0,695
Gas lift	Iron-Nickel-Chromium Alloy	0,578
	Polypropylene	0,375
Wheel	Nylon 6-6 Glass Filled	0,935
Mechanism	Iron-Nickel-Chromium Alloy	3,77
Crossfoot	Aluminium Cast Alloy	2,071978022

Auxiliary	Iron-Nickel-Chromium Alloy	0,227
Back textile	Polyethylene	0,401
Back frame	Iron-Nickel-Chromium Alloy	4,395604396
Back Font	Polyurethane	0,695
Arm support	Polypropylene	0,928
Corrugated board box	Cardboard	3,32
Packaging film	Low Density Polyethylene	0,888

As it can be seen from two material composition tables, the plastic contents for Dastan 30 and Dastan 30 v.2 are 37 and 27 percent respectively. Besides, the material content of Dastan 30 v.2 composes more than 50 percent of whole chair with 56 percent whilst Dastan 30 has pretty much the same metal content with 42 percent. The remaining 21 and 17 percent of material come from corrugated board boxes of Dastan 30 and Dastan 30 v.2 respectively.

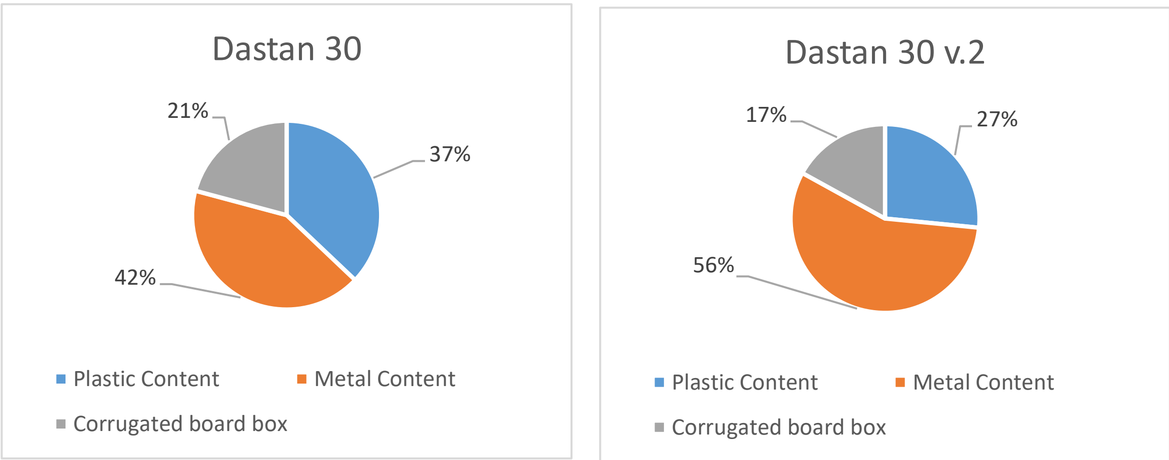

Figure 4-123: Material Compositions in Pie Chart

The production process of office chair in Tekirdağ plant includes sizing and matching related parts, then these items are delivered to assembly line. During the assembly applications, labourers are mostly taken in part. Due to the fact that, electricity consumption during production processes are considerably less. The final product goes out to packaging line where corrugated board box and packaging film are used as a purpose of covering the finished product to avoid any impact during the transportation. the flow of production line is basically demonstrated in Figure 4-4 **Hata! Başvuru kaynağı bulunamadı.**.

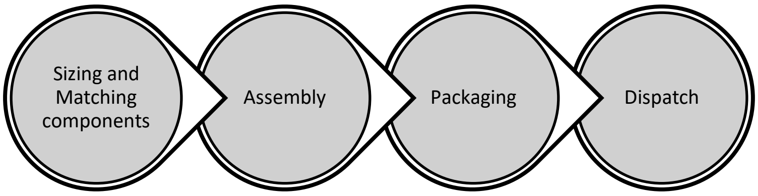

Figure 4-14: Flow Diagram of Production Line

4.2.2. Declared unit

In this thesis study, declared unit is the production of one-piece Dastan office chair. This studied chair represents both Dastan 30 and Dastan 30 v.2. The minimum life time of office chair is mentioned as 15 years in PCR UN CPC 3811.

4.2.3. System boundaries

Regarding to ISO 14040/44 and PCR UN CPC 3811, system is divided in three main process such as upstream, core, and downstream processes. According to this breakdown, LCA study in this thesis evaluates environmental impacts of two office chairs throughout raw material extraction, transportation of raw material to facility, production processes, finished product transportation, use phase, and end-of-life scenarios. With this respect, cradle-to-grave approach is used in this thesis study. The system boundary is shown in Appendix – 1 (Figure 3). The framework in this study can be explained:

- Upstream processes (Cradle-to-Gate): Raw material, and packaging materials
- Core processes (Gate-to-Gate): Transportation of raw materials and production processes (sizing and matching components, assembly, packaging, dispatch)
- Downstream processes (Gate-to-Grave): Transportation of finished goods, use phase, and end-of-life

In **Hata! Başvuru kaynağı bulunamadı.**, colour coding is used in order to show each process of the system. The green boxes represent upstream processes where the starting point of office chair is. Upstream process includes raw materials of Components and Packaging processes. After extracting raw materials, core processes start with raw material transportation to the production facility and it contains packaging, manufacturing, production, and ultimately production of the office chair. This schema is the same for both Dastan 30 and Dastan 30 v.2. as it can be understood from the figure, electricity consumption and waste involve in manufacturing process. It is coloured with orange. Finally, downstream process includes transportation activities of final good to the end user, use phase of the chair, and end-of-life scenarios of the office chair. The use phase does not include any of process due to the product requires neither electricity nor water. Besides, transportation of final product is assumed based on UN CPC 3811. End-of-life scenarios are defined through the information taken from the production engineers and department supervisor. The purple colour is used for demonstration of downstream processes. The detailed data information on processes are explained in data collection approach section.

4.2.4. Power mix

For this thesis study, electricity data is taken from Ecoinvent 3.0 database which includes the Turkish electricity values in 2014. According to TurkStat, the distribution of electricity production from resources is shown in the Figure 4-15.

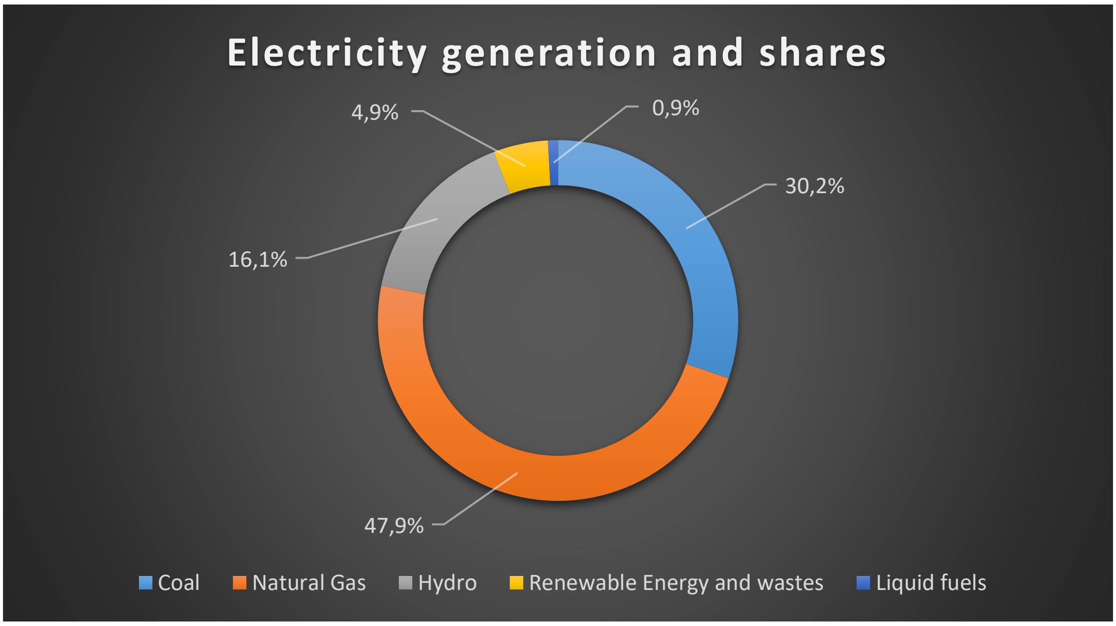

Figure 4-15: Electricity generation and shares (TurkStat)

As it can be seen from the pie chart, the majority of electricity generation source of Turkey in 2014 comes from natural gas with almost 50 percent whilst coal has approximately 30 percent of entire sources. Unfortunately, renewable energy resources such as wind, and solar have only 5 percent.

4.2.5. The cut-off rules

There are no cut-off rules applied in this study.

4.3. Life cycle Inventory

4.3.1. Data collection approach, Product Level Scenarios & Assumptions

For this thesis study, two types of data are used through following ISO 14040/44 rules. At the beginning of data collection process, the primary data are taken from Koleksiyon. when the data are missing, some assumptions based on UN CPC 3811 and secondary data from Ecoinvent 3.0 database are involved. The related information and material types of raw materials used in production process are given by the production engineers. Based on material types, recycling rates and production loss vary on. The information on loss rates are taken from engineers at the production side. The recycling rates of metals are related to The Steel Market Development Institute's study. In that study, the recycling rate for aluminium relies on 79-95%, whilst the steel has greater recycling rate with 90–95% (Steel Market Development Institute, 2016). With that respect, the average rate of recycle is considered as their mean value such as 87% and 92.5% for aluminium, and steel respectively. Moreover, recycling rate and rate of loss of steel used in mechanism part is 92,5 % and 9 % correspondingly. Iron-nickel-chromium alloy material is used in gas lift, auxiliary, and back frame parts in the chair. The material has 5% loss rate and 92.5% recycling rate. Polyethylene in seat textile, polyurethane rigid foam in seat font, nylon reinforced with glass fiber in wheel, polyamide in cross foot, polypropylene in arm support have the same loss rate which is 5%. Polypropylene part in gas lift and polyethylene textile part in back frame have 4% loss rate. As they are considered plastics in general, the recycling rate is assumed 17% regarding to Plastics Europe study (Denkstatt, 2014). Furthermore, the packaging components of the final product is corrugated box, and packaging film. Even though the packaging film is considered plastics, the recycling rate and loss rate differs from the other part of plastics in this office chair. According to Plastics Europe study, the packaging film recycling rate is 60% and the rate of loss is 0 percent due to the packaging film is used completely (. Additionally, Turkish Ministry of Science, Industry and Technology published

National Recycling Strategy Document and Action Plan for 2014-2017. Regarding to this document, corrugated boxes must be recycled at least 54% in year of 2016 (Sanayi Genel Müdürlüğü, 2013). Likewise, the loss rate of packaging film, the corrugated box is used entirely.

As it can be understood from the Appendix – 2 (Table 5), the scrap amounts of each item represent the amount differences between input and output content. Besides, dummy content shows the amount of recycled material of each item. The reason using dummy variable for showing the recycled content of the material is that the benefit of recycled content is not for neither Koleksiyon nor the end user. Due to the fact that, recycled content info is not linked to the system. Ultimately, the landfill content demonstrates the rest of material after going to recycling process.

Data on transportation is based on both information taken from the production engineers and assumptions from related PCR which is UN CPC 3811. There are two types of transportation information that are raw material transportation and transportation of the final good to the end user. As production engineers the raw material transportation can be 150 km to the facility gate. Additionally, the last transportation to the end user is assumed as 1000 km.t through transported by lorry.

The electricity consumption data during the production is relatively lower, since manufacturing processes of office chair are needed to hand workmanship activities. The production processes of the office chair generally include assembly activities, except of steel, aluminium, or chromium material formation applications the electricity is used slightly. For both version of Dastan 30 office chair, upholstery, metal, and epoxy stations are involved. Actual consumption of electricity is calculated in that way: Actual Consumption [kWh] is divided by actual production [min]. Actual Value of Energy Consumption represent this [kWh/min]. After that, the Lead time [min] at stations taken from the production engineers are multiplied with Actual Value of Energy Consumption, finally the unit of result is kWh

4.3.2. Calculation methods

When the collection data activities are done for the system, the model is developed through SimaPro life cycle assessment software version 8.2. As Koleksiyon requires, CML- IA baseline (Normalized for GWP 100a) is used.

4.3.3. Selecting data

The primary data taken from the production engineers are based on 2016 production figures of Koleksiyon Tekirdağ plant. Therefore, the data quality is acceptable due to the data is less than 5 years old. Emission to air and water are not measured, however, it was taken from Ecoinvent database for relevant energy consuming processes. Moreover, secondary data is taken from Ecoinvent v.3 database, since the database is comprehensive for raw materials types particularly for the plastics. Additionally, the Ecoinvent database's data is less than ten years old which is suitable for the high qualified system modelling.

4.3.4. Allocation

There are no co-products occurred during the production processes. Thereupon, there is no allocation rule applied in this thesis study.

4.4. Life cycle Inventory Analysis and Potential Environmental Impacts

and **Hata! Başvuru kaynağı bulunamadı.** are related to the contributions in the production of Dastan 30 and Dastan 30 v.2 according to these environmental impact categories: abiotic depletion (fossil fuels), acidification, abiotic depletion, eutrophication, global warming potential, ozone layer depletion, photochemical oxidation, terrestrial ecotoxicity, marine aquatic ecotoxicity, fresh water aquatic ecotoxicity, and finally human toxicity calculated CML-IA Baseline Method. These impact categories are come from the processes which are named as upstream, core, and downstream defined in related PCR UN CPC 3811.

Table 4-10: Environmental Impacts of Dastan 30 According to CML IA Baseline Method

Impact category	Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Abiotic depletion (fossil fuels)	MJ	9,70E+02	4,12E+01	2,99E+01	1,04E+03
Acidification	kg SO2 eq	7,21E+00	2,17E-02	1,00E-02	7,24E+00
Abiotic depletion	kg Sb eq	2,85E-03	1,07E-06	4,93E-06	2,86E-03
Eutrophication	kg PO4--- eq	2,94E-01	1,81E-02	3,28E-02	3,45E-01
Global warming (GWP100a)	kg CO2 eq	7,00E+01	4,22E+00	4,10E+00	7,84E+01
Ozone layer depletion (ODP)	kg CFC-11 eq	2,97E-06	9,95E-08	3,43E-07	3,41E-06
Photochemical oxidation	kg C2H4 eq	2,90E-01	1,15E-03	9,48E-04	2,92E-01

Fresh water aquatic ecotox.	kg 1,4-DB eq	1,22E+02	6,36E+00	1,10E+01	1,40E+02
Human toxicity	kg 1,4-DB eq	6,40E+02	1,95E+00	4,84E+00	6,47E+02
Marine aquatic ecotoxicity	kg 1,4-DB eq	2,41E+05	7,79E+03	1,17E+04	2,60E+05
Terrestrial ecotoxicity	kg 1,4-DB eq	1,12E+00	9,70E-03	6,59E-03	1,14E+00

Table 4-11: Environmental Impacts of Dastan 30 v.2 According to CML IA Baseline Method

Impact category	Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Abiotic depletion (fossil fuels)	MJ	1,09E+03	4,19E+01	3,82E+01	1,17E+03
Acidification	kg SO2 eq	9,91E+00	2,20E-02	1,27E-02	9,95E+00
Abiotic depletion	kg Sb eq	4,00E-03	1,09E-06	6,40E-06	4,01E-03
Eutrophication	kg PO4--- eq	4,22E-01	1,86E-02	3,62E-02	4,77E-01
Global warming (GWP100a)	kg CO2 eq	8,04E+01	4,34E+00	4,64E+00	8,94E+01
Ozone layer depletion (ODP)	kg CFC-11 eq	6,48E-06	1,01E-07	4,38E-07	7,02E-06
Photochemical oxidation	kg C2H4 eq	3,99E-01	1,18E-03	1,04E-03	4,02E-01
Terrestrial ecotoxicity	kg 1,4-DB eq	1,58E+00	1,00E-02	7,01E-03	1,59E+00
Marine aquatic ecotoxicity	kg 1,4-DB eq	3,83E+05	8,01E+03	3,36E+04	4,25E+05
Fresh water aquatic ecotox.	kg 1,4-DB eq	1,74E+02	6,68E+00	1,53E+01	1,96E+02
Human toxicity	kg 1,4-DB eq	8,90E+02	2,01E+00	5,96E+00	8,98E+02

The Appendix – 1 (Figure 6) explains the Dastan v.2 office chair is determined with CML-IA baseline v3.3/EU25 through characterisation method in terms of abiotic depletion (fossil fuels), acidification, abiotic depletion, eutrophication, global warming potential, ozone layer depletion, photochemical oxidation, terrestrial ecotoxicity, marine aquatic ecotoxicity, fresh water aquatic ecotoxicity, and ultimately human toxicity. The figure represents how the processes contribute as a percentage to the overall impact in three main processes group. For acidification, abiotic depletion, photochemical oxidation, terrestrial ecotoxicity, and human toxicity impact category, the upstream processes including raw materials for components, their transportation and packaging materials have significant effect, approximately 98 percent of overall processes. This effect can be seen on the figure via red column.

Despite upstream processes have great adverse effect based on the eutrophication, ozone layer depletion, and fresh water aquatic ecotoxicity, downstream processes have also slight adverse effect on these impact categories comparing to the other categories such as acidification, and abiotic depletion.

Addition to these, the core processes in most impact category do not have more effect than downstream processes have. On the contrary that, downstream process has less effect than core processes in categories of abiotic depletion (fossil fuels), terrestrial ecotoxicity, human toxicity. To sum up, the significant amount of contribution comes generally from upstream processes.

The Appendix – 1 (Figure 7) demonstrates Dastan 30 office chair analysed with CML-IA baseline v3.3/EU25 through characterisation method based on the same impact categories with Dastan 30 v.2. As it is discussed for Dastan 30, not the all but almost each impact category such as abiotic depletion, eutrophication, global warming potential has the same adverse effect percent on the overall processes. However, Dastan 30 v.2 has more negative effect than Dastan 30 office chair model due to weight differences and type of materials between these two models.

Table 4-12: Resource Use for Dastan 30

			Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Non-renewable Resources	Material	Calcite	kg	8,72E+00	3,02E-02	3,55E-02	8,79E+00
		Bauxite	kg	1,97E+00	4,95E-03	1,07E-02	1,98E+00
		Gravel	kg	6,39E+01	5,15E-01	2,52E+00	6,69E+01
		Iron	kg	3,37E-01	1,70E-02	3,12E-02	3,85E-01
		Sodium Chloride	kg	1,56E+00	4,57E-04	8,85E-04	1,56E+00
	Energy	Coal	kg	1,24E+01	1,48E+00	9,89E-02	1,40E+01
		Oil, crude	kg	7,04E+00	9,06E-02	5,70E-01	7,70E+00
		Uranium	kg	1,92E-04	4,45E-07	9,86E-07	1,93E-04
Renewable Resources	Materi	Wood	m3	3,67E-03	1,14E-05	1,83E-05	3,70E-03

	al						
	Energy	Solar	MJ	1,45E-03	1,47E-04	2,76E-04	1,88E-03
		Biomass	MJ	4,67E+01	1,44E-01	1,96E-01	4,71E+01
		Hydropower	MJ	7,01E+01	3,43E+00	1,85E-01	7,37E+01

The indicators for use of resources are shown in Table 4-12 and Table 4-13 for Dastan 30 and Dastan 30 v.2. Use of resources are determined in two main categories which are renewable and non-renewable resources. These resources have basically material and energy dimensions. The materials and energy resources are sorted from the highest to lowest regarding their weight in the entire resource. The material and energy item having less than 5 percent of weight on total amount of resources are not seen in this table.

Table 4-13: Resource Use for Dastan 30 v.2

			Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Non-renewable Resources	**Material**	Calcite	kg	1,20E+01	3,08E-02	4,71E-02	1,21E+01
		Bauxite	kg	8,98E+00	5,03E-03	1,38E-02	9,00E+00
		Gravel	kg	8,94E+01	5,43E-01	2,90E+00	9,29E+01
		Iron	kg	5,48E-01	1,73E-02	3,99E-02	6,06E-01
		Sodium Chloride	kg	2,14E+00	4,69E-04	1,21E-03	2,15E+00
	Energy	Coal	kg	1,65E+01	1,51E+00	1,25E-01	1,81E+01
		Oil, crude	kg	8,09E+00	9,24E-02	7,28E-01	8,91E+00
		Uranium	kg	2,27E-04	4,57E-07	1,21E-06	2,29E-04
Renewable Resources	**Material**	Wood	m3	3,67E-03	1,14E-05	1,75E-05	3,70E-03
	Energy	Solar	MJ	2,36E-03	1,54E-04	3,38E-04	2,85E-03
		Biomass	MJ	6,07E+01	1,47E-01	2,44E-01	6,11E+01
		Hydropower	MJ	1,01E+02	3,48E+00	2,31E-01	1,04E+02

Table 4-14: Water Resource Use for Dastan 30

Parameter		Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Water Use	Total Amount of Water	m3	1,14E+0	1,42E-02	7,10E-03	1,16E+00
	Directly Amount of Water Used by Core Processes	m3	-	0.00	-	0.00

The direct amount of water is zero throughout the upstream, core, and downstream processes. However upstream processes use some amount of water due to the epoxy station requires it. Addition to that, amount of water in core processes and downstream is related to background data in Ecoinvent v.3 database. Water resources use for Dastan and Dastan v.2 is represented in Table 4-15 and Table 4-14. The amount of water used in core processes particularly in epoxy station is calculated in that way: Koleksiyon Mobilya production facility in Tekirdağ demanded the water as a purpose of being used in manufacturing stations. The amount of water used in 2016 is 2000 m^3 and the annual manufacturing process time is 2.7 million minutes. Therefore, the amount of water used in per min is 0,000721 m3/min.

Table 4-15 : Water Resource Use for Dastan 30 v.2

Parameter		Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Water Use	Total Amount of Water	m3	1,33E+00	1,45E-02	8,56E-03	1,36E+00
	Directly Amount of Water Used by Core Processes	m3	-	0.00	-	0.00

Both Table 4-16 and Table 4-17 represent output flows and waste types regarding to hazardous, non-hazardous, and radioactive waste respectively.

Table 4-16: Output Flows and Waste Categories of Dastan 30

Parameter	Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Hazardous waste	kg	-	1,12E-02	-	1,12E-02
Non-hazardous waste	kg	-	8,79E-01	1,038E+01	1,13E+01
Radioactive waste	kg	-	0.00	-	0.00

Non-hazardous waste includes scrap amounts related to core processes and final product's amount occurred in downstream processes for both Dastan 30 and Dastan 30 v.2 cases. There is no radioactive waste produced during whole life cycle of Dastan 30 and Dastan 30 v.2.

Table 4-17: Output Flows and Waste Categories of Dastan 30 v.2

Parameter	Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Hazardous waste	kg	-	1,12E-02	-	1,12E-02
Non-hazardous waste	kg	-	8,79E-01	1,338E+01	1,43E+01
Radioactive waste	kg	-	0.00	-	0.00

In **Hata! Başvuru kaynağı bulunamadı.** and **Hata! Başvuru kaynağı bulunamadı.**19 show the energy demand of Dastan 30 and Dastan 30 v.2 based on non-renewable and renewable resources.

Table 4-18: Energy Demand of Dastan 30

Impact category	Unit	Total	Upstream Processes	Core Processes	Downstream Processes
Non-renewable, fossil	MJ	1,04E+03	9,70E+02	4,12E+01	2,99E+01
Non-renewable, nuclear	MJ	1,08E+02	1,07E+02	2,49E-01	5,52E-01
Non-renewable, biomass	MJ	9,10E-02	8,95E-02	8,16E-04	7,73E-04
Renewable, biomass	MJ	4,70E+01	4,66E+01	1,43E-01	1,96E-01
Renewable, wind, solar, geothermal	MJ	3,21E+00	2,93E+00	2,50E-01	3,28E-02
Renewable, water	MJ	7,37E+01	7,01E+01	3,43E+00	1,85E-01

Table 4-19 Energy Demand of Dastan 30 v.2

Impact category	Unit	Total	Upstream	Core	Downstream
Non-renewable, fossil	MJ	1,17E+03	1,09E+03	4,19E+01	3,82E+01
Non-renewable, nuclear	MJ	1,28E+02	1,27E+02	2,56E-01	6,78E-01
Non-renewable, biomass	MJ	2,03E-01	2,01E-01	8,29E-04	9,85E-04
Renewable, biomass	MJ	6,09E+01	6,05E+01	1,46E-01	2,43E-01
Renewable, wind, solar, geothermal	MJ	4,03E+00	3,74E+00	2,54E-01	4,11E-02
Renewable, water	MJ	1,04E+02	1,01E+02	3,48E+00	2,31E-01

For both Dastan 30 and Dastan 30 v.2, fossil fuels, nuclear from non-renewable energy resources, and hydropower from renewable energy resources is leading the impact category. Specially, using fossil fuels in the upstream processes for the both two office chair cases has the biggest share among the other processes. Ultimately, the amount of energy produced from the renewable resources used in the production of Dastan 30 and Dastan 30 v.2 is significantly less than the amount of energy produced from non-renewable resource as it can be seen from Appendix – 1 (Figure 8 and 9). They are calculated using Cumulative Energy Demand v.1.09.

4.5. Product Development Based on Eco-Design Approach

After analysing two LCA studies according to such criteria, a new product is designed based on changing items causing the more environmental loads. During the design phase, ideas from the production engineers in Koleksiyon and literature are main sources for making critical decisions while selecting material and its related information. As it can be seen in Section 4.4, the hotspots of Dastan 30 and Dastan 30 v.2 come from back frame and mechanism part substantially. Besides, Dastan 30 has one more hotspot which is the cross foot since glass-filled plastics is used in it. Thereby, The Eco Audit Tool from Granta Design is adopted for material selection process which is quite essential for this thesis study. The Eco Audit Tool is a software using tremendous database including materials and it includes the detailed information such embodied energy, carbon footprint, and cost information of materials which are quite essential for product development procedures.

In Figure 13**Hata! Başvuru kaynağı bulunamadı.**, Compressive strength (MPa) and Young's modulus (GPa) is selected with the purpose of finding an appropriate material performing as metals and alloys. Since, these parameters are fundamental features for this case study due to provide durability of the office chair. Compressive strength or compression strength shows when the maximum load is applied, the solid item or material can maintain its shape and structure without any deformation.

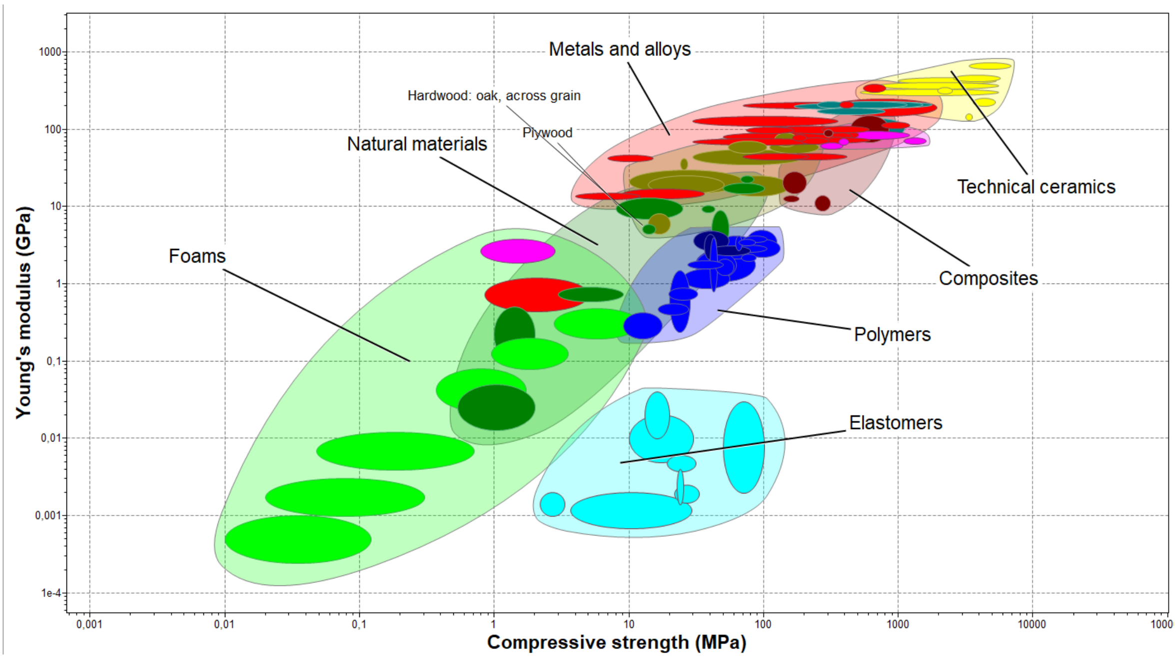

Figure 14: Selecting Alternative Material for Metals and Alloys Using Eco Audit Tool

Additionally, Young's Modulus defines the capability of a material to resist to changes in length. It is a numerical constant for representing the elastic properties of a solid material under the one direction either compression or tension. Therefore, these two variables can be directly correlated to performance of the chair during its life time. As it can be seen in the Figure 15, the natural materials such plywood are slightly different from metals. Hence, the plywood is selected as an eco-friendly material substituting the alloy frame. After deciding using of plywood instead of using iron-nickel-chromium alloy in back frame of office chair, and removing arm support from the design, the amount of plywood is assumed in this way:

Through web search, there are various type of office chair produced. As a design example for the eco-friendly chair, Lydia Mid-Back Desk Chair from Porthos Home is selected. Portos Home accepted to the product image to be used in this thesis study. Porthos Home is furniture brand found in San Francisco Bay area. The company has wide range product category including accent, office, and dining chair, upholstery benches, barstools, consoles and coffee tables, lastly nightstands and side tables.

As a reference chair Dastan 30's final weight without arm support and back frame is 7,454 kg. The simple and similar office chair with wood frame and without arm support named as

Lydia Mid-Back Desk Chair is weighted 10,97 kg taken from the Porthos Home website Hence, the weight difference between two office chair comes from wood component which is 3,5165 kg.

Figure 4-17: Lydia Mid-Back Desk Chair (Porthos Home)

The rest of chair components and related information, for instance, raw material and final product transportation is remained same with model of Dastan 30 for making a significant and logical comparison. The technical information on Eco-Dastan 30 is shown in the Appendix – 2 (Table 7). Moreover, the detailed bill of material table is demonstrated in Appendix – 2 (Table 8). Figure 4-17 shows that the material composition of Eco-Dastan differs from the other two office chair with high percentage of wood content.

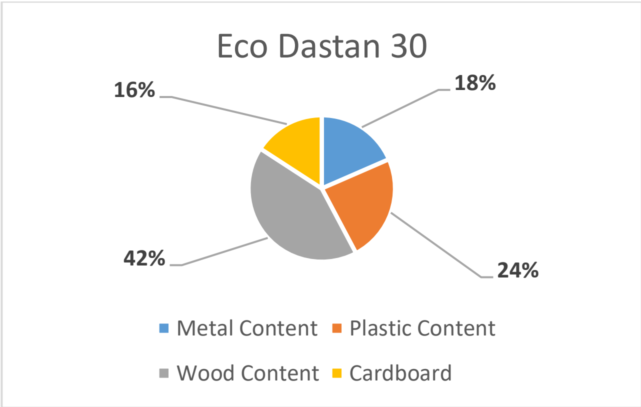

Figure 4-17: Material Composition Pie Chart for Eco Dastan 30

In the Appendix – 2 (Table 8), dummy content demonstrates the amount of recycled material of each item. In Turkey, Ministry of Environment and Urbanization Department states that waste of plywood can be used as refuse derived fuel (RDF) for energy production or in the other forms. If it cannot be used as supplementary fuel, it is disposed through burning called as Hazardous Waste Incineration. (ODTÜ Çevre Mühendisliği Bölümü, 2016). Thus, waste of plywood is delivered to the facility for energy recovery purpose (Dawson et. al, 1986). The energy generation from wood waste in Europe is approximately 34% percent in 2005 (Haas et al. 2015, p. 765-777). This is used as an assumption for percent of plywood recycling rate in the system.

The electricity consumption data during the production of Eco-Dastan is almost same with the other two model of office chairs. There is additionally one station performed in Eco-Dastan which is solid wood. Cutting and shaping processes of wood is held in this station for 15 mins. Also, upholstery station is needed the less time due to the arm supports is not used in this model.

4.5.1. Life cycle Inventory Analysis and Potential Environmental Impacts

Table 4-20 is related to the contributions in the production of Eco Dastan 30 according to these environmental impact categories: abiotic depletion (fossil fuels), acidification, abiotic depletion, eutrophication, global warming potential, ozone layer depletion, photochemical oxidation, terrestrial ecotoxicity, marine aquatic ecotoxicity, fresh water aquatic ecotoxicity, and finally human toxicity calculated b CML-IA Baseline Method. These impact categories are defined the same with Dastan 30 and Dastan 30 v.2 which are named as upstream, core, and downstream defined in related PCR UN CPC 3811.

Table 4-20: Environmental Impacts of Eco-Dastan According to CML IA Baseline Method

Impact category	Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Abiotic depletion (fossil fuels)	MJ	8,88E+02	5,78E+01	3,35E+01	9,80E+02
Acidification	kg SO2 eq	4,75E+00	2,82E-02	1,15E-02	4,79E+00
Abiotic depletion	kg Sb eq	1,87E-03	3,71E-06	5,34E-06	1,88E-03
Eutrophication	kg PO4--- eq	2,25E-01	2,91E-02	4,40E-02	2,98E-01
Global warming (GWP100a)	kg CO2 eq	6,07E+01	6,98E+00	7,07E+00	7,47E+01
Ozone layer depletion (ODP)	kg CFC-11 eq	3,11E-06	2,43E-07	3,79E-07	3,73E-06
Photochemical oxidation	kg C2H4 eq	1,95E-01	1,84E-03	1,74E-03	1,99E-01
Terrestrial ecotoxicity	kg 1,4-DB eq	7,59E-01	1,61E-02	1,44E-02	7,89E-01
Marine aquatic ecotoxicity	kg 1,4-DB eq	1,67E+05	1,19E+04	1,62E+04	1,95E+05
Fresh water aquatic ecotox.	kg 1,4-DB eq	8,28E+01	1,33E+01	2,11E+01	1,17E+02
Human toxicity	kg 1,4-DB eq	4,18E+02	2,95E+00	5,60E+00	4,27E+02

The indicators for use of resources are shown in Table 4-21**Hata! Başvuru kaynağı bulunamadı.**. Use of resources are categorized in two main headline which are renewable and non-renewable resources. These resources have basically material and energy dimensions. The material and energy item having less than 5 percent of weight on total amount of resources are not shown in the table.

Appendix – 1 (Figure 11) demonstrates that how the processes contribute as a percentage to the overall impact in three main processes group. The upstream processes have less than 90 percent effect on overall processes regarding to global warming, ozone layer depletion marine aquatic ecotoxicity, and eutrophication. For the other categories, upstream processes have at least 90 percent impact on the overall assessment.

Table 4-21: Resource Use for Eco-Dastan

			Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Non-renewable Resources	**Material**	Calcite	kg	5,93E+00	4,77E-02	4,11E-02	6,02E+00
		Bauxite	kg	1,41E+00	1,11E-02	1,18E-02	1,43E+00
		Gravel	kg	4,67E+01	1,57E+00	3,47E+00	5,17E+01
		Iron	kg	3,43E-01	3,37E-02	3,45E-02	4,11E-01
		Sodium Chloride	kg	1,33E+00	1,04E-03	1,21E-03	1,33E+00
	Energy	Coal	kg	1,07E+01	1,71E+00	1,26E-01	1,25E+01
		Oil, crude	kg	6,79E+00	3,19E-01	6,28E-01	7,74E+00
		Uranium	kg	1,66E-04	9,55E-07	1,28E-06	1,68E-04
Renewable Resources	**Material**	Wood	m3	4,44E-02	2,04E-05	2,17E-05	4,44E-02
	Energy	Solar	MJ	3,99E-03	3,63E-04	5,27E-04	4,88E-03
		Biomass	MJ	5,20E+02	2,48E-01	2,43E-01	5,20E+02
		Hydropower	MJ	5,09E+01	3,92E+00	2,41E-01	5,50E+01

Besides, the downstream processes have more adverse effect comparing to the core processes in some impact category such as eutrophication, global warming potential. However, downstream process has less effect than core processes in category of abiotic depletion (fossil fuels), acidification, photochemical oxidation, and terrestrial ecotoxicity. Finally, the significant amount of contribution comes generally from upstream processes.

The direct amount of water is zero throughout the upstream, core, and downstream processes. However, epoxy station requires the water which is held in the upstream processes. Moreover, amount of water in core processes and downstream is related to background data in Ecoinvent v.3 database. Water resources use for Eco-Dastan is shown in the Table 4-22. The amount of water used in core processes particularly in epoxy station is explained in the other office chair cases.

Table 4-22 : Water Resource Use for Eco-Dastan

Parameter		Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Water Use	Total Amount of Water	m3	9.11E-01	2.72E+01	1.53E+00	2,96E+01
	Directly Amount of Water Used by Core Processes	m3	-	0.00	-	0.00

Table 4-23 indicates output flows and waste types regarding to hazardous, non-hazardous, and radioactive waste respectively. Each parameter such non-hazardous waste have the same logic with both Dastan 30 and Dastan 30 v.2 cases. The amount of scraps amounts related to core processes and final product's amount belongs to downstream processes in this table. There is no radioactive waste produced during whole life cycle of Eco-Dastan

Table 4-23: Output Flows and Waste Categories of Eco-Dastan

Parameter	Unit	Upstream Processes	Core Processes	Downstream Processes	Total
Hazardous waste	kg	-	1,12E-02	-	1,12E-02
Non-hazardous waste	kg	-	12,97E-01	1,097E+01	1,23E+01
Radioactive waste	kg	-	0.00	-	0.00

In Table 4-24 is to show the energy demand of Eco-Dastan regarding to non-renewable and renewable resources basically. Additionally, the Appendix - 1 (Figure 14) the percentages of these resources regarding to upstream, core, and downstream processes**.**

Table 4-24: Energy Demand of Eco-Dastan

Impact category	Unit	Total	Upstream Processes	Core Processes	Down Processes
Non-renewable, fossil	MJ	9,80E+02	8,89E+02	5,78E+01	3,35E+01
Non-renewable, nuclear	MJ	9,41E+01	9,29E+01	5,35E-01	7,19E-01
Non-renewable, biomass	MJ	1,67E-01	1,65E-01	1,28E-03	8,68E-04
Renewable, biomass	MJ	5,20E+02	5,20E+02	2,47E-01	2,42E-01
Renewable, wind, solar, geothermal	MJ	3,16E+00	2,82E+00	2,96E-01	4,42E-02

Renewable, water	MJ	5,50E+01	5,09E+01	3,92E+00	2,41E-01

5. Discussion

After three office chairs' environmental impact analysis, this section includes explanation of analyses, and commends on results. First of all, comparison between three office chairs is shown in Table 5-25. As it results that Eco-Dastan model of chair has better results than the other two models regarding to such impact category i.e. acidification, human toxicity, and so on. The comparison result in terms of characterization is demonstrated in the Appendix – 1 (Figure 13)**Hata! Başvuru kaynağı bulunamadı.**.

Table 5-25: Environmental Impacts of Three Office Chairs According to CML IA Baseline Method

Impact category	Unit	LCA_Dastan	LCA_Dastan_v2	LCA_Eco_Dastan
Abiotic depletion (fossil fuels)	MJ	1,04E+03	1,17E+03	9,80E+02
Acidification	kg SO2 eq	7,24E+00	9,95E+00	4,79E+00
Abiotic depletion	kg Sb eq	2,86E-03	4,01E-03	1,88E-03
Eutrophication	kg PO4--- eq	3,45E-01	4,77E-01	2,98E-01
Global warming (GWP100a)	kg CO2 eq	7,84E+01	8,94E+01	7,47E+01
Ozone layer depletion (ODP)	kg CFC-11 eq	3,41E-06	7,02E-06	3,73E-06
Photochemical oxidation	kg C2H4 eq	2,92E-01	4,02E-01	1,99E-01
Terrestrial ecotoxicity	kg 1,4-DB eq	1,14E+00	1,59E+00	7,89E-01
Marine aquatic ecotoxicity	kg 1,4-DB eq	2,60E+05	4,25E+05	1,95E+05
Fresh water aquatic ecotox.	kg 1,4-DB eq	1,40E+02	1,96E+02	1,17E+02
Human toxicity	kg 1,4-DB eq	6,47E+02	8,98E+02	4,27E+02

Not only environmental impact results show that Eco-Dastan is eco-friendlier than the other, but also resource consumption table indicates that Eco-Dastan consumes less non-renewable material such as gravel, bauxite and iron. Besides, Eco-Dastan utilizes more energy from solar and biomass resources than Dastan 30 and Dastan 30 v.2 use. However, wood from renewable materials is consumed most by Eco-Dastan due to its raw material of back frame.

Table 5-26: Resource Use for Three Office Chairs

			Unit	LCA_Dastan	LCA_Dastan_v2	LCA_Eco_Dastan
Non-renewable Resources	Material	Calcite	kg	8,79E+00	1,21E+01	6,02E+00
		Bauxite	kg	1,98E+00	9,00E+00	1,43E+00
		Gravel	kg	6,69E+01	9,29E+01	5,17E+01
		Iron	kg	3,85E-01	6,06E-01	4,11E-01
		Sodium Chloride	kg	1,56E+00	2,15E+00	1,33E+00

	Energy	Coal	kg	1,40E+01	1,81E+01	1,25E+01
		Oil, crude	kg	7,70E+00	8,91E+00	7,74E+00
		Uranium	kg	1,93E-04	2,29E-04	1,68E-04
Renewable Resources	**Material**	Wood	m3	3,70E-03	4,89E-03	4,44E-02
	Energy	Solar	MJ	1,88E-03	2,85E-03	4,88E-03
		Biomass	MJ	4,71E+01	6,11E+01	5,20E+02
		Hydropower	MJ	7,37E+01	1,04E+02	5,50E+01

The energy resources for each office chair is represented in Table 5-27. It can be concluded that Dastan 30 v.2 requires more energy than Dastan 30. Additionally, Eco-Dastan consumes less energy than Dastan 30 with respect to fossil and nuclear resources. On the contrary that, consumption of wind, solar, geothermal, and water renewable sources are consumed most by Dastan 30. Ultimately, renewable biomass resources are required from raw material of Eco-Dastan back frame.

Table 5-27: Energy Demand of Three Office Chairs

Impact category	Unit	LCA_Dastan	LCA_Dastan_v2	LCA_Eco_Dastan
Non-renewable, fossil	MJ	1,04E+03	1,17E+03	9,80E+02
Non-renewable, nuclear	MJ	1,08E+02	1,28E+02	9,41E+01
Non-renewable, biomass	MJ	9,10E-02	2,03E-01	1,67E-01
Renewable, biomass	MJ	4,70E+01	6,09E+01	5,20E+02
Renewable, wind, solar, geothermal	MJ	3,21E+00	4,03E+00	3,16E+00
Renewable, water	MJ	7,37E+01	1,04E+02	5,50E+01

As a purpose of this thesis study, the eco-friendly product is designed based on changing the one of hotspots of two office chair particularly back frame part of the chair. With this respect, the raw material for back frame is manufactured with particle board, then Eco-Dastan office chair is made. The LCA outcomes of Eco-Dastan's back frame shows that it has significantly better result than Dastan 30 v.2 regarding to each impact category. It can be said that the type of raw material is essential for LCA result. Since back frame of Dastan 30 v.2 is made by iron-chromium-aluminium alloy which requires high volume of energy throughout the process of extracting from mining area and processing it as a raw material. Besides particle board demands less volume of energy due to it has a few numbers of procedures for extracting and other type of process in order to use it for the manufacturing purposes. Additionally, Dastan 30 has better environmental performance than Dastan v.2 regarding to CML IA baseline method characterized by global warming potential 100a. By reason of amount of back frame's raw material used in Dastan 30 is approximately half of the back frame in Dastan 30 v.2. It shows that the material consumption effects on the environmental performance results of the products. Furthermore, comparing eco-friendly office chair and Dastan 30 points that except of only in two impact categories, which are abiotic depletion (fossil fuels) and ozone layer depletion, Eco-Dastan has reasonably better results than Dastan 30 according to CML IA baseline method characterized by global warming potential 100a. The comparison results are demonstrated in separately the Appendix – 1 (Figure 13).

Table 5-28: Environmental Impacts of Three Office Chairs' Back Frame According to CML IA Baseline Method

Impact category	Unit	Dastan_BackFrame	Dastan_v2_BackFrame	Eco_Dastan_BackFrame
Abiotic depletion (fossil fuels)	MJ	1,19E+02	2,45E+02	1,24E+02
Acidification	kg SO2 eq	2,50E+00	5,17E+00	6,33E-02
Abiotic depletion	kg Sb eq	9,93E-04	2,05E-03	2,35E-05
Eutrophication	kg PO4--- eq	8,90E-02	1,84E-01	2,45E-02
Global warming (GWP100a)	kg CO2 eq	1,08E+01	2,23E+01	8,12E+00
Ozone layer depletion (ODP)	kg CFC-11 eq	7,73E-07	1,60E-06	8,99E-07
Photochemical oxidation	kg C2H4 eq	9,98E-02	2,06E-01	6,24E-03
Terrestrial ecotoxicity	kg 1,4-DB eq	3,89E-01	8,05E-01	2,58E-02
Marine aquatic ecotoxicity	kg 1,4-DB eq	7,97E+04	1,65E+05	7,03E+03
Fresh water aquatic ecotox.	kg 1,4-DB eq	4,19E+01	8,66E+01	2,54E+00
Human toxicity	kg 1,4-DB eq	2,25E+02	4,65E+02	3,69E+00

The Figure 5-20 for uncertainty analysis is calculated in order to show the significance of differences between three model of office chair.

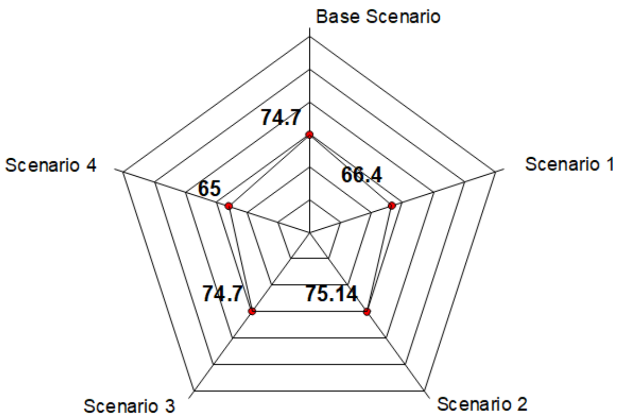

Figure 5-20: Uncertainty Analysis (Mean 71,18; Standard Deviation 5,02)

The Monte Carlo analysis is to address the uncertainty regarding to secondary data and calculation methods as well. It helps to make a comparison for each environmental impact category. In the Figure 16, Dastan 30 v.2 and Eco-Dastan are analysed. The blue bars demonstrate that the scenario including Eco-Dastan had a lower load than Dastan30 v.2 which means that in most impact category Eco-Dastan is better choice. However, impact factor of fresh water aquatic ecotoxicity, terrestrial ecotoxicity, and ozone layer depletion is the criteria that the decision cannot be made for which office chair is better regarding to environmental perspective. Moreover, the illustrates the same uncertainty analysis with Eco-Dastan and Dastan 30 model of office chair. In this figure, fresh water aquatic ecotoxicity, terrestrial ecotoxicity, and ozone layer depletion, global warming potential, and abiotic depletion (fossil fuels) are not suitable in order to make critical decision to select the better office chair in terms of the environmental load. The other criteria show that the same result with Figure 17.

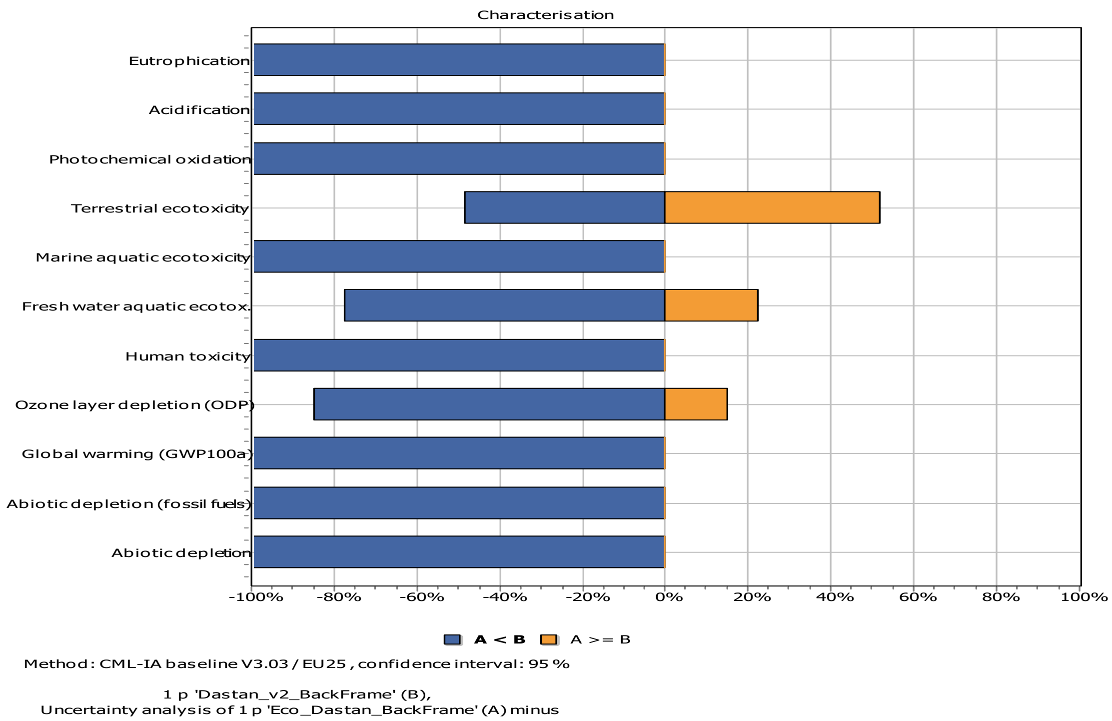

Figure 18: The Monte Carlo Analysis for Dastan 30 v.2 and Eco Dastan

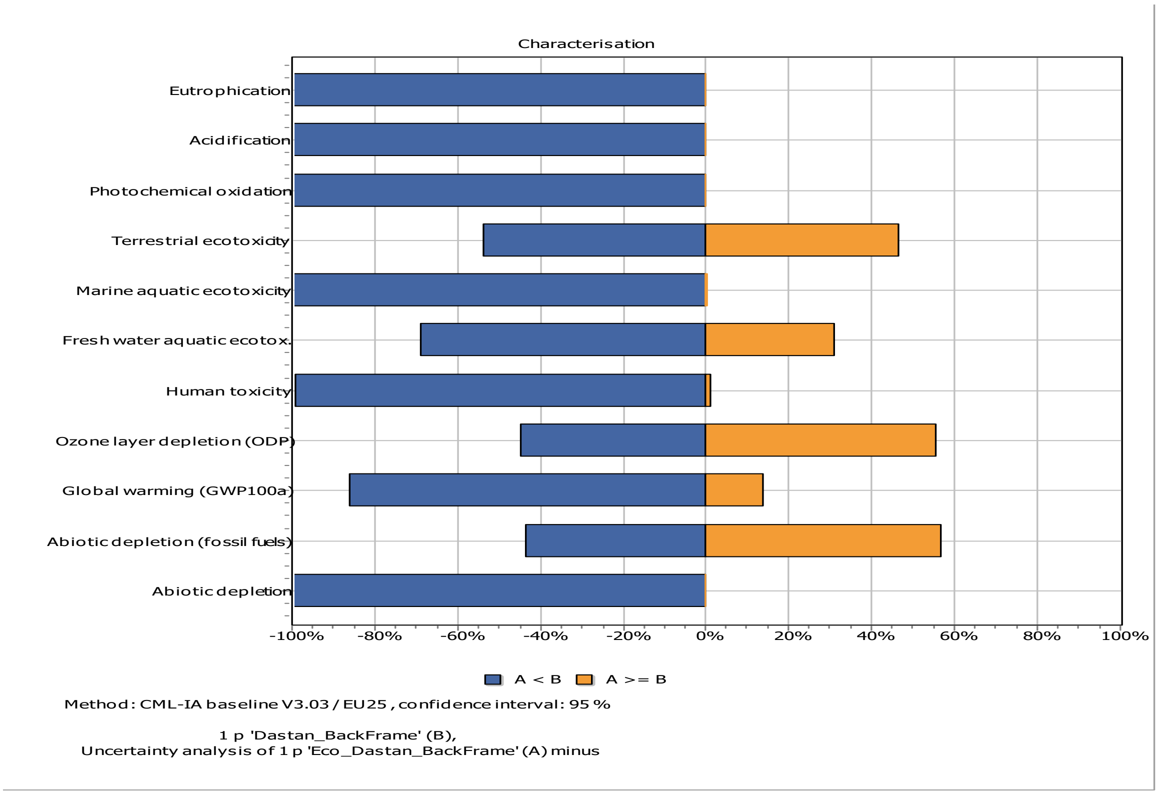

Figure 19: The Monte Carlo Analysis for Dastan 30 and Eco Dastan

6. Conclusion

The sustainability vision in this decade has been tremendously raised through new methodologies and best practices done by industrial and academic practices. With this vision, the importance of life cycle thinking has been widely acclaimed. Unfortunately, in Turkey there was no regulation or legislation made by government regarding to sustainability. On the other hand, some applications of the sustainability such as recycling facilities, renewable energy practices have been highly demanded by both customer and industry. This has started triggering the government, hence, the number of recycling facilities has been increasing and especially renewable energy sector has huge trade in current economy.

In this thesis study, one of the sustainability component is determined which is the environmental pillar. With the help of Koleksiyon Mobilya, there are two office chairs assessed in terms of their environmental performance. In this study, the global warming potential is the centre due to this topic is quite essential and known recently. Through these perspectives, CML IA baseline method is used for the life cycle assessments characterizing with Global Warming Potential 100a. After the results came out, the eco-design approach is applied. The eco-design study is implemented based on changing the raw material that is the one of hotspot of two office chairs. Because of high energy demand of metals, the one of big hotspot is iron-chromium-aluminium alloy. Through using Eco Audit Tool, the substitute material is found instead of using the material in back frame. This material is selected based on two criteria such as compressive strength (MPa) and young's modulus (GPa). Since these are the criteria that effect on the durability and utilization of the chair. Based on these constraints, the natural material is significantly close to metals. Due to the fact that, particle board is utilized as a raw material of Eco-Dastan back frame. Ultimately, the third office chair design by eco-design vision has better environmental performance than the other two.

To sum up, life cycle assessment is the key methodology for selection of raw material, eco-design approach, and it is also a decision-making tool for critical points of product life cycle. Through results of this assessment, it encourages the customers to demand the product having less adverse environmental impacts. Furthermore, there are some strict legislations and laws in global market that requires the product having life cycle assessment analysis or environmental labels. This shows that the product sustainability is quite known and hot topic in today. Therefore, this analysis might help both Koleksiyon Mobilya and other furniture producers to have a clue that they can start sustainability journey.

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APPENDIX I

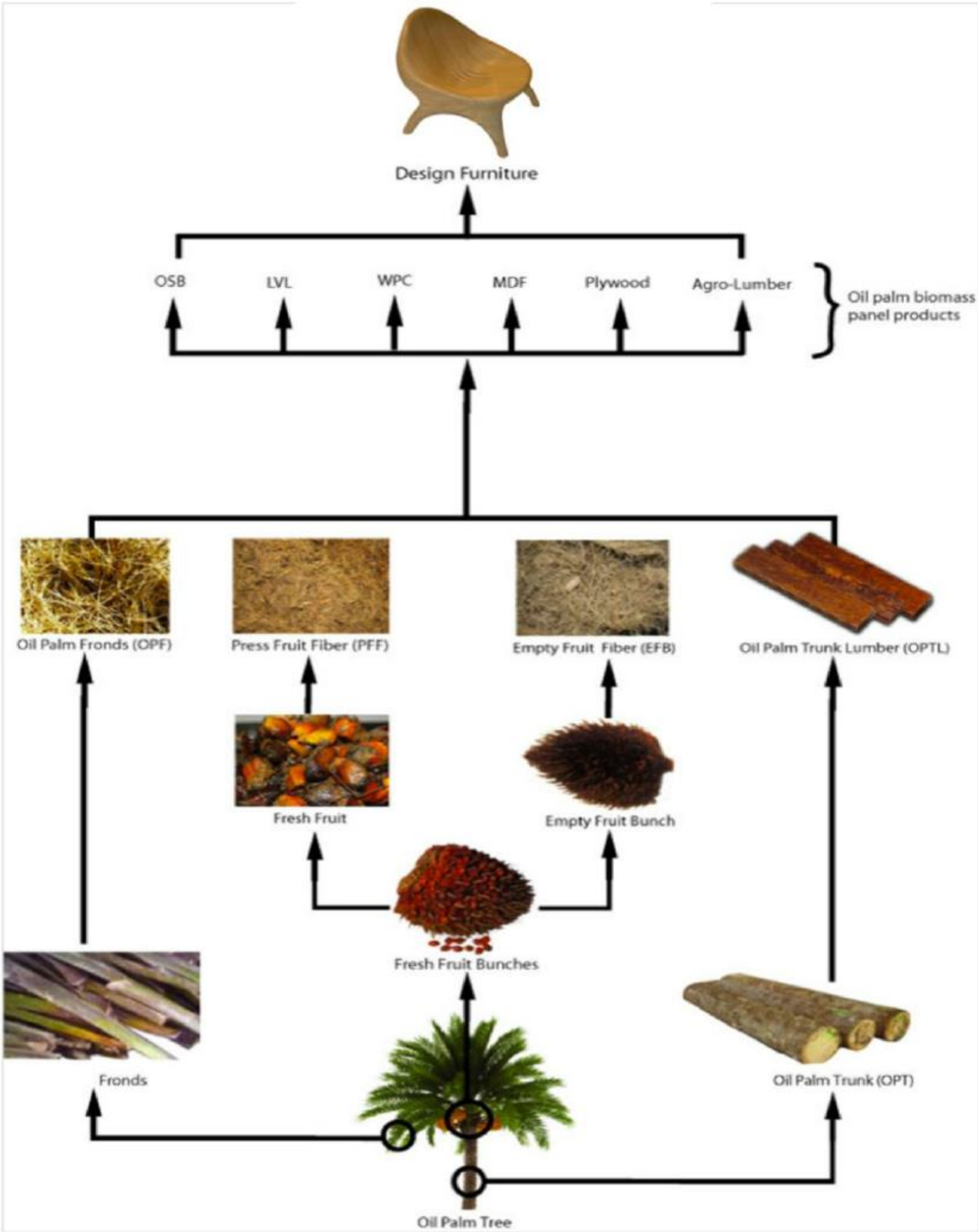

Figure 1: Oil palm tree biomass structure (Suhaily et. al, 2012, 4400-4423)

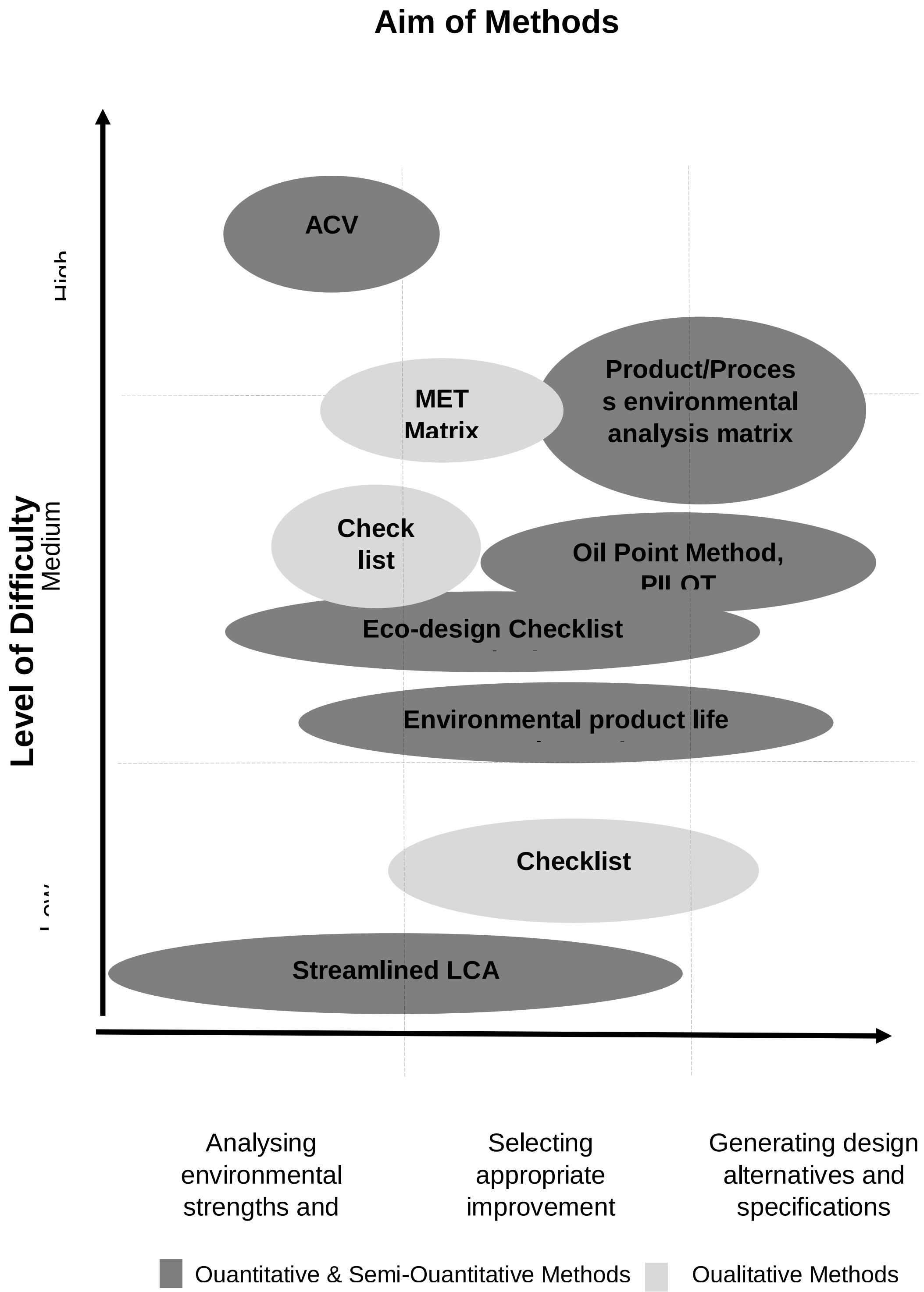

Figure 20: Software Tools for Eco-design

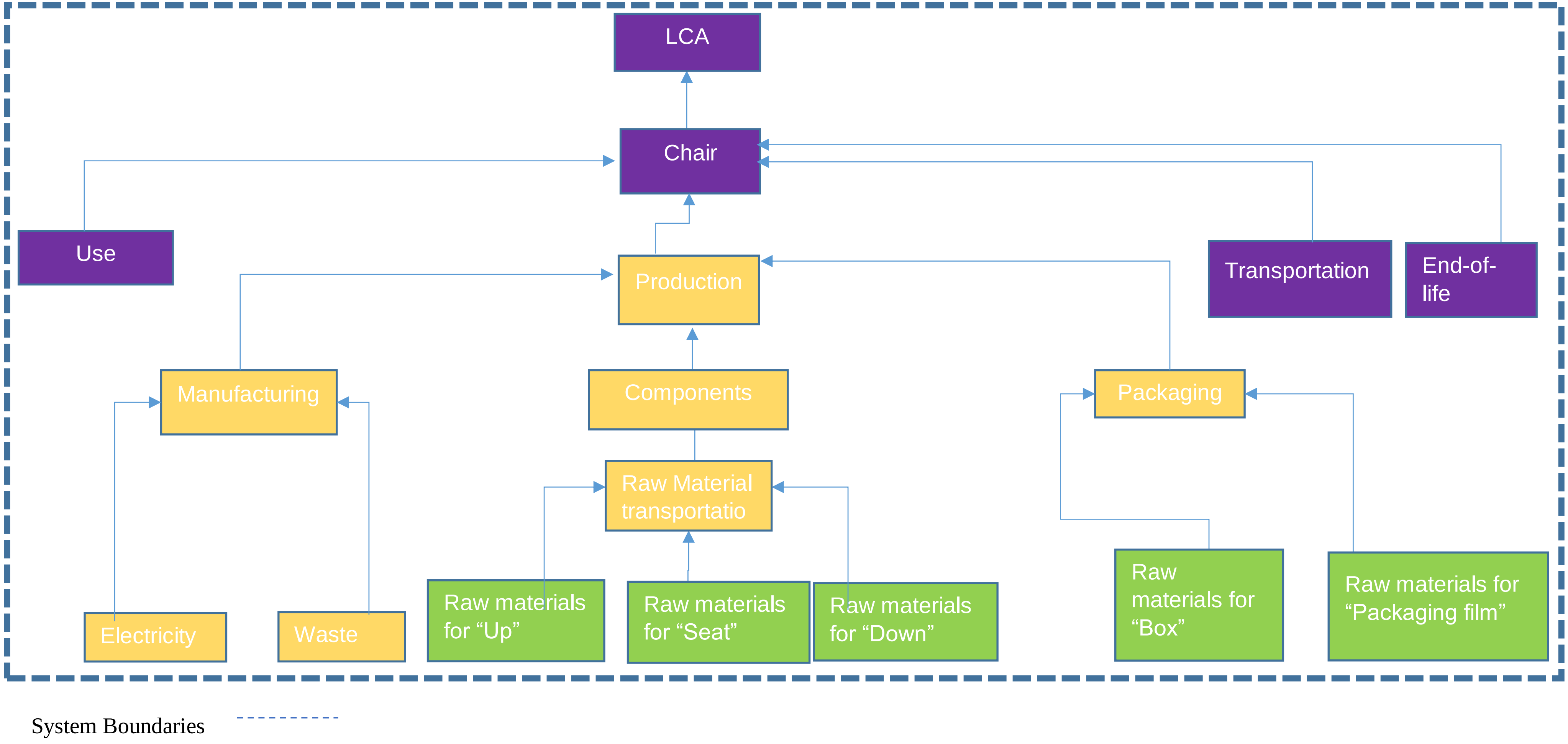

Figure 3: System Boundary of The LCA Study Conducted on Dastan 30

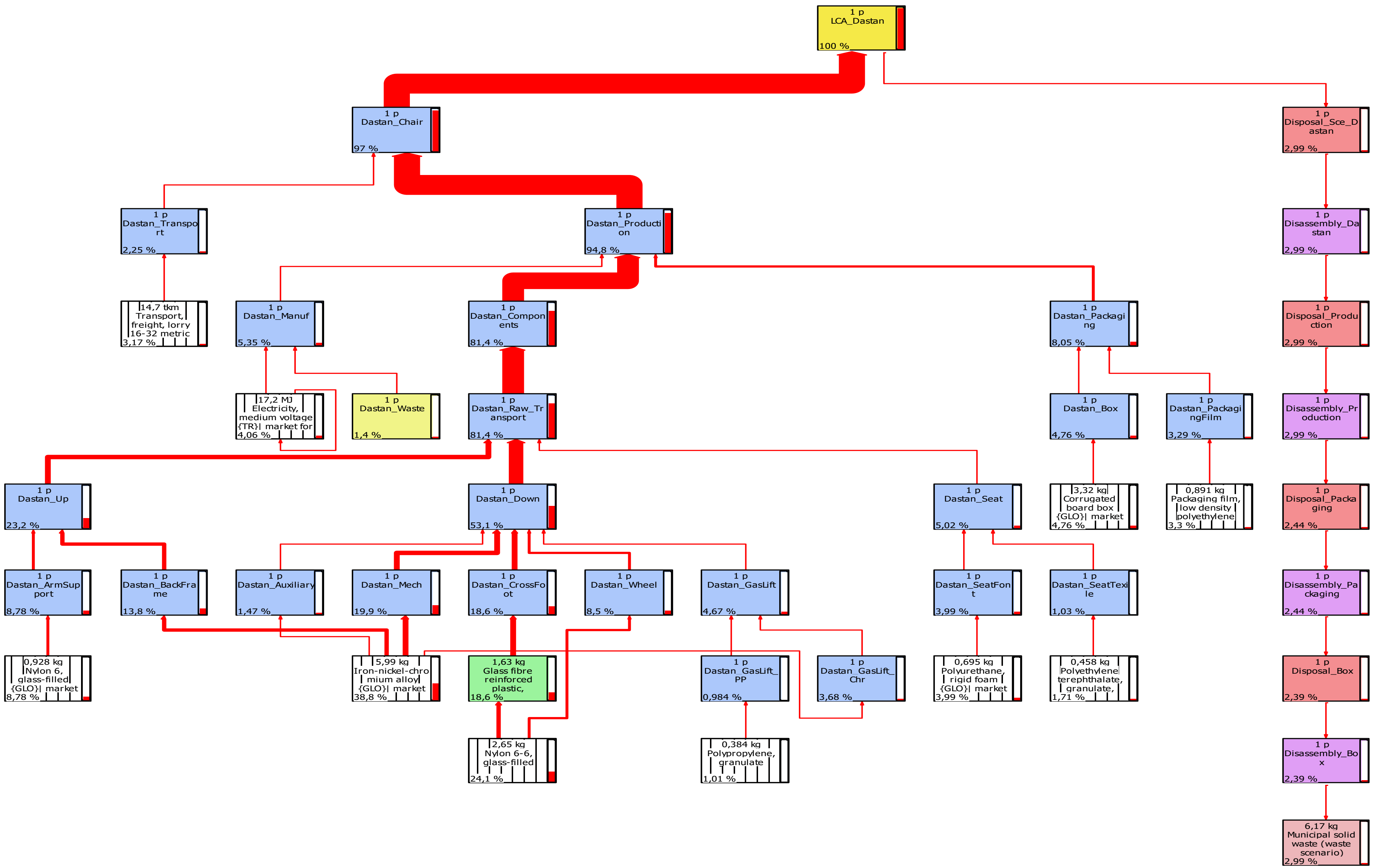

Figure 4: LCA flow of Dastan 30 LCA Study According to CML-IA Baseline Method

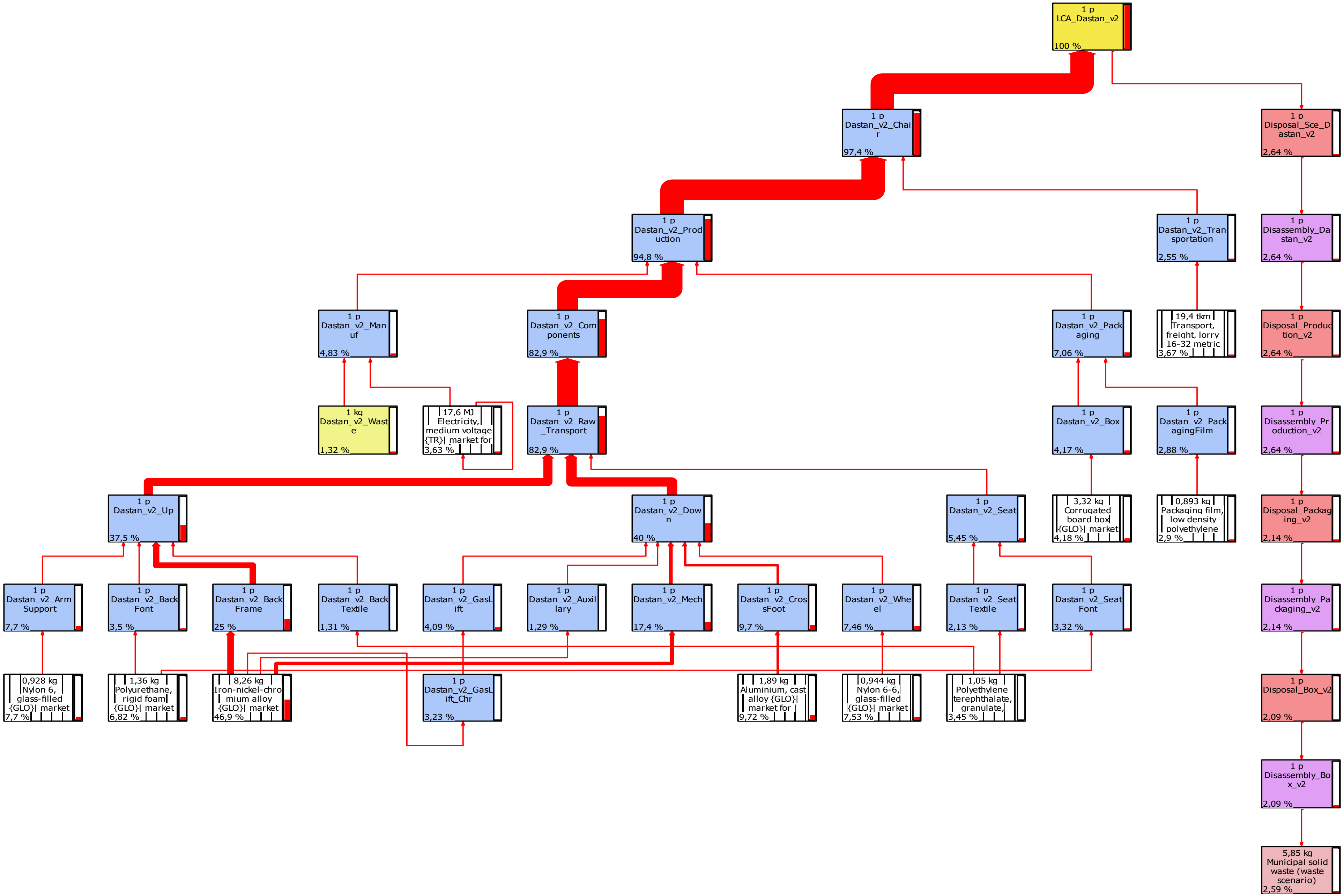

Figure 5: LCA flow of Dastan 30 v.2 LCA Study According to CML-IA Baseline Method

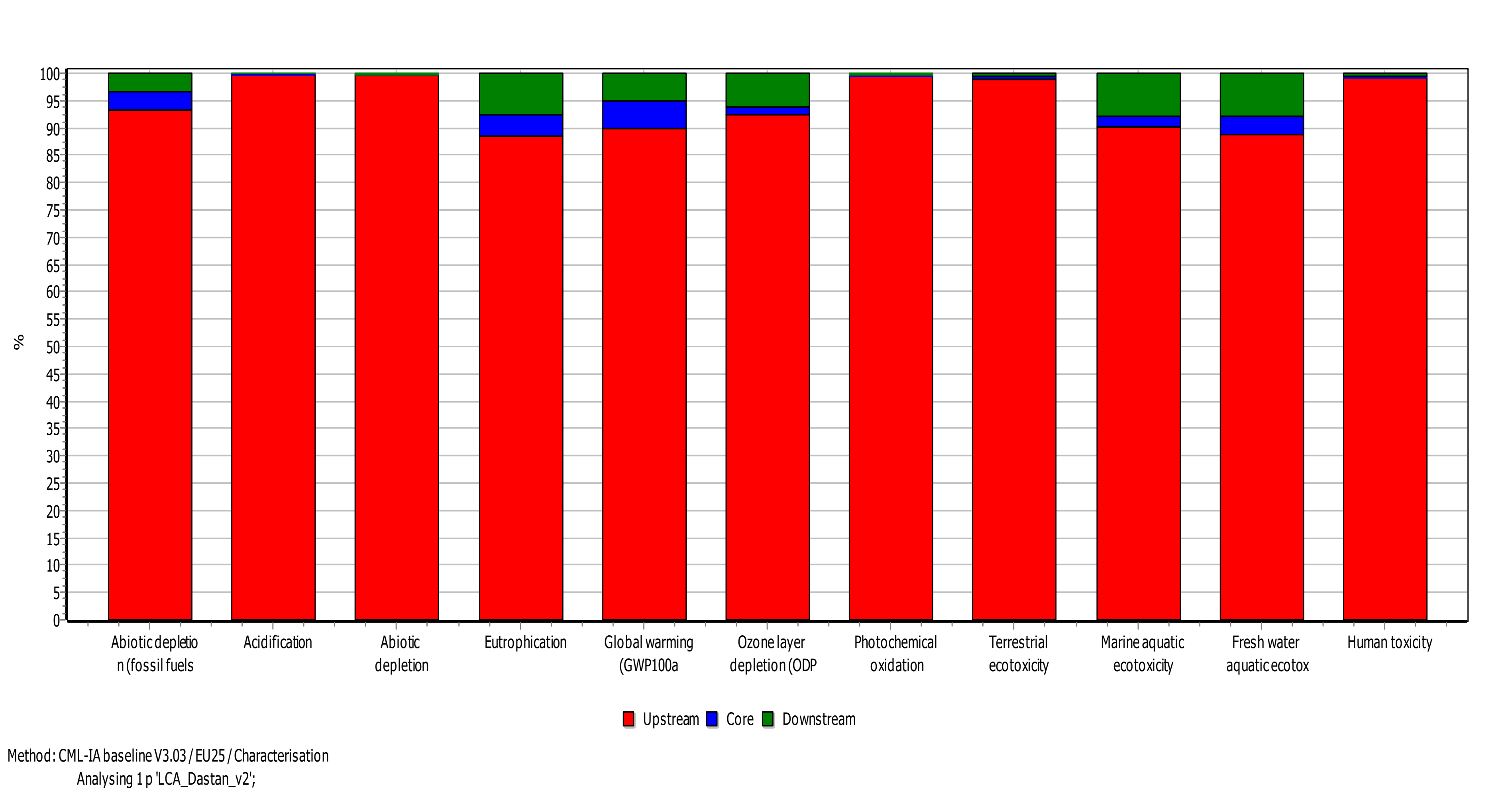

Figure 6: Related Impacts of Dastan 30 v.2 LCA Study According to CML-IA Baseline Method

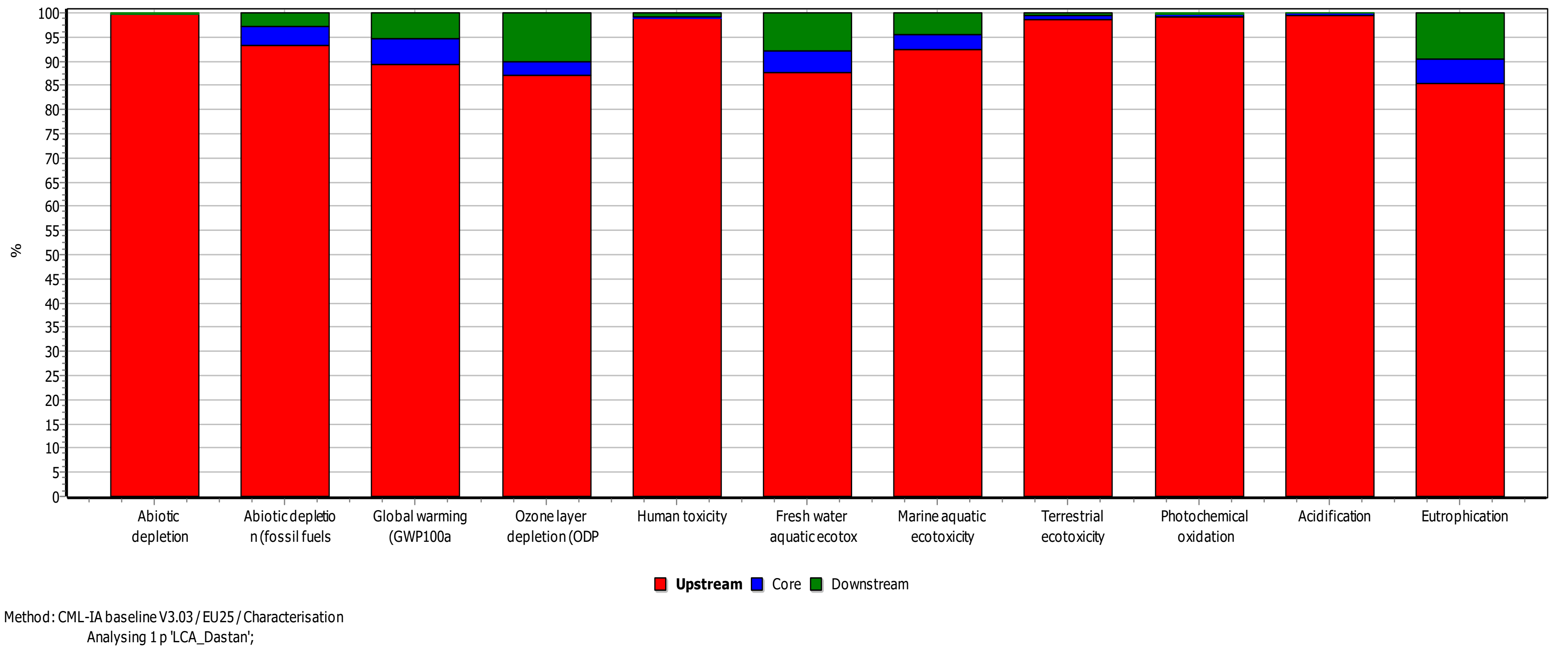

Figure 7: Related Impacts of Dastan 30 LCA Study According to CML-IA Baseline Method

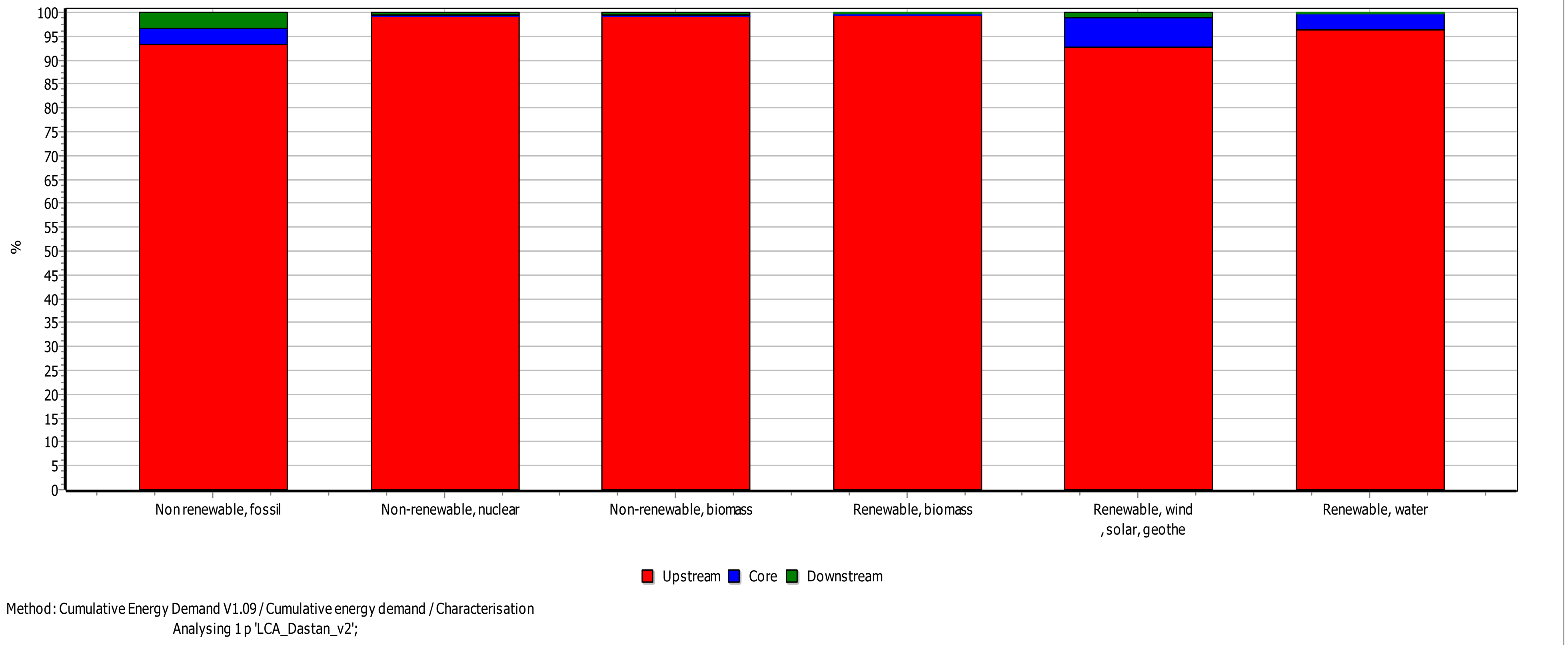

Figure 8: Cumulative Energy Demand of Dastan 30 v.2

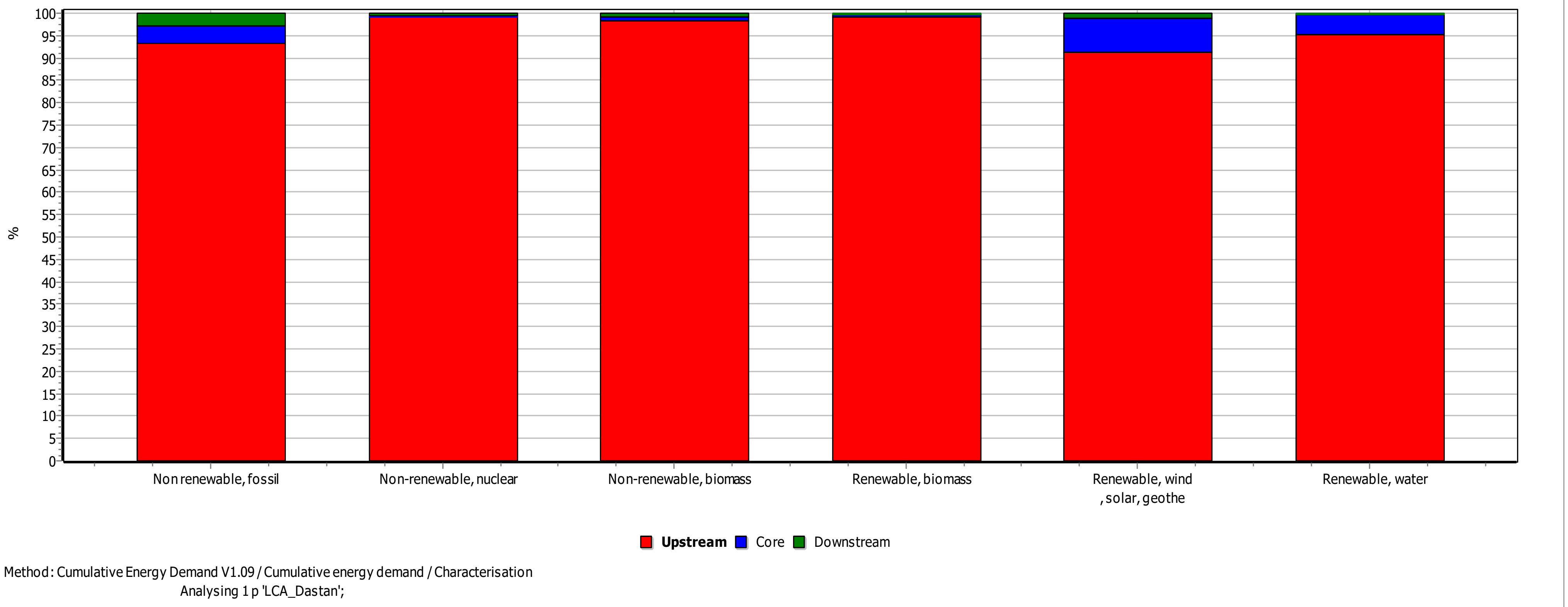

Figure 9: Cumulative Energy Demand of Dastan 30

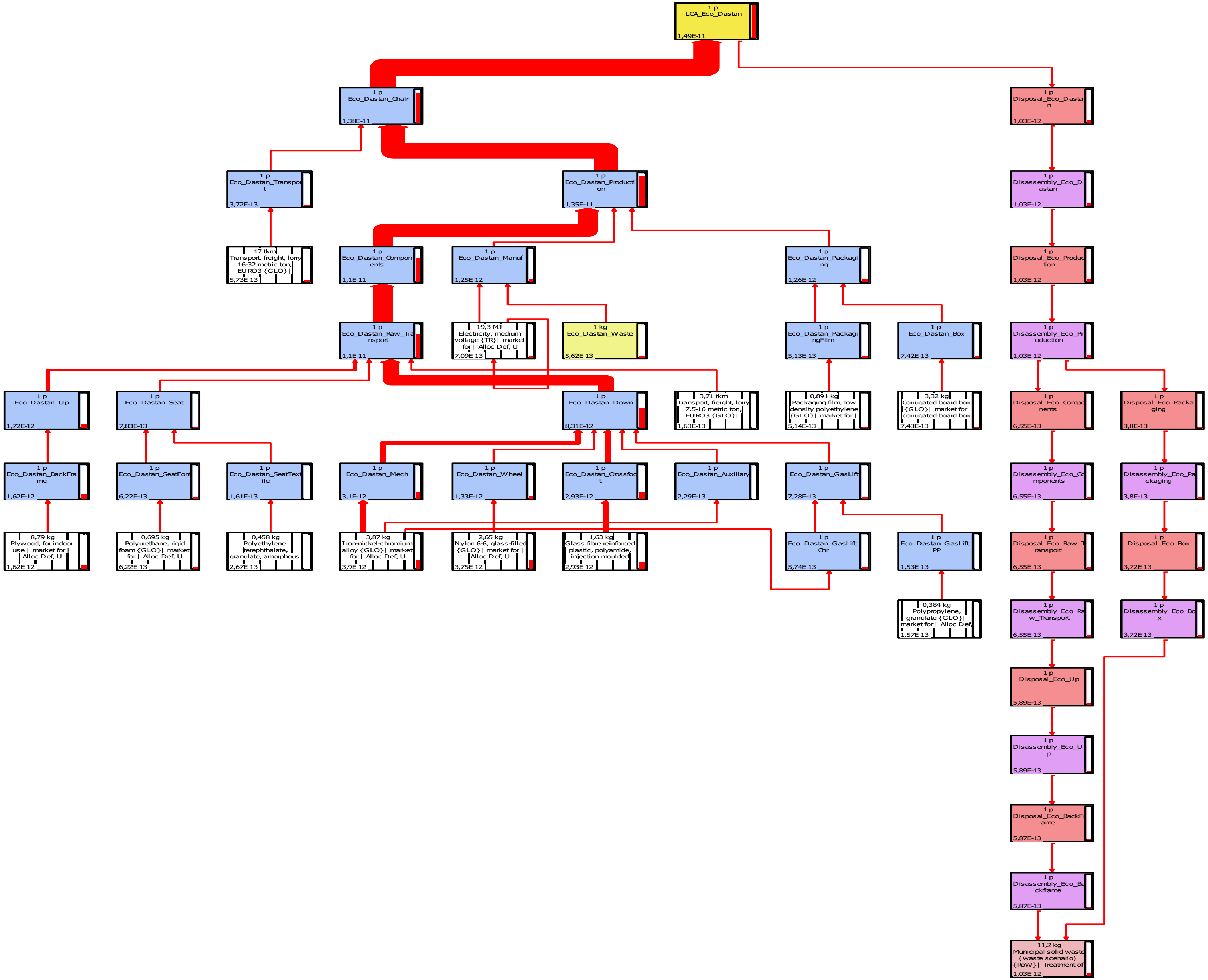

Figure 10: LCA flow of Eco-Dastan LCA Study According to CML-IA Baseline Method

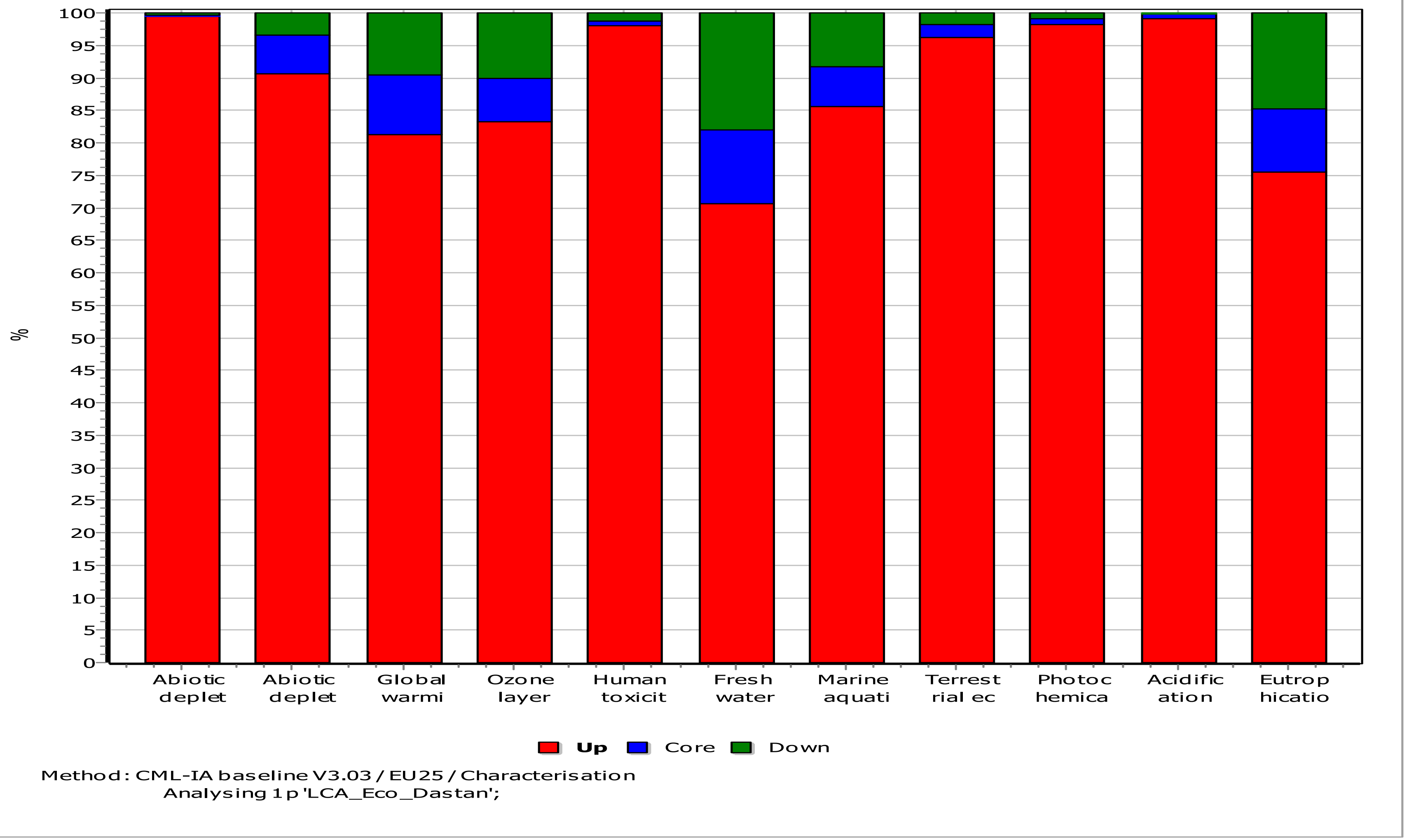

Figure 11: Related Impacts of Eco-Dastan LCA Study According to CML-IA Baseline Method

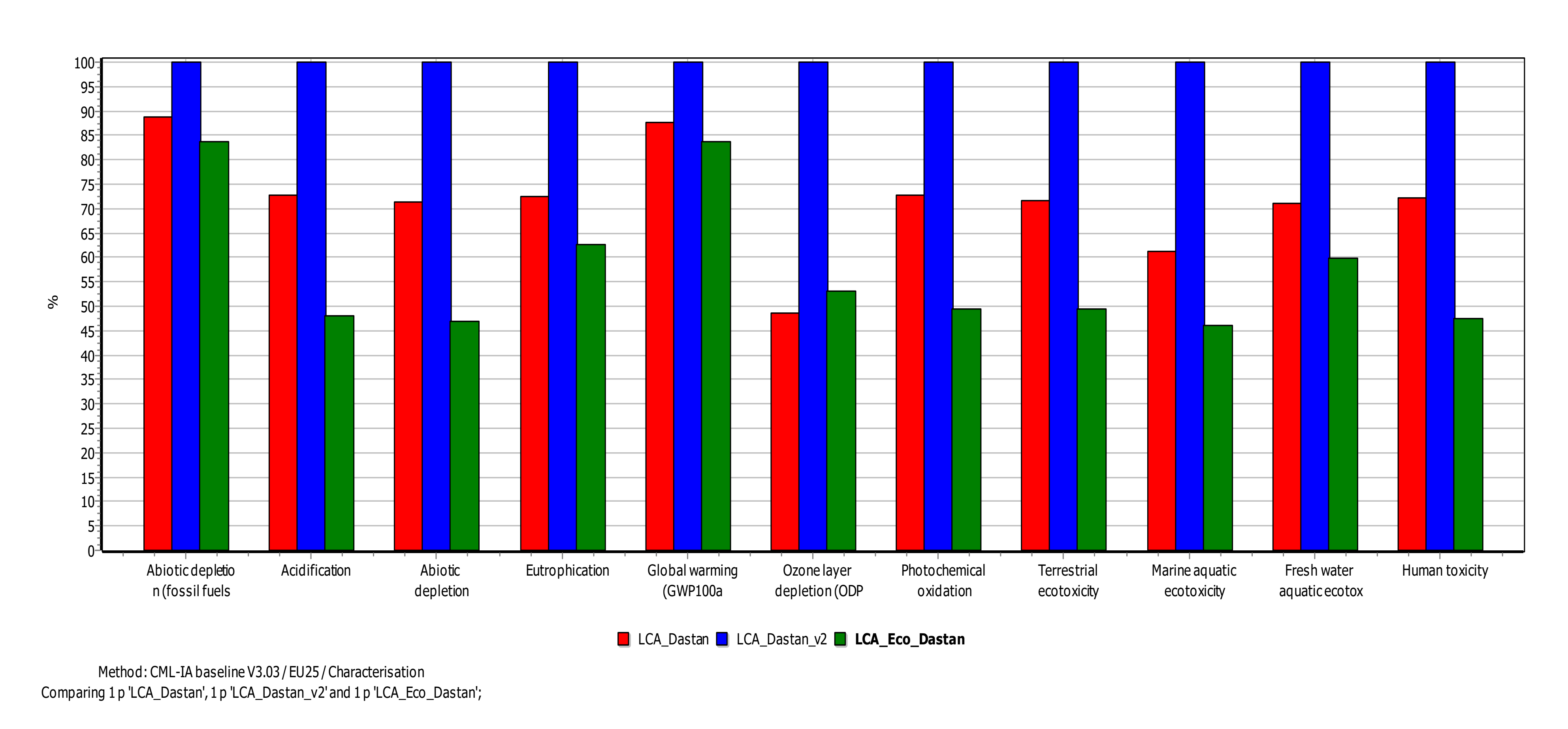

Figure 12: Related Impacts of Three Office Chairs LCA Study According to CML-IA Baseline Method

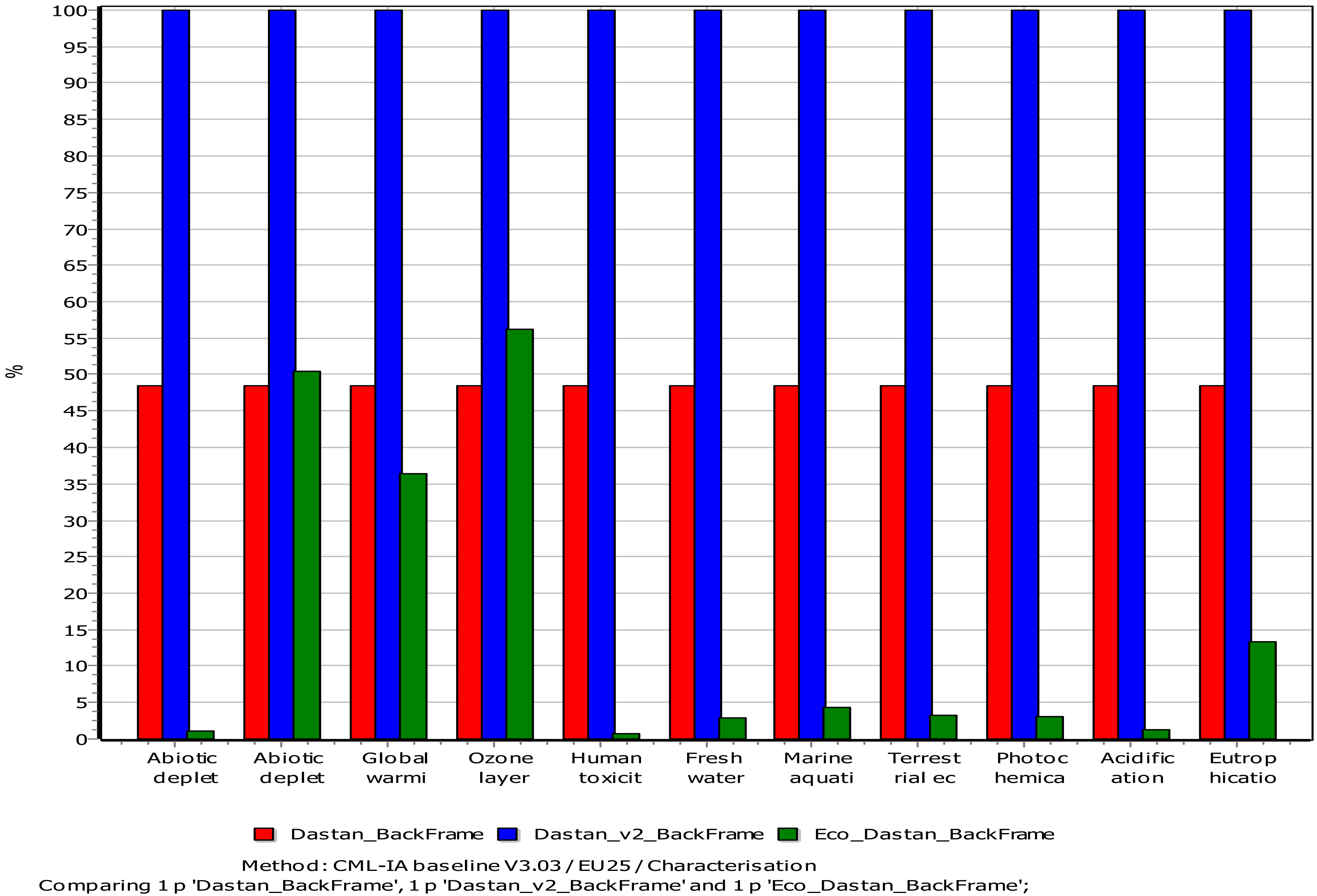

Figure 13: Related Impacts of Three Office Chairs' Back Frames LCA Study According to CML-IA Baseline Method

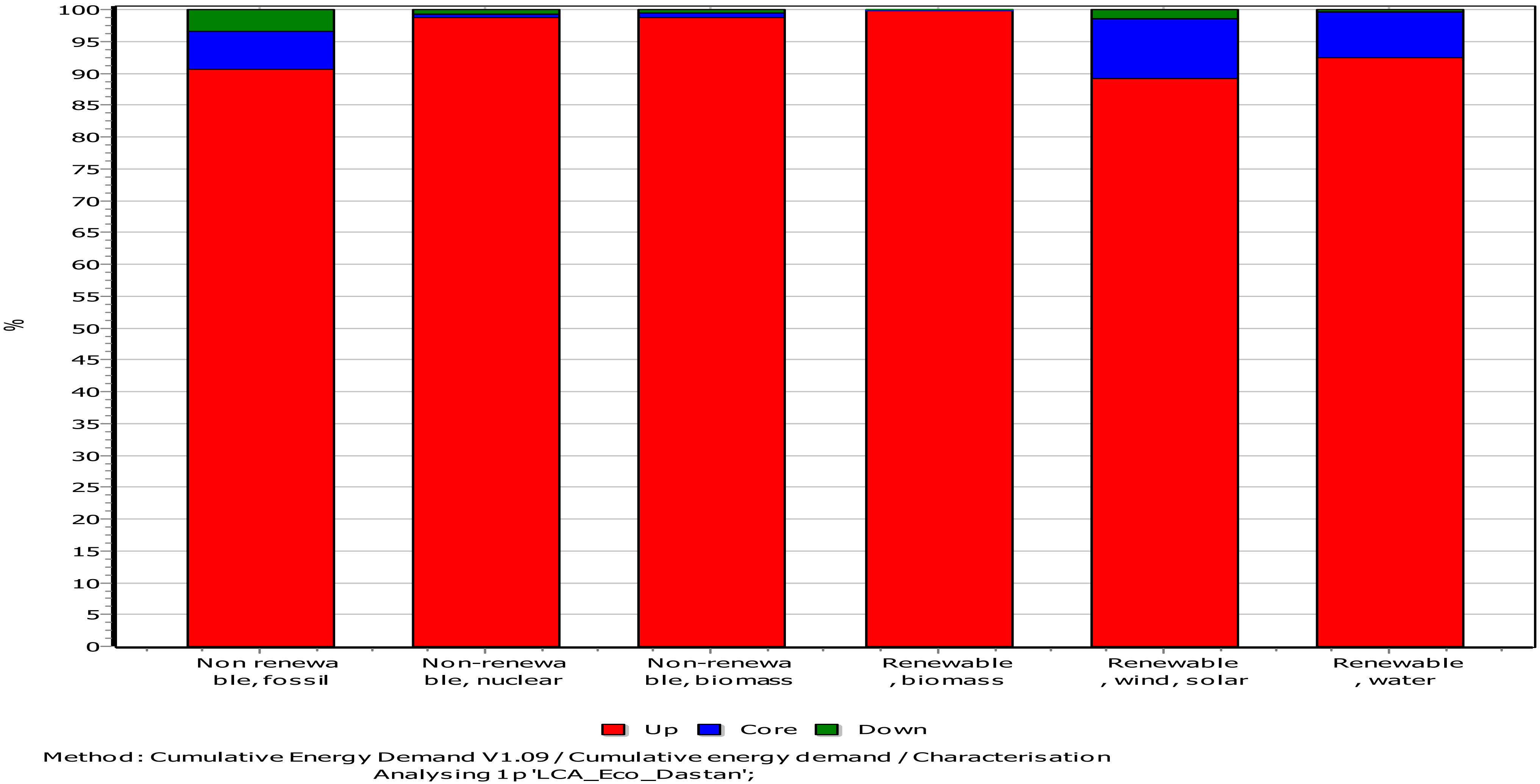

Figure 14: Cumulative Energy Demand of Eco-Dastan

APPENDIX II

Table 29: List of LCA Tools (Hannele Lehtinen et al. 2011, p. 1-24)

Tool name	Supplier	Supports LCI and/or LCIA*	Supports full LCA*	Language	Main database	Special area if any	Free?	If commercial, availability of free trials	Web page
AIST-LCA Ver.4	National Institute of Advanced Industrial Science and Technology (AIST)		Yes	Japanese	AIST-LCA database		No	No free trial available	http://www.aist-riss.jp/main/modules/product/software/nire.html?ml_lang=en
BEES 4.0	National Institute of Standards and Technology (NIST)		Yes	English	Bees database	Construction industry	Yes		http://www.nist.gov/el/economics/BEESSoftware.cfm
CCaLC Tool	The University of Manchester		Yes	English	CCaLC database including EcoInvent database		Yes		http://www.ccalc.org.uk/index.php
Eco-Bat 2.1	Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud	Yes		French, Italian, English	Eco-Bat database	Construction industry	No		http://www.eco-bat.ch/index.php?option=com_content&view=frontpage&Itemid=1&lang=en
Ecoinvent waste disposal inventory tools v1.0	Doka Life Cycle Assessments (Doka Okobilanzen)	Yes		English	Ecoinvent database	Waste management	No	Yes	http://www.ecoinvent.ch/
EIME V3.0	CODDE		Yes	English	EIME database	Electrical, mechanical and electronic products	No	Yes	http://www.codde.fr/page.php?rubrique=20
Environmental Impact Estimator V3.0.2	Athena Sustainable Materials Institute		Yes	English	Own database	Construction industry	No	Yes	http://www.athenasmi.org/
eVerdEE v.2.0	ENEA - Italian National Agency for New Technology, Energy and the Environment		Yes	Italian, English	ENEA database		Yes		http://www.ecosmes.net/cm/index-EP
GaBi 4	PE International GmbH University of Stuttgart, LBP-GaBi		Yes	English	Gabi database		No	Yes	http://www.gabi-software.com/index.php?id=85&L=0&redirect=1
GEMIS version 4.4	Oeko-Institut (Institute for applied Ecology),	Yes		Spanish, Czech,		Energy, transport,	No		http://www.gemis.de/

KCL-ECO 4.1	VTT		Yes	English			No		http://www.vtt.fi/research/technology/sustainability_assessment.jsp?lang=en
LEGEP 1.2	LEGEP Software GmbH		Yes	English, German	LEGEP database	Construction industry	No	Yes	http://www.legep.de/index.php?AktivId=1125
LTE OGIP; Version 5.0; Build-Number 2092; 2005/12/12	t.h.e. Software GmbH		Yes	German		Construction industry	No		http://www.the-software.de/ogip/einfuehrung.html
OpenLCA	GreenDeltaTC GmbH		Yes	English			Yes		http://www.openlca.org
Qantis suite 2.0	Quantis		Yes	English	Qantis database		No	Yes	http://www.quantis-intl.com/software.php?step=fonct
REGIS 2.3	sinum AG		Yes	Japanese, Spanish, German, English	ecoinvent Data v1.3:		No	Yes	http://www.sinum.com/en/products/software/
SALCA-tools	Agroscope Reckenholz-Tänikon Research Station ART	Yes		German		Agriculture		Free for tool developers, project partners. Access can be negotiated case by case with the developers	http://www.agroscope.admin.ch/aktuell/index.html?lang=en
SankeyEditor 3.0	STENUM GmbH	Yes		English			No	Yes	http://www.stenum.at/en/?id=software/sankey/sankey-intro
SimaPro 7	PRé Consultants B.V.		Yes	E.g. Spanish, French, Italian, German, English	SimaPro database		No	Yes	http://www.pre.nl/
TEAM™ 4.5	Ecobilan - PricewaterhouseCoopers		Yes	English			(Yes)	Some versions free, others have demo available	https://www.ecobilan.com/uk_team.php
The Boustead Model 5.0.12	Boustead Consulting Limited		Yes	English	The Boustead Model database		No	Yes	http://www.boustead-consulting.co.uk/
Umberto 5.5	ifu Hamburg GmbH		Yes	English	Umberto library		No	Yes	http://www.umberto.de/en/product/index.htm
USES-LCA	Radboud University Nijmegen	Yes		English		Toxic impacts between substances	Yes		http://www.ru.nl/environmentalscience/research/life_cycle/multimedia_toxic/
WRATE	UK Environment Agency		Yes	English		Municipal waste management systems	No	Yes	http://lca.jrc.ec.europa.eu/lcainfohub/tool2.vm?tid=197

Table 2: EPD Schemes (Borghi, 2013, p. 293–295)

Region	Institution	Website
Europe	The International EPD System The Norwegian EPD Foundation French Agency on Environment and Energy Management (ADEME) BRE Global Environmental Profiles Scheme (EPD) for construction products German Institute of Construction and Environment (IBU)	www.environdec.com www.epd-norge.no www.developpement-durble.gouv.fr/Product-Environme tal-Footprint.html www.bre.co.uk www.bau-umwelt.de
Asia	The Environment and Development Foundation (EDF) Japan Environmental Management Association for Industry (JEMAI) Korean Environmental Industry & Technology Institute (KEITI)	www.edf.org.tw www.cfp-japan.jp www.keiti.re.kr
North America	FP Innovations—EPD Program on Wood Products NSF National Center for Sustainability Standards—EPD The Institute for Environmental Research & Education—Earthsure EPD The Green Standard—EPD The Sustainability Consortium UL Environment—EPD	www.forintek.ca/pulic/eng/E5-Pub_Software/5a.fact_sheets.html www.nsf.org/business/sustainability_ncss/index.asp?program0SustainabilityNcs www.iere.org/earthsure.aspx www.thegreenstandard.org/ www.sustainabilityconsortium.org/ www.ul.com/global/eng/pages/offerings/businesses/environment/services/certification/epd/

Table 3: Technical Information of Dastan 30

Product Name	**Dastan 30**	
Product image		
Dimension	L: 685 mm D: 673 mm H: 950 mm	
Technical Information for Dastan 30		
Up	Arm Support	Nylon 6 glass filled
	Back Frame	Iron-Nickel-Chromium Alloy
	Back Textile	Polyethylene terephthalate
Seat	Seat Textile	Polyethylene terephthalate
	Seat Font	Polyurethane rigid foam
Down	Mechanism	Iron-Nickel-Chromium Alloy
	Gas Lift	Iron-Nickel-Chromium Alloy & Polypropylene
	Auxiliary	Iron-Nickel-Chromium Alloy
	Wheel	Nylon 6,6 glass filled
	Crossfoot	Glass fibre reinforced plastic

Table 4: Technical Information of Dastan v.2

Product Name	Dastan 30 v.2	
Product image		
Dimension	L: 685 mm D: 673 mm H: 950 mm	
Technical Information for Dastan 30 v.2		
Up	Arm Support	Nylon 6 glass filled
	Back Frame	Iron-Nickel-Chromium Alloy
	Back Textile	Polyethylene terephthalate
	Back Font	Polyurethane rigid foam
Seat	Seat Textile	Polyethylene terephthalate
	Seat Font	Polyurethane rigid foam
Down	Mechanism	Iron-Nickel-Chromium Alloy
	Gas Lift	Iron-Nickel-Chromium Alloy & Polypropylene
	Auxiliary	Iron-Nickel-Chromium Alloy
	Wheel	Nylon 6,6 glass filled
	Crossfoot	Aluminium cast alloy

Table 5: Material Details of Dastan 30

Component name	Material Name	Input Amount in kg	Output Amount in kg	Scrap Amount in kg	Rate of Loss %	Dummy Content in kg	Landfill Content in kg
Seat textile	polyethelene	2,789E-01	2,650E-01	1,395E-02	5,00	2,371E-03	1,158E-02
Seat font	polyurethane	6,947E-01	6,600E-01	3,473E-02	5,00	5,904E-03	2,883E-02
Gas lift	iron-nickel-chromium alloy	5,684E-01	5,400E-01	2,840E-02	5,00	2,627E-02	2,130E-03
	polyproplene	3,750E-01	3,600E-01	1,500E-02	4,00	2,550E-03	1,245E-02
Wheel	nylon 6.6 glass filled	9,352E-01	8,885E-01	4,673E-02	5,00	7,944E-03	3,879E-02
Mechanism	iron-nickel-chromium alloy	3,077E+00	2,800E+00	2,769E-01	9,00	2,561E-01	2,077E-02
Crossfoot	poliamide	1,632E+00	1,550E+00	8,150E-02	5,00	1,386E-02	6,764E-02
Auxillary	iron-nickel-chromium alloy	2,274E-01	2,160E-01	1,136E-02	5,00	1,051E-02	8,520E-04
Back textile	polyethelene	1,813E-01	1,740E-01	7,250E-03	4,00	1,233E-03	6,018E-03
Back frame	iron-nickel-chromium alloy	2,128E+00	2,042E+00	8,510E-02	4,00	7,872E-02	6,382E-03
Arm support	polyproplene	9,284E-01	8,820E-01	4,640E-02	5,00	7,888E-03	3,851E-02
Corrugated board box	cardborad	3,320E+00	0,000E+00	3,320E+00	100,00	1,793E+00	1,527E+00
Packaging film	low density polyethelene	8,880E-01	0,000E+00	8,880E-01	100,00	5,328E-01	3,552E-01
Total		**1,523E+01**	**1,038E+01**	**4,855E+00**		**2,739E+00**	**2,116E+00**

Table 6: Material Details of Dastan 30

Component name	Material Name	Input Amount in kg	Output Amount in kg	Scrap Amount in kg	Rate of Loss %	Dummy Content in kg	Landfill Content in kg
Seat textile	polyethelene	2,789E-01	2,65E-01	1,395E-02	5,00	2,371E-03	1,158E-02
Seat font	polyurethane	6,95E-01	6,60E-01	3,473E-02	5,00	5,904E-03	2,883E-02
Gas lift	iron-nickel-chromium alloy	5,684E-01	5,40E-01	2,840E-02	5,00	2,627E-02	2,130E-03
	polyproplene	3,750E-01	3,60E-01	1,500E-02	4,00	2,550E-03	1,245E-02
Wheel	nylon 6-6 glass filled	9,352E-01	8,89E-01	4,673E-02	5,00	7,944E-03	3,879E-02
Mechanism	iron-nickel-chromium alloy	3,077E+00	2,80E+00	2,769E-01	9,00	2,561E-01	2,077E-02
Crossfoot	aliminum cast alloy	2,07E+00	1,89E+00	1,865E-01	9,00	1,622E-01	2,424E-02
Auxillary	iron-nickel-chromium alloy	2,274E-01	2,16E-01	1,136E-02	5,00	1,113E-02	2,272E-04
Back textile	polyethelene	4,01E-01	3,85E-01	1,604E-02	4,00	2,727E-03	1,331E-02
Back frame	iron-nickel-chromium alloy	4,40E+00	4,00E+00	3,956E-01	9,00	3,659E-01	2,967E-02
Back Font	polyurethane	5,26E-01	5,00E-01	2,630E-02	5,00	4,471E-03	2,183E-02
Arm support	polyproplene	9,284E-01	8,820E-01	4,640E-02	5,00	7,888E-03	3,851E-02
Corrugated board box	cardborad	3,320E+00	0,00E+00	3,320E+00	100,00	1,793E+00	1,527E+00
Packaging film	low density polyethelene	8,880E-01	0,00E+00	8,880E-01	100,00	5,328E-01	3,552E-01
Total		**1,869E+01**	**1,338E+01**			**3,181E+00**	**2,125E+00**

Table 6*:* Energy Demand of Eco Dastan 30

Type of Energy Consumption	Station Name	Planned Production	Planned Consumption [kWh]	Energy Target Value [kWh/min]	Actual Production [min]	Actual Consumption [kWh]	Actual Distributed Consumption [kWh]	Actual Unit Consumption (EnPG) [kWh/min]	Energy Efficiency (μ)	Actaul Value of Energy Consumption [kWh/min]	Dastan 30 Lead Time [min]	Dastan 30 v.2 Lead Time [min]
Direct	Panel	3.240.000	926.883,00	0,286	2.611.238,00	789.351,20	1.432.098,72	0,548	-48%	0,302290025		
Direct	Solid wood	1.775.000	30.920,90	0,017	1.807.286,00	71.164,80	129.112,39	0,071	-76%	0,039376612		
Direct	Polishing	2.850.000	463.639,70	0,163	2.772.525,00	293.920,50	533.252,08	0,192	-15%	0,106011848		
Direct	Somat 1	4.695.000	222.738,50	0,047	4.213.693,00	191.350,41	347.161,92	0,082	-42%	0,045411569		
Direct	Somat 2	3.370.000	10.716,40	0,003	3.006.285,00	23.445,36	42.536,29	0,014	-78%	0,007798782		
Direct	Somat 3	1.345.000	30.712,13	0,023	1.378.496,00	18.367,00	33.322,76	0,024	-6%	0,013323941		
Direct	Upholstry	4.210.000	90.632,10	0,022	3.933.088,00	88.501,15	160.565,26	0,041	-47%	0,022501696	5	5
Direct	Epoxy	1.365.000	194.772,50	0,143	1.272.290,00	185.435,00	336.429,75	0,264	-46%	0,145749004	20	20
Direct	Sheet metal	1.945.000	102.669,50	0,053	1.888.844,00	138.754,24	251.738,10	0,133	-60%	0,073459873		
Direct	Metal	4.500.000	250.061,00	0,056	4.562.688,00	362.401,76	657.495,80	0,144	-61%	0,07942725	20	20
Indirect	Repair					516,41						
Indirect	Administrative building					17.676,85						
Indirect	Transportation					13.025,00						
Indirect	Technical office					5.605,13						
Indirect	Kitchen					55.053,44						
Indirect	Boiler room					179.871,52						
Indirect	Purification chamber					21.207,12						
Indirect	Compressor chamber					349.186,04						
Indirect	Maintanance					343,48						
Indirect	Other places					1.118.536,67						
	Total	29.295.000	2.323.745,73	0,079	27.446.433,00	3.923.713,08		0,143	-45%			

Table 7: Technical Information on Eco-Dastan 30

Product Name	**Eco-Dastan 30**	
Dimension	Overall	54 cm W x 54 cm H
	Seat	51 cm D x 51 cm W
	Base	54 cm D x 54 cm W
Technical Information for Eco-Dastan 30		
Up	Back Frame	Plywood for indoor use
	Back Textile	Polyethylene terephthalate
Seat	Seat Textile	Polyethylene terephthalate
	Seat Font	Polyurethane rigid foam
Down	Mechanism	Iron-Nickel-Chromium Alloy
	Gas Lift	Iron-Nickel-Chromium Alloy & Polypropylene
	Auxiliary	Iron-Nickel-Chromium Alloy
	Wheel	Nylon 6,6 glass filled
	Crossfoot	Glass fibre reinforced plastic

Table 8: Material Composition of Eco-Dastan 30

Component name	Material Name	Input Amount in kg	Output Amount in kg	Scrap Amount in kg	Rate of Loss %	Dummy Content in kg	Landfill Content in kg
Seat textile	polyethelene	2,789E-01	2,650E-01	1,395E-02	5,00	2,371E-03	1,158E-02
Seat font	polyurethane	6,947E-01	6,600E-01	3,473E-02	5,00	5,904E-03	2,883E-02
Gas lift	iron-nickel-chromium alloy	5,684E-01	5,400E-01	2,840E-02	5,00	2,627E-02	2,130E-03
	polyproplene	3,750E-01	3,600E-01	1,500E-02	4,00	2,550E-03	1,245E-02
Wheel	nylon 6.6 glass filled	9,352E-01	8,885E-01	4,673E-02	5,00	7,944E-03	3,879E-02
Mechanism	iron-nickel-chromium alloy	3,077E+00	2,800E+00	2,769E-01	9,00	2,561E-01	2,077E-02
Crossfoot	poliamide	1,632E+00	1,550E+00	8,150E-02	5,00	1,386E-02	6,764E-02
Auxillary	iron-nickel-chromium alloy	2,274E-01	2,160E-01	1,136E-02	5,00	1,051E-02	8,520E-04
Back textile	polyethelene	1,813E-01	1,740E-01	7,250E-03	4,00	1,233E-03	6,018E-03
Back frame	plywood for indoor use	8,791E+00	3,52E+00	5,275E+00	60,00	1,793E+00	3,481E+00
Corrugated board box	cardborad	3,320E+00	0,000E+00	3,320E+00	100,00	1,793E+00	1,527E+00
Packaging film	low density polyethelene	8,880E-01	0,000E+00	8,880E-01	100,00	5,328E-01	3,552E-01
Total		**2,097E+01**	**1,097E+01**	**9,999E+00**		**4,446E+00**	**5,553E+00**

Table 9: Energy Demand of Eco Dastan 30

Type of Energy Consumption	Station Name	Planned Production	Planned Consumption [kWh]	Energy Target Value [kWh/min]	Actual Production [min]	Actual Consumption [kWh]	Actual Distributed Consumption [kWh]	Actual Unit Consumption (EnPG) [kWh/min]	Energy Efficiency (µ)	Actaul Value of Energy Consumption [kWh/min]	Eco Dastan 30 Lead Time [min]
Direct	Panel	3.240.000	926.883,00	0,286	2.611.238,00	789.351,20	1.432.098,72	0,548	-48%	0,30229	
Direct	Solid wood	1.775.000	30.920,90	0,017	1.807.286,00	71.164,80	129.112,39	0,071	-76%	0,039377	15
Direct	Polishing	2.850.000	463.639,70	0,163	2.772.525,00	293.920,50	533.252,08	0,192	-15%	0,106012	
Direct	Somat 1	4.695.000	222.738,50	0,047	4.213.693,00	191.350,41	347.161,92	0,082	-42%	0,045412	
Direct	Somat 2	3.370.000	10.716,40	0,003	3.006.285,00	23.445,36	42.536,29	0,014	-78%	0,007799	
Direct	Somat 3	1.345.000	30.712,13	0,023	1.378.496,00	18.367,00	33.322,76	0,024	-6%	0,013324	
Direct	Upholstry	4.210.000	90.632,10	0,022	3.933.088,00	88.501,15	160.565,26	0,041	-47%	0,022502	3
Direct	Epoxy	1.365.000	194.772,50	0,143	1.272.290,00	185.435,00	336.429,75	0,264	-46%	0,145749	20
Direct	Sheet metal	1.945.000	102.669,50	0,053	1.888.844,00	138.754,24	251.738,10	0,133	-60%	0,07346	
Direct	Metal	4.500.000	250.061,00	0,056	4.562.688,00	362.401,76	657.495,80	0,144	-61%	0,079427	20
Indirect	Repair					516,41					
Indirect	Administrative building					17.676,85					
Indirect	Transportation					13.025,00					
Indirect	Technical office					5.605,13					
Indirect	Kitchen					55.053,44					
Indirect	Boiler room					179.871,52					
Indirect	Purification chamber					21.207,12					
Indirect	Compressor chamber					349.186,04					
Indirect	Maintanance					343,48					
Indirect	Other places					1.118.536,67					
	Total	29.295.000	2.323.745,73	0,079	27.446.433,00	3.923.713,08		0,143	-45%		