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Carbon Footprint and Environmental Documentation of Product - A Case Analysis on Road Construction

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MASTER THESIS

for

Master Student Laxmi Panthi

Field of study	Industrial Ecology
Start date	17. January 2011
Title	Carbon Footprint and Environmental Documentation of Product – A Case Analysis on Road Construction
Purpose	The purpose of this study is to look at systems for documentation of the environmental burden of a product. The study will have a specific focus on carbon footprints based upon life cycle assessment, and further illustrate how this can be integrated in documentation systems for product.

Main contents:

1. Give an overview of the existing systems for environmental documentation of product.
2. Give an overview of the current work and standardization of carbon footprint quantification and documentation and relate to EPD
3. Use systems theory to describe how to model a product system
4. Develop a methodology on how to calculate and document carbon footprints for system, discuss challenges related to system boundaries and aggregation models
5. Test the methodology on case-examples
6. Suggest recommendations for carbon footprint as part of the EPD system

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Acknowledgement

This study is a part of the international master study programme in Industrial Ecology at the Norwegian University of Science and Technology (NTNU), Trondheim, Norway. The research of this thesis is to apply industrial ecological perspectives within the area of environmental quantification and documentation through environmental analysis. In this regards, as a case road construction is used.

In this respect, I have been privileged to get support from many persons. First and foremost, I would like to give sincere thanks to my supervisor Professor Annik Magerholm Fet for her support, encouragement, valuable feedbacks and guidance. I would also thankful to Mr. Christofer Skaar, PhD research fellow at the Department of Industrial Economics and Technology management of NTNU. His feedback and constructive discussions in some aspect of the thesis were valuable.

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Abstract

Environmental accounting and documentation of each industry and organization is required for the sustainable development. In addition, environmental awareness is creating pressure to the industry to declare and label environmental features of their product to the consumers. Industrial products interact with environment during entire life cycle of a product and consequences are undesirable environmental impacts. The solution for minimum environmental impacts is the development of methods and tools to measure and compare environmental impacts of products (goods and services are summarized under the term product according the ISO 14040). ISO 14020 series, ISO 14025 - environmental declaration, ISO 14024 - environmental label, and ISO 14021 - self declared environmental claim are facilitating to the industry to communicate environmental impacts of their product. At present, global warming and it's consequences in climate change are major concerns of environmental impacts for the global society. One specific means to communicate global warming environmental impact is 'carbon footprint' of the product, which can be declared to the consumers following the methodology of upcoming ISO 14067- carbon footprint of products. Life cycle assessment is the back bone for industries to quantify environmental impacts, and to document and declare environmental impacts of production activities.

This thesis reviews existing environmental documentation system of product, accesses ISO standard for carbon footprint of product and relates it to the environmental product labeling and declaration (EPDs), develops system theory to model a road case system for carbon footprint, calculates carbon footprint of the road construction case and recommends carbon footprint as part of environmental product declaration (EPD).

The thesis starts with reviewing existing environmental documentation and carbon footprint accounting systems with a main focus on ISO requirements. The thesis further discusses system theory of industrial ecology to account carbon footprint of the products. System engineering and LCA methodology are taken as tools to account carbon footprint of the products. Road construction case E6 – Kroppen – Tonstad, Trondheim, is taken as case for the carbon footprint account, which is a part of transportation service. Finally, discussions are made on the connection between environmental declaration and carbon footprint, issues of ISO 14067 – carbon footprint of product, system boundary and data aggregations for LCA methodology for road case.

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Abbreviations

CF	Carbon Footprint
CFP	Carbon Footprint of Product
CML	Institute of Environmental Science (Nederland)
CO	Carbon mono-oxide
CO2	Carbon dioxide
COP	Convention of the parties
CSR	Corporate Social Responsibility
EPD	Environmental Product Declaration
GHG	Greenhouse Gases
GRI	Global Reporting Initiatives
GWP	Global Warming Potential
IOA	Input Output Analysis
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
LCGGE	Life Cycle Greenhouse Gas Emission
LCI	Life Cycle Inventory
MFA	Material flow analysis
NO2	Nitrogen dioxide
NOx	Nitrogen oxide
OECD	Organization for Economic and Co-operation Development
PAHs	Polycyclic aromatic hydrocarbons
PAS	Publicly Available Specification
PCR	Product Category Rules
SE	System Engineering
SO2	Sulphur dioxide
UN	United Nations
UNDP	United Nation Development Program
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework for Climate Change
VOCs	Volatile organic compounds
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WCS	Wild Life Conservation Society
WHO	World Health Organization
WRI	World Resource Institute

Terms and definition

Product: Any goods and services are collectively called product (ISO 14040).

EPD: Environmental labels and product declarations / Type III Environmental declarations according to ISO 14025.

EPDs: Environmental labels and declarations / Type I, type II and type III according to ISO 14020.

Carbon footprint: Net amount of greenhouse gas emission and greenhouse gas removals, which is expressed in CO2 equivalent.

Carbon footprint of product: Carbon footprint covering all stages of a product.

Partial carbon footprint: Carbon footprint of selected process of a product system. Partial carbon footprint covers only selected one or more processes of the product system.

Greenhouse gas: Greenhouse gas includes among others carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) (ISO/ CD 14067).

Global warming potential: Factor describing the radiative forcing impact of one mass-based unit of a given greenhouse gas relative to an equivalent unit of carbon dioxide over a given period of time (ISO/CD 14067). A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). For example, 100 years GWP of methane is 25, which means if same weights of methane and carbon dioxide were introduced into the atmosphere, and methane will trap 25 times more heat than that of carbon dioxide over the next 100 years.

Life cycle perspective: Consideration of life of product from extraction of raw material to processing, transportation, manufacturing, uses and end of life disposal.

Chapter 1: Introduction

1.1 Background

In the process of development people invented energy and extracted natural resources for the purpose of industrial production. Industrial production and related development activities rapidly increased during last century. Since long back development was understood as economic prosperity and industrialized society. It was beyond the thinking of human that their creativity will create another great problem for the existence of same human being. The problem of industrial economy began to be seen in around 1950. It was only realized when Rachel Carson's published book in 1962 called "Salient Spring". In this book Rachel Carson writes about environmental consequences of herbicides and pesticides. After this incident the era of environment began. The revolution on environmental protection and management was initiated rapidly from late 1980s while the effect of industrial activities in environment appeared in the form of hole in the ozone layer, global warming, acid rain, drought and human health disorder (Welford, 1996). Trans-boundary natures of different environmental impacts have consequences varying from local to global scale. As a consequence the old concept of development now is changed to the sustainable development that gives equal importance to economic, social and environment aspects.

It is good that the demand for sustainable development is increasing due to conscious people around the world. Aware people alert industry to consider environmental and social issue right from the beginning since they are the one who benefits the most from their industrial activities. Likewise, educational disciplines regarding natural resource management, environmental science and sustainable development studies started from secondary school to university educational system. Industrial ecology is one of the educational disciplines that focus environmental aspects of industrial system. Within this discipline Life Cycle Analysis (LCA), Material Flow Analysis (MFA) and Input Output Analysis (IOA) are developed tools that are being used for the quantification of the environmental impacts. In parallel, many national and international environmental organizations have been established, many researchers started to devote their time to develop concepts for sustainable development. One of the achievements in sustainable development is the effort of International Organization for Standardization in the development of series of environmental related international standards (ISOs). Brattebø et al (2007) states that ISO 14000 series related to environmental ISOs and industrial ecological tool LCA are the back bone for environment management and analysis.

LCA is the base for ISO series 14020 - Environmental Labels and Declarations and emerging ISO 14067 - Carbon footprint of products. These ISOs and industrial ecological tool LCA encourage businesses to declare environmental impact of their product in clear quantitative figure. Quantitative environmental impact statement is more effective for self awareness of business community and consumer. Quantitative information facilitates people to evaluate their activities and makes them responsible against environmental degradation. These tools and mechanism are encouraging industry to consume less energy and resource for their production and assist consumer's decision to purchase sustainable products (goods and services). According to Fet et al (2009) it is very important to label the product which encourages both business and consumer to choose environmentally friendly products.

ISO 14020 series and newly coming ISO 14067- Carbon Footprint of Products are made for environmental declaration of product. Similarly, few other standards, for example, British Standard for greenhouse accounting and greenhouse protocol from World Business Council are also developed to count carbon footprint. The aim of ISO 14067 is to develop similar system all over the world with the aim to eradicate confusion and dilemma on carbon footprint accounting system from available many standards from different organizations. This type of dilemma should be minimized. This study sets the research question ***"What is the importance of coming standard ISO 14067- Carbon Footprint of Product in relation to environmental labeling and declaration?"*** The research question will be discussed with illustration of one road case example on Carbon Footprint. Product refers to both goods and service according to ISO 14040. Carbon footprint accounting and documentation method is different for different products. Here road as transportation infrastructure is taken for the case study and presented methodology on how company can document by calculating carbon footprint of product step by step. The methodology is applied in defined system boundary of the road construction case.

Ultimate aims of environmental related tools, discipline and ISOs are to create sustainable development preserving earth for future generation. But people in societies are more consumable than before and industry is producing more products today than yesterday to meet growing demand from new consumers. Every responsible person, industry and nation should be aware on how long the earth can sustain such existing pattern of development. Everybody must realize and provide serious commitment on second massage of Brundtland Commission's opening speech for the report "Our Common Future", at Nairobi 1987. The speech states "*Change is not necessary, it is also possible. Humanity has the knowledge, technology, ingenuity and resources. What we need is new concepts, new values and to mobilize will. We need global ethics*" (Brundland, 1987).

1.2 Thesis objectives

The purpose of this MSc study is to look at the system for documentation of the environmental burden of a product. The study gives specific focus on carbon footprints based on life cycle assessment. It further illustrates how this can be integrated in documentation systems for a product. As a study objective road construction is selected as a case to look carbon footprint of transportation service.

Hence, the goal of this MSc study is categorized by following main objectives:

1. to review existing environmental documentation system of product
2. to access ISO standard for carbon footprint of product and relate it to the environmental product labeling and declaration (EPDs)
3. to present system theory to model a case system for carbon footprint
4. to propose carbon footprint mapping methodology and discuss challenges related to system boundaries and aggregation models
5. to calculate carbon footprint of the case
6. to recommend carbon footprint as part of environmental product declaration (EPD)

1.3 Case selection

This thesis work takes Road as a case, which is important infrastructure for transportation service, and looks on carbon footprint from construction phase of life cycle phases of the road. The issue is discussed as product declaration in relation to carbon footprint. System thinking is considered as essential approach for accounting carbon footprint of whole system of a product.

Even though, all life phases are connected for the complete carbon footprint of a product in regards with system thinking, only construction phase of the case road is covered due to time and resource data constrains. Nevertheless, life phases of the road are presented to show the whole system of the road before presenting construction phase in detail.

There are many tools that are available to quantify environmental impacts of the products. LCA methodology, one widely used tool, is applied to map the carbon footprint of road construction case. The case is selected from Trondheim city, Norway

The case is the extension of bus lane in E6 between Kroppen and Tonstad, which is located about 8 km south of Trondheim (Figure 7-1). The owner of road project is *The Norwegian Public Roads Administration*. The project name is given as “E6 Kroppan – Tonstad - New Bus Lane”. The project construction is planned to start by alte May and planned to be finished by the end of August 2011. Therefore, used material input information of the case is estimated data. The information related to case is obtained from personnel in Statens vegeves, Trondheim, through direct discussion and e-mail correspondence.

1.4 Research concept and approach

The research concept and approach for this thesis is application of system thinking principle of industrial ecology. Industrial ecology studies the flow of material and energy during production (construction in the case of infrastructure), consumption and decomposition of the product and it's interaction to social and natural environment. Industrial ecology argues that environmental problem can be minimized or solved through holistic approach that means all related elements should be treated inside one system during the analysis. Holistic approach helps to find environmental cause effect relations with clear view. Different developed standards and mechanism for environmental declaration are also recommended to look holistic perspectives. For example, ISO series related to environment is suggested for analyzing environmental impacts of product and service considering life cycle phases of the respective product. This research therefore talks all life phases of a case following the principle of industrial ecological system thinking, but construction phase of the case and it's impact are main scopes of the study.

The conceptual model of the study is presented in Figure 1-1. Beginning point of the research is to find existing environmental accounting and documentation system till now and it's brief presentation. Among many systems, ISO series 1420- Environmental Labeling and Declaration of product and newly coming ISO 14067 - Carbon Footprint of Product is covered in detail. ISO series 14020, which include all environmental impacts along climate change already exists. In this circumstance, the significance of new ISO 14067 is very important study. Therefore, draft version of ISO 14067 is reviewed and attempts are made to find out relation between this and ISO series 14020.

ISO series 14020 are already developed standards, which are adopted by many industries while ISO 14067 is under it's development stage. Therefore, it is important to review ISO 14067. LCA methodology and system engineering principles are presented as useful step by step process for carbon footprint accounting and documentation system. Among different system thinking approaches, system engineering approach purposed by Fet (1997) is considered for the accounting and documentation of carbon footprint of a product and service. System engineering approach facilitates to look the case through system perspectives. Quantitative aspect of system engineering is fulfilled by applying quantitative tool LCA.

According to ISO 14040 a product covers both goods and service sector. For the research purpose, transportation service is selected as case study. Carbon footprint accounting and documentation method for road construction is hence discussed in detail. The study focuses on the road case with system engineering perspectives. System of the road infrastructure is discussed and documentation of carbon footprint of road construction through system engineering principle is presented. Carbon emission of the case system is analyzed using system thinking methodology LCA. GaBi computer software is used as LCA tool for data processing.

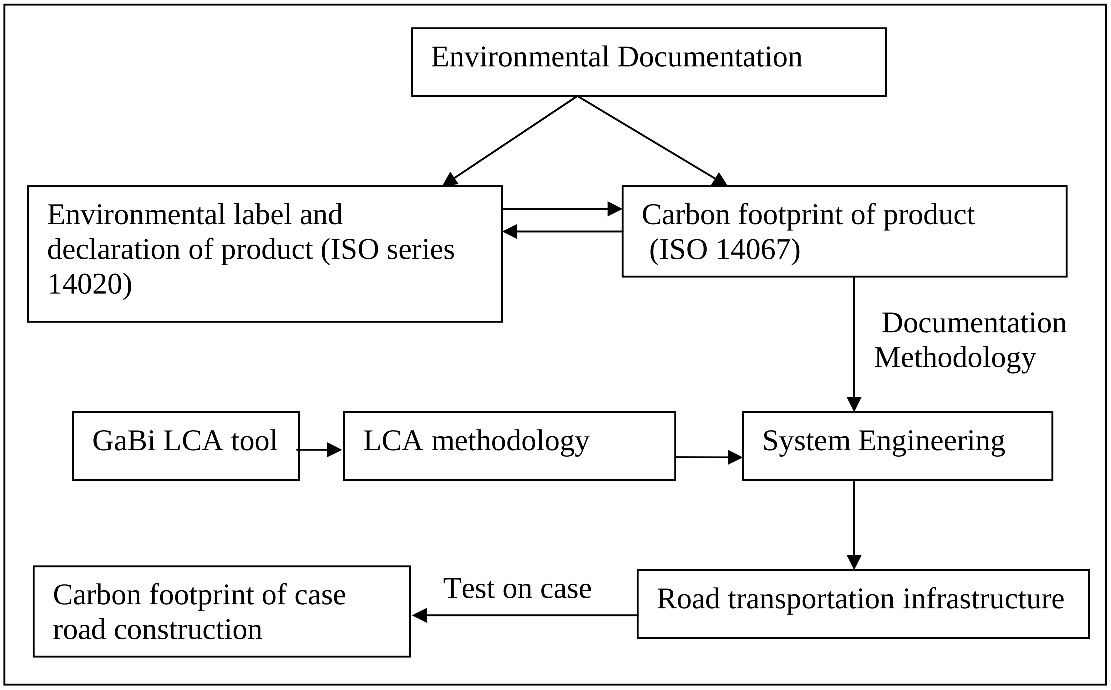

Figure1-1: Conceptual model of the study

Carbon footprint is also recommended to include in existing environmental product declaration (EPD) system along with other environmental declarations.

1.5 Chapter outline

The whole study is divided mainly in four parts. Part one is introduction (Chapter 1) that covers background, objectives of the study, case selection and research concept.

Part two of the thesis mainly includes literature review, which is covered in Chapters 2, 3 and 4. Chapter 2 discusses the research methodology that is applied for the research. Chapter 3 is the presentation of background theory for the environmental documentation. Chapter 4 is the overview of the existing environmental documentation system, which mainly presents ISO recommended EPD system and upcoming ISO 14067 for carbon footprint.

Part three of the thesis is the presentation of road as transportation service and carbon footprint analysis of the case road construction, which is covered in Chapters 5, 6, 7 and 8. Chapter 5 discusses road system, which is a part of transportation service. In addition, Chapter 5 discusses possible environmental aspects of road construction. Chapter 6 is the presentation of frame work or methodology for the documentation of carbon footprint of the road case. The frame work is a combination of system engineering and life cycle analysis (LCA) methodology. The framework is applied in Chapters 7 and 8. Chapter 7 discusses the case in detail through system perspectives. Chapter 8 covers carbon footprint analysis of the case road with the application of LCA methodology.

Part four of the study includes discussions, conclusion and recommendation, which is covered in Chapters 9 and 10, respectively. Chapter 9 is the discussion chapter. Discussion is carried out on the findings of part two and part three. Last section of the discussion covers fulfillment of the objectives. Chapter 10 is the conclusion and recommendation.

Chapter 2: Research methodology

Mixed research methodology, i.e. both qualitative and quantitative methodology, is applied to complete the research. Collected information and data are analyzed through descriptive perspectives, system engineering principles and by the use of LCA methodology. Detail of each procedure is discussed in this chapter.

2.1 Mixed methodology

This study has adopted both qualitative and quantitative methodologies through different stages of the research process. Combination of qualitative and quantitative methodology is understood as mixed methodology. Mixed method of research is defined by Johnson and Onwuegbuzie (2004) as "*the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study*."

Qualitative method: Qualitative method of research emphasis words rather than numbers in the collection and analysis of data (Bryman, 2008). For this research, presentation of existing system of environmental documentation and communication system in Chapter 4 are qualitative approach of the study. Qualitative method focuses more on the Environmental labeling and declaration of products and services as well as Carbon Footprint of the products and services. Application of system engineering principles for carbon footprint accounting and documentation in transportation infrastructure is presented qualitatively. Qualitative method used in achieving research objective is based on secondary information. Techniques for secondary information collection are described in Chapter 2.2.

Quantitative method: Quantification of collected data and analysis of quantified data are quantitative method (Bryman, 2008). Carbon footprint accounting of a case is quantitative approach. Quantitative data are collected through primary and secondary sources. Material information for carbon footprint calculation is received from *Statens Vegvesen*, The Norwegian Public Roads Administration. Emission data for carbon footprint are obtained from existing data base given in GaBi software. The quantitative data are analyzed with application of Life Cycle Analysis (LCA) methodology. To perform LCA methodology, LCA program tool GaBi is used as supporting software. LCA methodology and working approach through GaBi is discussed in Chapter2.3

2.2 Data and information collection

A. Literature review: *"The literature is usually concerned with the research and study subject matter. The purpose of the literature review is to establish academic and research areas which are of relevance to the subject of the research"* (Oliver, 2004). Information for introduction, background theory and other qualitative presentation of the study are outcome of literature review. Relevant scientific journal papers, conference papers and books are the source for the literature review.

B. Internet search: Different relevant internet sites are visited to collect secondary information. Internet sites of International Organizations for Standardization and Norwegian Public Road Administration are frequently visited.

C. ISO review: For the research objective, environmental related ISOs are studied. ISO related to Environmental labeling and declaration (ISO 14020, ISO 14021, ISO 14023 and ISO 14025) and ISO 14067- Carbon footprint of products (committee draft) are mainly reviewed. In addition, other environmental related standards are also used as source of information for qualitative analysis.

D. Discussion: *"Group interview, questionnaire and open questions are the mechanism for the discussion"* (Morgan, 1996). Information from discussion is used during presenting Carbon Footprint of products and services. Open discussions with Professor Annik M. Fet and researcher Cristofer Skaar are made to get updated information about ongoing work for upcoming ISO 14067- Carbon Footprint of Products. Discussion with personnel from Statens Vegvesen is carried out to get case information.

E. Case study: A case study is a collection of information and data that investigate the existing happening form real case context. Case study research can be based on mixture of quantitative and qualitative approaches. Typically, it uses multiple data sources including two or more of direct detailed observations, interviews, and documents. In addition, case studies can involve single or multiple cases (Rowley, 2002).

Single case is studied in this MSc research. For this a road project is chosen. The owner of the case is Norwegian Public Roads Administration, *Statens Vegvesen*. This case is the outcome of series of communication made by the researcher with different personal working at Statens

Vegvesen since the researcher had great interest in carrying out MSc study related road transport. Quantitative methodology is applied for the analysis of the case.

2.3 Analysis

The next step after data collection and processes is to carry out the analysis of data and information collected. Information on Environmental labeling and declaration and Carbon footprint of products are analyzed by Descriptive perspective. System Engineering (SE) principle is purposed for the Carbon footprint accounting and documentation framework for road construction. The case is defined and analyzed applying system engineering principles. Similarly, quantitative data are analyzed with LCA methodology in the system engineering step 4 “Analyze and optimize”. Computer software program GaBi is used as tool for LCA. In the following brief discussions are made on system engineering principles, LCA methodology and GaBi software.

2.3.1 System engineering

The definition of system is discussed in Chapter 3 in brief. There are different types of systems such as natural systems, manmade systems, physical systems, closed system and open systems, static and dynamic systems etc. Blanchard (2008) mentions that all man-made systems are embedded in the natural system; there are numerous interfaces that must be addressed. The objective of this research is to look on the manmade system that comprises road transportation system and its interaction with the natural system. Among numerous interactions, carbon emission from road construction and its interaction to natural system is the main focus.

System engineering is the concept, which deals the system throughout its projected life cycle and system engineering process and is applicable in all phases of the life cycle (Blanchard, 2008). System engineering is such an analytical and management tool, which deals with the performance of a system. System performance may be presented both qualitatively and quantitatively. According to Blanchard (2008), Haskins (2008) and Fet (1997) there are different types of system engineering processes purposed. Fet (1997) has applied simplified six step system engineering methodology (Figure 2-1) in several environmental analysis studies for the optimization of environmental performance of industrial system. This MSc study considers system engineering approach as appropriate model in accounting, documentation and reporting of carbon footprint of the products and services. These system engineering steps are applied to develop the framework of carbon footprint documentation of the case. On the basis of this frame work, case is introduced and carbon footprint of the case is analyzed. Carbon footprint is considered as performance of a case system. Since Carbon footprint is one of the environmental performances, the system engineering method proposed by Fet (1997) is used (Figure 2-1).

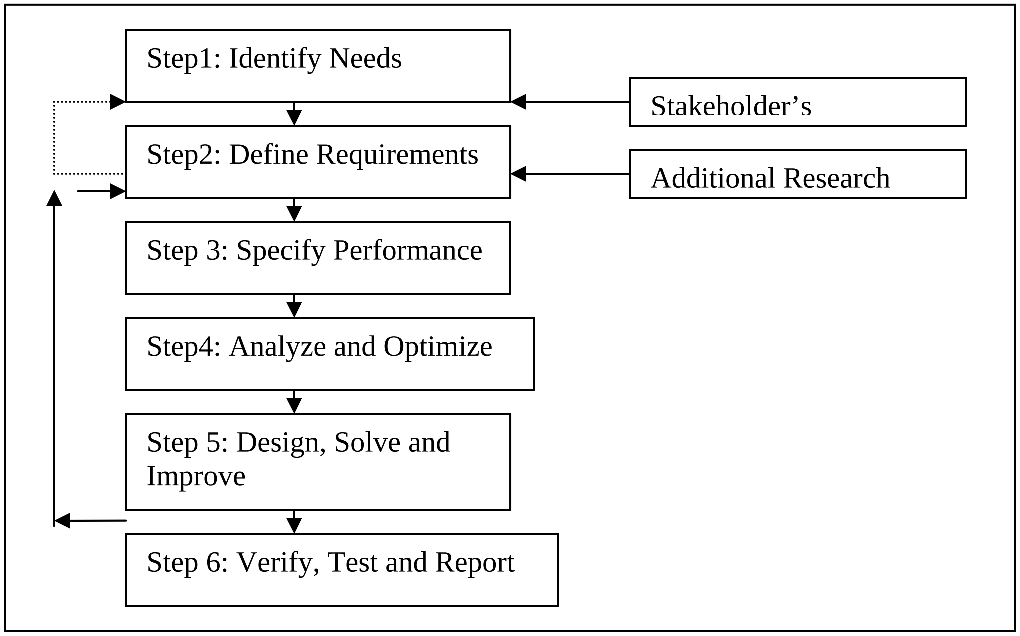

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Figure 2-1: System engineering process (Fet, 1997)

Step1. Identify Needs: Need is identified on the basis of feedback and demand of stakeholders. Stakeholders are those who are directly and indirectly involve in organizational (system) activities. According to Freeman (1984), "*A stakeholder is any group or individual who can affect or is affected by the achievement of the organization's objectives*". The stakeholder of the system could be the owner, user group, customers, market, civilian, and government. Need of the stakeholders are defined in answers of three questions consisting; 1) what is needed?, 2) why is it needed? and 3) how may the need be satisfied?. The statement of need may be qualitatively or quantitatively presented. The need may be more than one and is dependent on the demand of stakeholders.

Step2. Define Requirements: In this stage, requirement of the system is defined in such that the need of the stakeholders is addressed. Need and requirement are related to each other because the need defines the requirement. Functional, operational and physical performance requirements for each need are defined. These requirements should satisfy the three questions of need, respectively. While environmental performance of the system is the need, environmental aspects of system throughout the system function is the requirement.

Step3. Specify Performance: The next step after defining need and requirements is specification of performance. Performance should satisfy the need of the stakeholders. In this stage whole life cycle activities of the system must be described. Functional and operational relation between sub-systems or among sub-systems and elements are illustrated. Performance may be presented as whole system or sub-system, which depends on the need statement. In this step, flow chart may be created to illustrate and describe the life cycle activities of the system. If environmental performance of the system is the need, one of the performance specifications could be total CO2 emission from the system.

Step4. Analyze and Optimize: In this step system performance is evaluated and analyzed. In comparative analysis different system alternatives for same function are analyzed and optimized for further design. Various mathematical techniques and tools are useful. LCA is one of the helpful mathematical analysis tools in this step and next step of system engineering to evaluate environmental performance of the system. If the performance specification is set with quantitatively defined term, analyses and optimization process should be repeatedly carried out until required performance specification is met. For this various system design alternatives are established. If the performance is specified just for the documentation than studied different alternative systems are purposed. In this stage input and output from the system are illustrated in flow chart. Its interaction with environment is discussed.

Step5. Design, Solve and Improve: Based on preliminary system design, detail design phase begins. In this stage, the involvement of multidisciplinary team is crucial. If the system is large and different sub-systems and elements are connected on it then experts of different sub-system are needed to be involved to know how the system functions and reacts with the environment. Data are collected according to preliminary design.

Step6. Verify, Test and Reporting: In this step, detail design is implemented and verified with the design documentation. Report is prepared and feedback is given to the design. Improvement of the system is made if needed following the feedback.

2.3.2 LCA methodology process

LCA is a tool to map environmental impacts of a product or service over a life time from raw material extraction and acquisition, materials processing and manufacture, material transportation, product fabrication & transportation, distribution, operation, consumption, maintenance, repair to finally product disposal/scrapping (Shama, 2005). Therefore, LCA adopts not only single process but also all processes of the system that analyzes entire life cycle of a product. LCA describe environmental impacts in quantitative terms. It is an environmental decision support tool.

It is useful for the product policy like green procurement, product design for environmental declaration and carbon footprint accounting. According to ISO 14040, the use of LCA is relevant for Product development and improvement, strategic planning, public policy making, Marketing and others. New upcoming ISO 14067- Carbon footprint of products has recommended the LCA methodology to account the carbon footprint of a product.

ISO 14040 explains that the LCA describes environmental aspects and potential impacts throughout a product's life cycle. In LCA concept, product refers both to goods and also to services. The process of LCA is discussed here.

The LCA process consists four systematic phases consisting goal definition and scoping, inventory analysis, impact assessment, and interpretation (Figure 2-2).

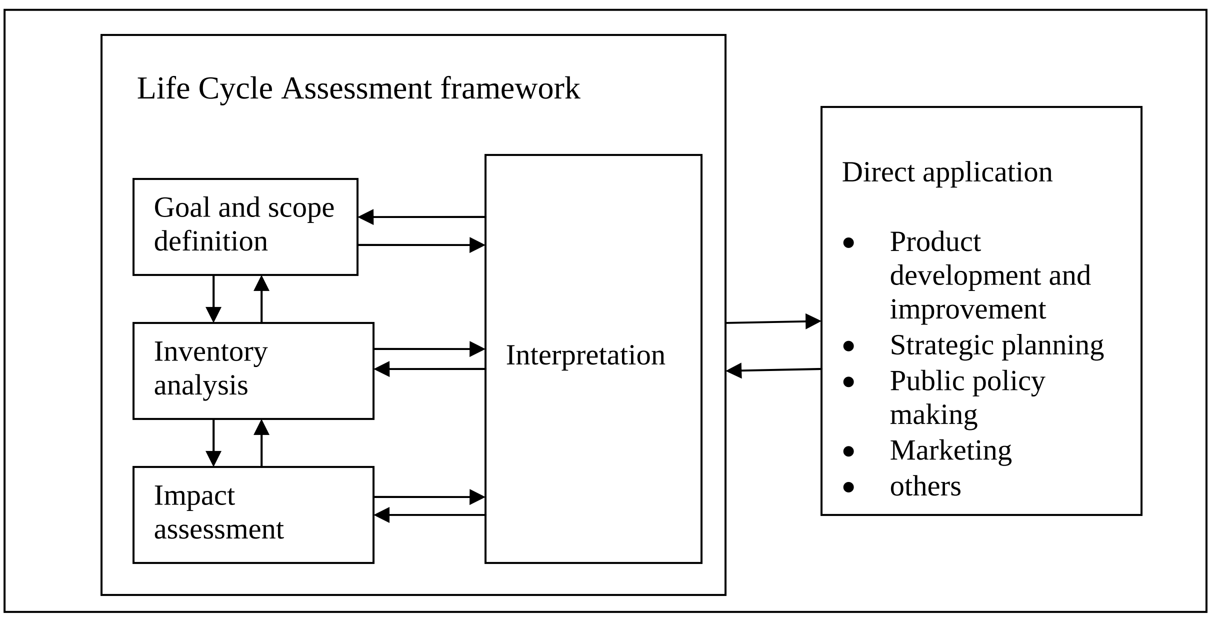


Figure 2-2: Elements of LCA according to ISO 14040- 2006

(I) Goal definition and scoping

The product, process or activities are defined in the goal and scope definition. According to ISO standard (ISO 14040) the goal definition has to include objectives, reasons and to whom results are intended to be communicated must be clearly defined. Establishment of study boundary should be cleared for the assessment in this phase. Production and process activities that have environmental effects are considered to be the part of the system boundary. System boundary always follows the goal of the study. The depth of the goal determines the range of the system boundary. System boundary generally presented in flow diagram showing the unit processes and their inter relationship.

In addition, it needs to pay attention on *functional unit* at this phase. LCA results are always analyzed relating to functional unit. Functional unit is especially important when products are compared. For example, if we have to compare carbon footprint of energy from bio fuel and diesel fuel. For instance, functional unit can be one km car driving. LCA of both bio fuel and diesel fuel to operate one km car should be done separately and conclusion should be made on the best one that is based on the finding on carbon footprints performance.

(II) Inventory analysis

It is an identification and quantification of energy, water, resources and materials use and environmental releases i.e. air emissions, solid waste disposal, waste water discharges etc. (for carbon footprint GHGs releases, storage and capture) during the life period of a product. At this stage, system model is fixed according to the identified system boundaries. The system boundary includes main production sequence, extraction of raw materials, handling, transportation, production and use of fuels, energy, resources and disposal of all process wastes (Shama, 2005). Coordination among actors involved in production sequences is necessary to identify inputs and outputs of material flow of a product system. The input and output is allocated to different product in this step. Where allocation is important, the input and output of the system should be partitioned between its different products or functions. Allocation procedure for reused and recycled materials is mentioned in ISO 14044: 2006. Inventory data are collected form site specific or from past documentation. Collected inventory data are related to unit process or functional unit (ISO 14044, 2006).

(III) Life cycle impact assessment

Impact assessment estimates the potential human and ecological damage and resource depletion of energy, water and material. Impact depends upon the nature of emissions that come from a product (Shama, 2005). Impact assessment is often divided into mandatory and optional having following sub steps. In the case of carbon footprint, all greenhouse gases are related to global warming potential.

***Classification*:** Classification means sorting inventory parameters according to the selected environmental impact categories. For carbon footprint, all green house gases are sorted.

***Characterization*:** It is defined as the calculation of the relative contributions of emissions and resource consumptions to each type of environmental impact. Emissions related to impact categories are aggregated. Acidification, eutrophication, global warming, ozone layer depletion are examples of impact categories. Different system impact categories are available like CML 2001, Eco-indicator 99 and EPS 2000. Global warming potentials gases are multiplied by related characterization factor in unit kg CO2 equivalents per kg emission. Major six Global warming potentials gases which are covered in Kyoto Protocol and their characterization factors according to IPPC are mentioned in table2-1.

Table2-1: Global warming potential of greenhouse gases covered in Kyoto Protocol (committee draft ISO 14067, 2011)

Common name	Chemical formula	GWP for 100 year time horizon
Carbon dioxide	CO2	1
Methane	CH4	25
Nitrous oxide	N2O	298
Hydrofluorocarbons	CHF	124 to 14,800
Perflurocarbons	CF	7,390 to 12,200
Sulfur hexafluoride	SF6	22,800

***Normalization*:** Normalization is an optional step in life cycle impact assessment. In this step, the result from characterization is related to relative contribution from system to impact indicators. Total early emissions for a reference year in a reference region are normally used to calculate normalization figure. The region may be global, regional, national or local (ISO 14040). The world (1990 and 1995), The Netherlands (197/1998), Western Europe (1995) are some available examples of reference situation (Huijbregts et al, 2002). It is mandatory for detailed LCA (Simapro 7, 2004).

Valuation / Weighting: Valuation is an optional step in LCA that groups and weights the impacts. It is related with the question of relative importance of various impact categories, for example, acidification versus global warming versus resource depletion. Total environmental performance of the system is presented in one value.

This step is not demanded for Carbon footprint accounting and reporting system according to ISO 14067. Because, Carbon footprint accounting system only considers global warming potentials and there is no comparison with other impact categories.

(IV) Interpretation

Interpretation is an evaluation of results from the inventory analysis and impact assessment. In this stage, environmental performance of the products is analyzed and interpretation is made considering the purpose of LCA. Feedback is suggested on the basis of identified significant issues. Feedback may be redesign of the product process, suggestion to take least environmental impact approach, minimization of consumption and waste management. Feedback is the reflection of objectives and scope of the analysis (Welford, 1998). Results should be presented in such a way that the decision maker understands LCA language. In addition uncertainty on quantitative or qualitative assessment, limitations during assessment are also recommended to include in reporting process in the case of carbon footprint of a product.

2.3.3 GaBi software

GaBi is supporting software for Life Cycle Analysis of product and services. GaBi claims that PE provide over 2,000 cradle to gate material data sets, 8,000 intermediary chemical process modes and thousands of LCA project from quality controlled industry projects. Different package are offered by PE.

Educational version GaBi LCA software tool is applied to have emission information of material. Primary Life Cycle Inventory data are entered into GaBi and in the absence of primary data secondary data from GaBi database are used to locate input output flow in model.

Each product process is modeled separately by entering input and output flow to the process. Output flow of each process is connected to another product process. Connection of different product process to end product is processed in GaBi plan. GaBi plan is process for connecting different sub-processes that represents system boundary of the end product. Product process is created for one unit process. While product process is connected to plan, required amount of product flow is fixed for final product in plan.

First GHG emission from unit process of system boundary is estimated and transferred to an excel sheet. Afterwards on the basis of unit processes, carbon footprint per functional unit of the case is estimated and presented in the main text of this thesis. Whole case road construction is considered as one single functional unit. System boundary of different activities of the case is modeled in GaBi plan, which is illustrated in Appendix B.

The data set contained in this educational version of GaBi, *GaBi Education* is the small fraction of the available data within PE. This is the limitation of the research that research has to complete on the basis of available limit database.

Chapter 3: Background theory

3.1 Sustainable development

Economic improvement is obvious to combat poverty. It is true that along economic development of countries, the consumption rate of industrial products also increases i.e. there is more industrial production than earlier. Causes of exploitation of resources, use of industrial chemicals and emissions for the industrial production are heading the earth towards unsustainable environment and unbalanced society. Existing production and consumption behavior of business and consumers should be revised timely to maintain the limit of the earth. The world can not go on using resources of the planet at the present rate. It is realized and recognized at the beginning of 1980s that the industrial societies are mainly responsible for the degrading the environmental condition of the earth (Welford, 1998). Hence, the response for the protection and conservation of environment and society is the notion of sustainable development.

The concept of sustainable development is defined by Brundtland commission in 1987 in their famous report "Our common future". The report defines sustainable development as "*development which meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development, 1987). Since then sustainable development has received significant attention from the global community at the local, national and international level. The concern is given about climate change, bio diversity loss, tropical forest deforestation, and other natural resource depletion and environmental degradation (Burgess and Barbier, 2002).

Sustainable development does not focus solely on environmental issues. World Summit on Sustainable Development in Johannesburg in 2002 did focus on different activities to aim sustainable development (World Summit on Sustainable Development, 2002). The United Nations World Summit, 2005 also committed for the three pillars of sustainable development as economic development, social development, and environmental protection for the implementation of Agenda 21 (world Summit, 2005). Thus, sustainable development does not deny the economic development but argues that sustainable development of the world's people can not be met if all countries following the growth path taken by the industrialized countries. Existing path of development would over burden the world's ecosystem. However, economic growth is required to satisfy the justifiable and rightful need of the world's poor. Thus, economic growth should be promoted with "be aware of environmental consequences and social justice". Justice refers not only to the distribution within present generation, but also for the future generation. Sustainable development is not just a strategy for the future of developing societies but also for industrialized societies to reduce the excessive stress their past economic growth has imposed upon the earth (Welford, 1998, Dryzek, 2005, Tietenburg, 2009).

Burgess and Barbier (2002) suggests that sustainable development must begin with four objectives. (1) First is improving existing effort to measure the economic and ecological consequences of natural capital depletion and degradation. (2) Second is that it is necessary to determine the correct economic values for environmental goods and services, and to develop a variety of economic tools for assessing these values. (3)Third objective should be finding out the causes of environmental degradation, particularly the failure of the institution, markets and government policy, and correct these failure. (4) Fourth objective is that the economy and ecology should work together towards the common goal of sustainable development.

The above mentioned objectives are addressed by many national and international mechanism, and researches. The series of ISO 14000 are the contribution of International Organization for Standardization, which is one of the results of international effort. Latest ongoing work of ISO for the new ISO 14067- carbon footprint of products is dealing with climate change problem of the earth. According to Swart et al (2003), Climate change and its consequences is one of the sustainable issues, which is given more attention by many literatures and scientific works. Similarly, there are many efforts from different other sectors too. Fet (1997) states that the cooperation between all actors in the society, both government agencies, industries, environmental organizations, research and academic institutions, individual citizens are essential for the effectiveness of sustainable development.

3.2 Environmental responsibility: production and consumption

Environment has its own system and it is also a part of whole social system. The growing negative impact on environment due to industrial production and consumption system ultimately effect on whole social system. Result of environmental degradation is loss of both biodiversity in terrestrial and water body due to exploitation of natural resources and pollution. There are many other direct and indirect social consequences caused by environmental degradation. Degradation of health due to pollution, human body disorder because of industrial chemicals is few examples of direct impacts. Loss of agricultural crop because of drought, flood and extinction of local crop are impacting on socio economic life of the people, which are indirect impacts.

Continuous economic development is increasing industrial production and the result is excessive resource and energy consumption, and environmental pollution. According to UNEP report (2010), doubling the wealth will lead to 80% higher CO2 emissions. Population prediction for 2050 makes this even more critical. Therefore, if existing trends in industrialization, production and resource depletion continues and becomes unchanged to fulfill the growing demand, the limits to growth on the planet would be reached within one hundred years (Brattebø et. al, 2007). Hence, existing development pattern is a great challenge for the industry and consumers in maintaining sustainable society. During the World Summit for Sustainable Development (WSSD) in 2002 in Johannesburg the world leaders recognized that in spite of some progress on improved technologies, legislation and public awareness, the increase in production and consumption has worsened the general environmental situation. The summit agreed that it is necessary to change unsustainable patterns of consumption and production for achieving global sustainable development (Hertwich, 2005 and Opoku, 2007). Therefore, social actors comprising both business community and consumers are responsible for sustainable consumption and production against the degradation of environment.

3.2.1 Responsibility of the industrial sector (business)

Each industry is using resources from the Mother Nature for their economic benefit and disposing the wastage back to the nature. Only the intensity of impact is different and depends on the economic size and the type of the industry. So, every industry is responsible for the depletion of world resources and polluting the nature. Bratebø et al (2007), highlights that the main environmental responsibility of industry is to improve sustainability on production system. Sustainability on production system means investing in improved new eco-efficiency technology, consuming minimum resources as possible as and minimizing and managing wastes through environmentally friendly ways. Recycling and reuse approach is the way to minimize resource consumption and waste management, which is also called creating product loop in industrial ecology.

Another responsibility of industry is to comply rules and regulations and even beyond this (Berry and Rondinelli, 1998). Many national international organizations and educational institutions are developing concepts, regulations and tools to facilitate industry to be environmental responsible. For example application of environmental management system within industry, reporting environmental information of their products to their stakeholders are voluntary actions that society wants from industry to perform environmental responsibilities. Similarly environmental declaration of a product is another voluntary action that industry can apply. This mechanism makes industry to be environmentally responsible and encourages to consider environmental aspects of a product through life cycle perspectives (ISO 14025). The industrial environmental responsibilities are summarized in Table 3.1.

3.2.2 Responsibility of consumers

If we view from a life cycle perspective, all production ultimately serve the purpose of consumption and all emissions and resource used during production are assigned to the final consumption of the products and services. In most countries household consumption determines 60% of the life cycle impacts of final consumption. Even though household consumer is major actor regarding consumption, other consumers like governmental organization, civil organization and other industries are equally responsible to create sustainable consumption society.

All mentioned consumers can show their environmental responsibility behavior through two perspectives. One way is least consumption of industrial products as possible, which may help to reduce direct emissions from consumption (UNEP, 2010). For example consumer can use public vehicle instead of private car, which ultimately leads to minimum consumption of fuel. Another way to be responsible is demanding most sustainable products from market, which has environmental declaration and labeling on it (Fet et al, 2009). Later behavior of consumers gives pressure to industries to apply product declaration that lead to less indirect emission of consumption. Consumption is therefore an important economic activity to reduce the direct and indirect emissions. Environmental responsibilities of consumer are summarized in Table 3.1.

Table 3-1: Environmental responsibility actions

Environmental responsibility of industry	Environmental responsibility of consumer
• Use resources responsibly • Minimize waste by recycle and reuse • Minimize environmental and carbon footprint • Offer eco-friendly products • Embrace environmental sustainable practices • Develop and deploy eco efficiency technology	• Choose sustainable products: those marked by eco labels and declaration • Buy long lived products • Promote for reuse and recycled material • Shift pattern of consumption: eating behavior, travelling pattern etc • Reduce the level of consumption

Hence, both industry and consumers are sensible actors of the socio-economic society. Their contribution will make the earth sustainable. There are already many successful application tools and mechanisms to help their will. Environmentally responsible attitude and actions of both industry and consumers are important.

3.3 System thinking for environmental protection

System thinking is understood through different terminology. Richmond (1991) has stated that system theory, system dynamic and system approach are commonly used name to describe system thinking. System can be classified as closed and open system, natural and man made system, physical and conceptual system, and static and dynamic system (Fet, 1997).

System thinking not only studies relationship of the components but also with surrounding. More importantly, it acknowledges the system rather than thinks and talks about the system (Forrester, 1994). The feature and operation of an industrial system affects those environmental and social factors that come in contact with the system (Werhane, 2007). Therefore, through system thinking view society and nature are related to the industrial system. This approach of system thinking helps to understand industrial system and impact on its surrounding environment and society. Therefore, system thinking is an important tool for industries to contribute in sustainable development.

A system dynamic model in system thinking is equally important to understand environmental impact of industrial system, because it (system dynamic) characterizes the flow of stock, rate of conversion or change in the stocks with feedback loops. It also helps to construct and analyze complex system to find system behavior, performance and possible improvements. System thinking in industrial product system shows inflow of resources and outflow of products, emissions, waste and pollution during production life period, market demand and prices. In addition, it sends feedback from market and surroundings where it interacts. Environmental system analysis can therefore be a benefit from system theory since it gives feedback to industries in the issue of environmental and social impact through feedback loop. Based on these feedbacks industries can take decision on the choice of technology design with environmentally friendly and high efficiency (Brattebo and Kjelstrup, 2007).

Blanchard and Fabrycky (1990) defined that systems are composed of components, attributes and relationships. Components are elements that are involved in operating the system, which consists of input, process and output. Attributes are properties of a system where sum of attributes characterizes the system as a whole. Relationship is the links between components and attributes. According to this definition it can be said that society, economy and environment are three main components of sustainable development. These three have relationship and interconnections and their attributes are responsible for the sustainability of the earth system.

System engineering is another discipline of system thinking. According to Sage (1992) *system engineering is management technology to assist and support policy making, planning, decision making, and associated resource allocation or action deployment* (in Fet, 1997). It can also be used for the environmental analysis. Fet (1997) further defines that system engineering is a *discipline* that deals with technology, management, legal aspects, social and environmental issues, finance and corporate strategies through life cycle; i.e. from the design, construction, operation to maintenance phase of a large system. LCA, stakeholder analysis, input output analysis, green supply chain management, environmental product declaration and sustainable reporting are practiced system thinking tools and approaches for the environmental management of the industry.

From above discussion it can be concluded that system thinking approach helps to better understand sustainable development, environmental impacts and climate change. All these issues are related terminology to each other and are global issues. Therefore, global system thinking is essential for the effective and result oriented implementation. System Thinking Approach (STA) therefore is one of the concepts that contribute for the effective application of sustainable development because system thinking approach integrates all information related to components of sustainable development.

3.4 Industrial Ecology: a broad system thinking discipline

Industrial ecology is relatively young discipline. The concept of industrial ecology was first introduced in 1989 through an article “Strategies for Manufacturing” by Rebert Frosh and Nicholas Gallopoulis in a special issue of *Scientific American.* The paper argued the need for new ways of thinking about environmental constraints connected to industrial production against old concept where industrial production system got input from environment and disposed byproducts, wastes again to the environment. The paper suggested that the industry has to mimic natural balance mechanism of ecosystem into industrial system (in Duchin and Hertwich, 2003). Erkman (1997) explains that industrial ecology emerged at a time when it was realized that the traditional pollution control approach (end – of –pipe) is insufficient. Then the industrial ecology came with the methods of life cycle analysis, total quality management, design for the protection of environment. Therefore, the discipline of industrial ecology is developed to provide new thinking and new working approach to industrial system. The discipline makes it possible to protect environment with an ultimate goal of sustainable development.

The concept of industrial ecology is defined in many ways by different writers. Robert White (1994) definition is widely used definition, which is cited in many industrial ecology articles. White (1994) defines "*Industrial ecology is the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources. The objective of industrial ecology is to understand better how we can integrate environmental concerns into our economic activities. This integration, an ongoing process, is necessary if we are to address current and future environmental concerns*" (in Brattebø et al, 2007).

The definition given by Graedel et al (1995) is based on system view and is defined as "*Industrial ecology is the means by which humanity can deliberately and rationally approach and maintains a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not on isolation from its surrounding systems, but in concert with them. It is a system view in which one seeks to optimize the total material cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital*" (in Fet, 2006).

Industrial ecology suggests all producers and consumers to adopt following objectives in their activities to aim sustainable development with less resource extraction and pollution (in Brattebø et al, 2007).

- Reduce level of material consumption by producing long lived, few goods.
- Avoid harmful products and substances by product redesign and material substitution.
- Closed material cycle in society by use of recycling and reuse services.

Acording to Garner (1995) industrial ecology includes following goals:

- Change the linear nature of industrial system to a cyclic system where wastes are reduced as energy or raw materials for another product or process.
- Identify energy and material flow through life cycle of a product and try to optimize resource efficiency and minimize environmental burden

3.4.1 System thinking in industrial ecology

As above discussions have indicated industrial ecology always takes account the system thinking view. It links human system (economic/industrial system and social system) to environmental system. Industrial ecology takes account the flow of materials into industrial system, their impact on environmental system and response from social system (Brattebø et al, 2007). Hence, industrial ecology aims to protect the environment through principle of system thinking. Industrial ecology advocates system thinking principle considering environmental issues through life cycle perspectives of a product presenting quantitative environmental information of a product. According to Fet (2006) industrial ecology operates at 3 different levels; i.e. at the firm level, across the firms and at a regional or global level if life cycle perspective of a product is major. Therefore, industrial ecology does not only study the interaction between industrial system and ecological system but also interaction between different industrial systems. Allenby (2000) argues that industrial ecology is a study of industrial and economic systems linking with natural systems and it is about technology and evolution of human culture and economic systems. System thinking approach also recognized by Erkman (1997) and stated that industrial ecology perspective acknowledges the existence of a wide range of industrial ecosystems with varying degrees and patterns of interactions with the biosphere from certain kinds of natural ecosystem to artificial ecosystem.

Life cycle assessment (LCA), material flow analysis (MFA), life cycle costing (LCC) and input output analysis are different system thinking tools for the implementation of the science of industrial ecology. Among these tools LCA is widely used tool for the product declaration. LCA is supporting industrial ecological tool for ISO 14020, ISO 14021, ISO 14024 and ISO 14025, which are international standard for Environmental labeling and declaration of product and also for new coming ISO 14067 for carbon footprint of products. These environmental related standards are facilitating for the realization of industrial ecology. Garner (1995) states that a system view of industrial ecology enables manufacturers to develop products in a sustainable manner recognizing interrelationship between industrial and natural systems. He further argues that ideal goal of industrial ecology is creation relationship between industries and nature in such a way that minimum waste possible and minimum energy and resource input per unit of a product output.

3.5 Responsibilities for climate change: urgency to address

Manmade Greenhouse gases are rapidly warming the earth causing changes in the global climate that will have increasingly severe environmental, economic and social impacts over the coming decades (European Commission, 2009). In Kyoto protocol (UN, 1998) six major gases are mentioned mainly responsible for global green house effect. These are Carbon dioxide (C02), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). Among other environmental challenges climate change is highlighted in many literatures, in policy level (Kyoto protocol, carbon trade) and industry level (GHG protocol, carbon footprint declaration) and it is one of the most talked environmental issues that are being faced by the international community (Bohringer, 2003) . The reason may be that emission of greenhouse gases happens locally but the threat is global and the risk of climate change is high. UNEP (2007) indicates unprecedented environmental problems due to increasing air and water temperature at regional and global levels. These are 1) Melting of snow and ice, and rising global average sea level. 2) Change in water availability, land degradation, food security. 3) Loss of biodiversity. 4) Increase in frequency and intensity of heat waves, storms, floods and draughts.

Greenhouse gases emission is one major global environmental issue challenging to sustainability of the world. The concentrations of GHGs have increased noticeably as a result of human activities since 1750. While looking past 30 years, concentration of CO_2 equivalent gases reached from 28.7 GT per year in year 1970 to 49 GT per year in the year 2004. Increasing population and economic growth of developing countries will add more GHG in the air (IPCC, 2007). UNEP study report (2010) states that CO_2 emission is highly correlated with income and population growth, and hence will lead to higher emission unless production and consumption are changed. The Inter-governmental Panel on Climate Change (IPCC) estimates an increase in the global temperature of 1.8 to 4 degree centigrade by the end of the century if present situation prevails. This will lead to potentially massive consequences even if atmospheric concentrations of GHGs are established today land and ocean temperatures would increase for decades and sea levels would rise for centuries (UNEP, 2007).

Hence mitigation and adaptation programs from every level (policy, industry, and consumer) are urgent to address climate change. The first effort in the issue of climate change from international level is the United Nations Framework Convention on Climate Change (UNFCC) that was adopted during the Rio Earth Summit in 1992. It is ratified by majority countries of the world. Periodic meeting of these countries to the climate change convention is called "*Conference of Parties*" (COP). The UNFCC is backbone of the international climate change co-operation. The treaty sets out a number of general goals and rules to confront climate change. The objective of UNFCC is to prevent dangerous human interferences with the climate system. The concern of climate change led to the Kyoto protocol in 1997 and it is legally binding treaty. The Kyoto protocol is the result of negotiation from third conference of parties (COP3) that entered into force in February 2005. It sets emission reductions targets for several industrialized countries with a goal of reducing total emissions from these countries by 5% against 1990 levels during the period of 2008 - 2012. The major distinction between the Protocol and the Convention is that while the Convention encouraged industrialized countries to stabilize GHG emissions, the Protocol commits them to do so (Bohringer, 2003; UNFCC, 2009; UNFCC,2010).

According to UNEP report (2010) the energy sector contributes more than a quarter of the total GHG emissions followed by industrial process according to 2007 data (Figure 3-1)

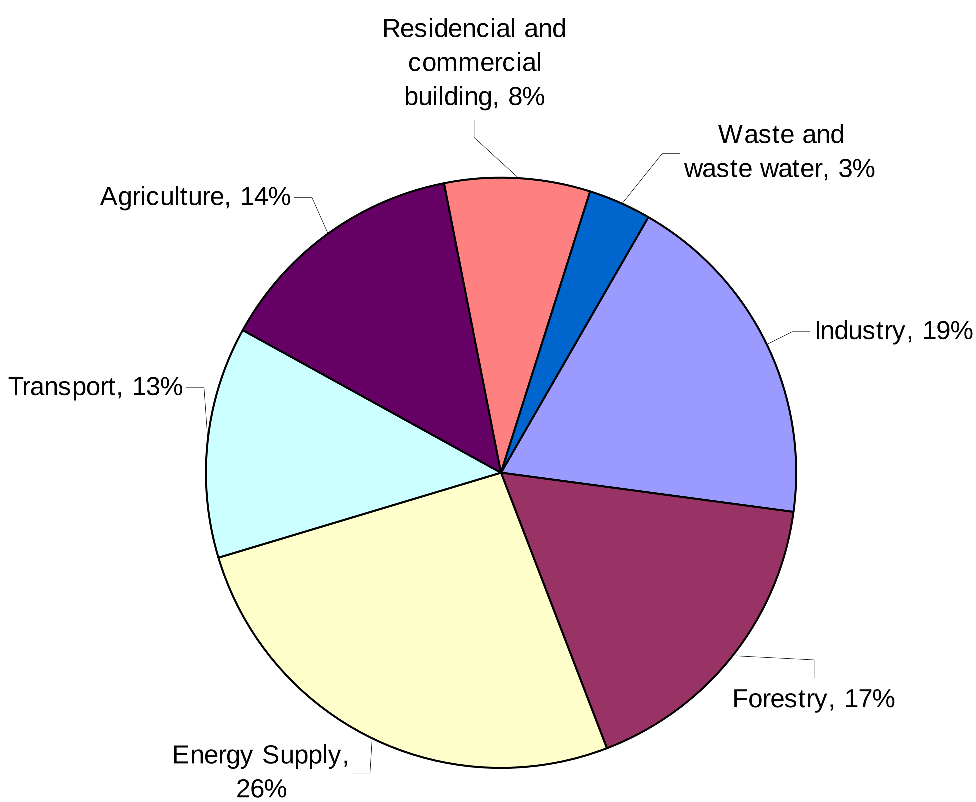


Figure 3-1: Total GHG emissions followed by industrial process according to 2007 data (UNEP, 2010)

Figure 3-1 clearly shows that industry is the second major responsible sector for GHG emissions followed by forestry, agriculture and transport. It is urgent for all these sectors to revise their activities to take action against manmade GHGs. IPCC report (2007) has recommended few examples of key mitigation technology, policy, measures and instruments and key constraints or opportunities for every sector. Among these industry and transportation sector are tabulate here being the relevant sector for the study is industry.

Table 3-2. Purposed mitigation technology, measures and constraints &opportunities for industry and transportation sector (IPCC, 2007).

Key mitigation Technology	Policies, measures and instruments	Constraints and opportunities
Industry • More efficient end use electrical equipment • Heat and power recovery • Material recycling and substitution • Control of non co2 gas emission • A wide array of process-specific technologies • Advanced energy efficiency • CCS for cement, ammonia and iron • Inert electrode for aluminum manufacture	• Provision of benchmark information • Performance standards • Subsidies • Tax credits • Tradable permits • Voluntary agreements	• Appropriate to stimulate technology uptake • Stability of national policy important in view of international competitiveness • Predictable allocation mechanism and stable price signals important for investments • Success factors include: clear targets, baseline scenario, third party involvement in design and review and formal provision of monitoring, close cooperation between government and industry.
Transport • More fuel efficient vehicle • Modal shift in transport • Non motorized transport • Land use and transport planning • Advanced electric and hybrid vehicle	• Mandatory fuel economy; bio-fuel blending and CO_2 standards for road transport • Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing • Influence mobility needs through land use regulations and infrastructure planning; investment in attractive public transport facilities and non motorized forms of transport	• Partial coverage of vehicle fleet may limit effectiveness • Effectiveness may drop with higher incomes • Particularly appropriate for countries that are building up their transportation system

In general, the Kyoto protocol is defined as a weak treaty. This is because it does not cover all countries and is prone to free riders. In addition, it does not count real carbon footprint of a nation due to carbon leakage. Many developing countries are not binding for the Kyoto Protocol and are called non annex B countries. If the climate regime has inadequate participation, and then there is a risk that production will increasingly shift to nonparticipating countries. Either industries may close down and move to nonparticipating countries, or more problematically expanded production may occur in nonparticipating countries as is indicated by the rapid growth of production in China. Further, with increasingly global production, most low-cost mitigation options may be located outside the country of consumption (Hertwich and Peters, 2008)

According to Kyoto protocol only domestically produced carbon and GHG are accounted for the national emission inventories, which are based on production based allocations. Regarding transparency and fairness of the emission accounting process, Carbon footprint of nations should be counted due to consumption not due to production. Carbon footprint of consumable goods and services occur during production process. The GHG emissions occur either directly through the production process or indirectly in the global supply chain due to acquisitions of electricity, transportation, manufacturing and so on. Hence, GHG emissions through life cycle perspectives need to count total accumulated emission of a product (Hertwich and Peters, 2008; Vetone, 2011).

Copenhagen summit 2009, convention of the parties (COP) 15 was hoped to have new and better treaty. According to Rogelj et al (2010) unfortunately, the convention was concluded with blank binding tables that were to be filled in by 1 February 2010 with national pledges of emissions reductions. EU committed to reduce its emission by 20 % to 30% in Copenhagen Accord, which has committed 20% by 2020 following the Kyoto protocol. Current assurance means greater than 50% chance that warming will exceed 3 °C by 2100. If nations agree to halve emissions by 2050, there is still 50% chance that warming will exceed 2 °C and will almost certainly exceed 1.5 °C.

Instead of international policy level continued urgent efforts from international organizations to fight against climate change is needed. GHG protocol product standard for WRI and WBCSD, British standard PAS 2050 and upcoming ISO 14067 are examples of international efforts, which are encouraging industries to implement climate change mitigation measures from industry level. These mechanisms are developed to consider product life cycle perspectives. This mechanism will provide awareness to the consumers to reduce carbon footprint from their lifestyle and behavior. IPCC Mitigation of climate change report (2007) suggested one of the mitigation measures is changing in lifestyle and behavior patterns. It declares that "*lifestyle changes can reduce GHG emissions. Changes in lifestyles and consumption patterns that emphasize resource conservation can contribute to developing a low carbon economy that is both equitable and sustainable*". Changing lifestyle and choosing sustainable path gives pressure to the production sectors to take measures in lowering GHGs emissions. Every sector, industry, developer and consumers need to try to minimize carbon footprint through their local actions contributing to limit the global carbon emission. Environmentally friendly local decisions force to global community to adopt environmentally friendly decisions in this globalized world. For example; if consumers of specific regions decide to buy only such goods that are produced with minimum level of CO2 emission then this will force the supplier from other part of the world to adopt such technology that meets the requirements of the consumers.

Hence, the saying "think globally act locally" is really applicable to fight against the climate change issues.

Chapter 4: Environmental documentation system

4.1 Historical Background

Beginning of Environmental documentation system started back in 1950s. By then the environmental acknowledgment along other economic development was in the form of natural resource management. The objective of natural resource management was to supply resources for the industries (for example forest management for the smooth supply of timber), for recreation purpose like animal hunting and jungle safari. The modern era of environmental consideration began after 1960, when Silent Spring was written by Rachel Carson in 1962(Lear, 1993). From 1960 to 1970s many writers also recognized environmental issues and series of books printed out. The work of Meadows et al (1972) *"The Limits of Growth"* was most popular and paid attention internationally. After that the potential of major environmental disasters inspired for environmental consolidation continued till 80s. The first important event was in 1972, when UN conference on human development constituted. The next event was World Conservation Strategy of 1980. Since then the consolidation is growing every year till 2009 Copenhagen summit (In Brettebo et al, 2007; Van, 2011) and till to date.

Industries and development projects (few examples; mining, transportation infrastructure, energy, agricultural channel etc.) started to consider environment issues partly as their activities since acknowledgement of the importance of environment. At the beginning the environmental consideration was more focused to fewer disturbances on natural scenery, human settlement and animal habitat. Environmental Impact Assessment Report of large development project was one of the documentation systems on environmental study (Lawrence, 2003)

At the begging these environmental considerations were reactive in nature than preventive. These were more site specific rather than holistic considerations. Figure 4-1 shows on how environmental issues developed chronologically. The figure describes on how environmental issues were expressed. Some writers like Rachel Carson awaked people writing the consequences of excessive use of chemicals and medicines to the nature. Awareness on environmental protection is continuing. As shown in Figure 4-1the industries have made great leap in environmental issues from initial site specific effort like dilution strategies in the 60s to holistic perspectives of the present era that considers all environmental consequences due to each and every related activity within each industry. Environmental reporting system has also been developed from national level priorities to international level priorities. Sustainable Reporting and Global Compact Reporting are examples of international reporting systems in organizational level. The figure also presents the development of different concept for environment protection including options for environmental protection through developed pollution control strategy to Corporate Social Responsibility (CSR) strategy (Van, 2011; Hansen et al, 2005; Fet, 2006)

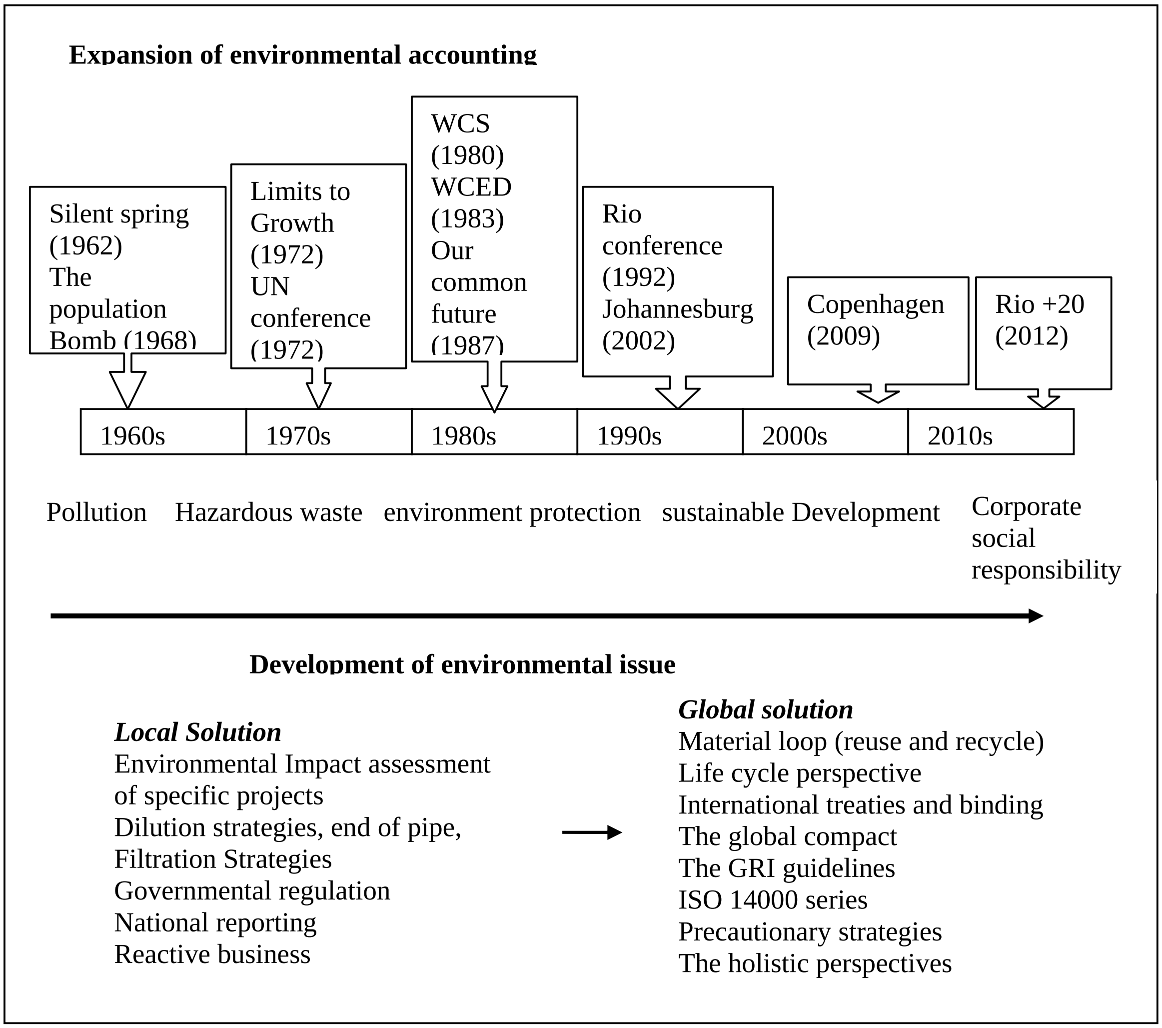


Figure 4-1: The chronology of development of environmental accounting

The purpose of CSR strategy is to maintain the balance among environment, social and economic aspects of the development through holistic thinking. CSR is such strategy that guides the world towards sustainability by preventing negative consequences of industrial actions.

New development in the sector of environmental protection and sustainable development is Rio+ 20 or earth summit 2012, which is going to take place in the Rio di Jenerio from 4th to 6th June 2012. The focus of the summit is on two specific themes. The first is “a green economy in the context of poverty eradication and sustainable development”. The second is “Institutional framework for sustainable development” (www.earthsummit 2012.org).

Many tools and mechanisms are developed for environmental accounting, documentation and reporting in organizational level, in project level and also in product level. The objective of this study is to discuss the environmental documentation system for product level. Therefore, in the following focus is made on environmental documentation system of the product. Discussions are made about the mechanisms that are recommended by ISO standards.

4.2 Environmental labels and declarations

The growing awareness about environmental issues are forcing for greater responsibility on organizations to transmit information about environmental quality of their products. A large number of environmental label and declaration have been in action that focuses different aspects over the past few years. Nationally and internationally developed environmental label and declaration mechanism provide enterprises credible and complete tool or method to account environmental issues. The environmental labels are printed label on a package or product that provides environmental information regarding some attribute of the product. There are varieties of environmental labels in market such as label with the information of recycled content, reduced packaging, non-toxic, safety performance, biodegradability, product from sustainable forest and energy consumption etc. Environmental labels and declarations show environmental liability of the industries to their stakeholders (customers, public institutions, local community, etc.). These environmental systems are facilitating to achieve competitive advantages for both environment and business community in growing environmental conscious market (ISO 14020, 2000 and Mazini et al, 2006).

Mostly used eco-labels and declarations programs supported by the International Organization for Standardization's ISO 14000 series standards are discussed in this chapter. ISO standard Environmental Label and Declaration Type I, Type II, Type III and up coming ISO 14067 Carbon footprint of products are covered in detail.

The International Organization for Standardization (ISO) established overall framework for environmental labels and declaration of a product worldwide via ISO 14000 group of standards. Environmental labeling and declaration is a set of voluntary tool aimed to provide relevant environmental information on product's life cycle. It motivates the consumers to demand for products and services with lower environmental burdens (Fullana et al, 2008).

According to ISO 14020 (2000) "*The overall goal of environmental labels and declarations is, through communication of verifiable and accurate information, that is not misleading, on environmental aspects of products and services, to encourage the demand for and supply of those products and services that cause less stress on the environment, thereby stimulating the potential for market driven continuous environmental improvemence*."

An environmental label and declaration indicates environmental aspects of a product or service which take in the form of a statement, symbol or graphic on a product or package label, in product literature, in technical bulletins, in advertisement or in publicity, amongst other things. Environmental label and declaration is based on major nine principles which are included on ISO 14020. In Table 4-1 nine principles of environmental label and declarations are presented.

Table 4-1: Principles of Environmental label and Declaration (ISO 14020: 2000)

1. Environmental labels and declarations shall be accurate, verifiable, relevant and not misleading. 2. Procedures and requirements for environmental labels and declarations shall not be prepared, adopted, or applied with a view to, or with the effect of, creating unnecessary obstacles to international trade. 3. Environmental labels and declarations shall be based on scientific methodology that is sufficient through and comprehensive to support the claim and produces results that are accurate and reproducible. 4. Information concerning the procedure, methodology, and any criteria used to support environmental labels and declarations shall be available and provided upon request to all interested parties. 5. The development of environmental labels and declarations shall take into consideration all relevant aspects of the life cycle of the product. 6. Environmental labels and declarations shall not inhibit innovation which maintain or has the potential to improve environmental performance. 7. Any administrative requirements or information demands related to environmental labels and declarations shall be limited to those necessary to establish conformance with applicable criteria and standards of the labels and declarations. 8. The process of developing environmental labels and declarations should include an open, participatory consultation with interested parties. Reasonable efforts should be made to achieve a consensus throughout the process. 9. Information on the environmental aspects of products and services relevant to an environmental label and declaration shall be available to purchasers and potential purchasers from the party making the environmental labels and declarations.

ISO 14020 series has developed three different types of environmental labeling and declaration arrangement, which are:

Type I: Environmental labeling ISO 14024-1999
Type II: Self-declared environmental claims ISO 14021-1999
Type III: Environmental declarations ISO 14025- 2006

These ISOs are related to the environmental labeling and declaration, which are developed by International Organization for Standardization. These ISOs do not certify, audit or register companies, products or environmental management systems. Another national and international level organization is created to certify the products according to ISOs rules. Therefore, eco-labeling organizations like EU Eco-labeling, the Nordic Swan and Blue angel (Germany), EPD Norway are few example organizations that certify the companies, goods and services according to ISOs requirement.

4.2.1 Type I: Environmental labeling ISO 14024

Label requirements according to ISO 14024:1999

Detail principles and procedures for type I environmental labeling is written in ISO 14024:1999. Major requirements according to the ISO are presented below:

- Need to define the product category: Product category is a group of products that fulfill same function.
- Environmental requirements that product shall meet: Life cycle stages to be taken into account when developing the product environmental criteria. Environmental aspects of a product from extraction of resources to disposal of a product should include and need justification if any removal. Environmental criteria could be no use of rain forest, amount of recycled materials, amount of energy used, emissions amount etc.
- Product function characteristic: Characteristics in the performances and use of a product.

All applicants who fulfill above listed three requirements are entitled to apply for the environmental labeling. Eco-labeling body evaluate the product criteria before certified and giving right to use type I environmental labels. Eco- labeling body is independent third party, which means it is neither supplier (first party) nor purchaser (second party). Handing over authority to use eco-label means the assurance from third party that the product, process or service conforms to specified requirements. Right to use label is provided for certain period because product environmental criteria and product function requirements shall be reviewed within predefined period taking account of changing technologies, new environmental requirements and market changes. For example; Nordic Swan, which is environmental label in Nordic countries permits between one to three years to use the label (Nordic Eco labeling, 2011).

Advantages with Type I environmental labeling (Faullana et al 2008) are;

- It is credible, because the program is ruled by a prestigious institution.
- Reliable and differentiating, because the certification assures that the product is at least as good as other products with more environmental impacts.
- It is visible, because label is usually used on the product's packaging.
- Give feedback to the Environmental Management System to present the significant aspects of the product.
- Competitive advantages through green supply.
- Guide to eco-design team in searching possible areas of improvements.

4.2.2 Type II: Self declare environmental claim

Self declared environmental claims may be made by manufactures, importers, distributors, retailers or anyone likely to benefit from such claims. Environmental claims may take in the form of statement, symbol or graphic that indicates an environmental aspect of a product, a component or packaging. Type II product declaration is claimed without independent third party certification. Therefore, environmental claims should be clear, transparent, scientifically sound, and documented so that validity and reliability can be claimed to those who want to be assured for the product. The standard provides 12 specific claim words and guidance on how to use these claims. These 12 claim words compostable, degradable, designed for disassembly, extended life product, recovered energy, recyclable, recyclable content, reduced energy consumption, reduced resource use, reduced water consumption, reusable and refillable, and waste reduction are proposed in self declared environmental claims. Vague and non specific words like environmentally friendly, non-polluting shall not be used (ISO 14021, 1999).

Objectives of the self declared environmental claims is to increase potential for market forces to motivate environmental improvements in production, processes and products, which lead to minimize the unwarranted claims, reduce market confusion and facilitate to international trade and purchasers to make more informed choices (ISO 14021).

Requirements to self-declared environmental claims are;

- It should follow the principles of ISO 14020.
- Should not use vague and non specific claims.
- The environmental claim of for example chemical free shall be only made if it is acknowledgeable.
- No claim of achieving sustainability shall be made
- Claim can be explanatory statement

- All environmental claims and explanatory statement shall be reliable, accurate and reasonable, and not misleading. Detail of specific requirements is mentioned in *ISO 14021, which has mentioned 18 specific requirements (from 'a' to 'r') for the self environmental claim*.
- Words, numbers and symbols can be used in addition to environmental symbol.
- Claimants are responsible for evaluation and verification. Environmental information related to product should be documented for verification and evaluation

The main advantage of product self declarations over other types of eco-labels is that they are generally cheaper to obtain than any other environmental labeling tool. This is because no certification or validation is required. On the other hand, the lack of certification and validation reduces their credibility and reliability when compared to other types of eco labels such as Type I or Type III (Fullana et al, 2008).

4.2.3 Type III: Environmental declarations

Type III Environmental declaration presents quantified environmental information based on the life cycle of a product and enables comparison between products having similar properties. Additional relevant information is also provided in qualitative and quantitative way. This declaration is a voluntary program. Environmental product declaration is not an environmental label. It only provides information about the environmental aspects of a product but does not specify whether or not the relevant product complies with certain environmental requirements. The environmental properties of a product provided through environmental product declaration (EPD) are based on life cycle assessment of a product all the way from raw material extraction, manufacture, use, to the disposal. LCA of a product should be carried out following the methodology, requirements and principles of international LCA standard ISO 14040 (EPD – Norge, 2011and EPD – International, 2011). Various name of EPD are seen in the market. Few examples are; EcoLeaf (Japan), EPD - Norway, EPD – International etc.

The objectives of Type III environmental declaration are:

- To provide LCA based information and additional information on the environmental aspects of the products.
- To assist purchasers and users to make informed comparisons between products; these declaration are not comparative assertions.
- To encourage improvement on environmental performance.
- To provide information for assessing environmental impacts of products over their life cycle.

Requirements and steps for Type III environmental declaration

Requirement 1: Product category rules

In order to develop EPD of a product, product category rules (PCR) are the first requirement. A product category is a group of product that fulfills same function and applications. The PCR aims to identify and define rules for the process of creating an EPD in order to enable a comparison between the products. Fet et al 2008 explains that PCR document should follow three main steps to fulfill the requirements of ISO 14025:2006, which are;

Step I: Define product category, its functional and performance characteristics
Step II: Produce appropriate product category background LCA, in order to identify the most significant environmental aspects and impacts of the product category.
Step III: Specify rules, parameters and requirements for reporting, and how to produce the data required for the product declaration.

Hence product category is the first requirement for environmental declaration. Many industries have already registered their products for environmental declaration system. As a result, PCR is an available option in the market if product in concern has same category. If PCR is not already available in the market then it needs to be prepared and approved. PCR is prepared by company and organization alone or in co-operation with other interested parties. Common PCR developed by the participation of similar parties facilitates harmonization with common PCR. The preparation of PCR documents include a number of issues that needs to be considered. The pre-set categories of parameters and the associated LCA-based information as well as other environmental information are needed. Therefore, PCR developer should or need to consult with both LCA experts and product expert. Detail guidance on how to prepare PCR is given in ISO 14025:2006.

Second step of PCR is collecting data input and output of a product from cradle to grave for the LCA purpose. LCA of a product should be done according to the principle of ISO 14040. All material information, environmental parameters and information are decided in this step. Third major step is decision on declaration of environmental parameters, material and substance declaration, and additional environmental information. The content of PCR document is presented in Table 4-2

Table4-2: Content of PCR, ISO 14025 (Fet et al, 2008).

1) General information
2) Product category definition and description
3) LCA based information
- Functional unit
- System boundary
- Description of data
- Criteria for the inclusion of inputs and outputs
- Data quality requirements
- Units
4) Inventory analysis
- Data collection and calculation procedure
- Cut off criteria
- Allocation of material and energy
5) Impact category selection
6) Parameters and source of data of the underlying LCA report
7) Other information
- Other product information and parameters to be declared in EPD
- Information on underlying LCA data
- Other instruction on data gathering for the development of EPDs
- Additional information (information from the organization)
8) Content of the environmental declaration
- General information to be declared
- Parameters to be declared

Requirement 2: environmental product declaration format

All type III environmental declaration in product category shall follow the format and parameters as identified in PCR. According to Fet et al (2008) following contents are included in type III environmental declaration format.

1. Identification and description of the organization
2. Description of the product
3. Product identification
4. Name of the program and program operators address
5. PCR identification
6. Date of publication and period of validity
7. Data from LCA, LCI, or information modules
8. Additional environmental information
9. Material and substance information
10. Information on which stages are not considered
11. Statement that environmental declaration from different program may not be comparable

Requirement 3: PCR review, EPD verification

Third requirement for type III environmental declaration program is that the program operator shall establish an appropriate verification procedure to ensure that the declaration complies. The PCR review and independent verification of type III environmental declaration are two separate processes. The independent verification of type III environmental declaration may be carried out by PCR review panel, or may be carried out by an independent verifier who may or may not have been a member of PCR review panel. Both bodies should have knowledge in relevant sector, product and product related environmental aspects and knowledge on LCA (ISO 14025). According to Fet et al (2008) verification system can vary between different program operators. For example verification of EPD by an independent third party is required in the Norwegian EPD system.

PCR review shall be conducted by a third-party panel, which shall constitute minimum a chair person and two members. PCR document shall include the results of PCR review as well as comments and recommendations made by the panel members. The certification body does not necessarily possess relevant knowledge of LCA and therefore, external LCA experts may be involved in the certification process. PCR review should conform that:

- The PCR have been developed in accordance with the ISO 14040, ISO 14020 and ISO 14025.
- The PCR fulfills the general program instructions
- LCA based information and other environmental information.

EPD verification body conforms the program has followed ISO 14020 principles and program instructions and PCR. The verification procedure shall conform whether the information is valid and scientifically sound. Product is registered after verification in EPD organization. In Norway Verification and registration is organized by “Næringslivet Stiftelse for Miljøedklarasjoner” (www.epd-norge.no)

4.3 Carbon footprint accounting

Carbon footprint is a new word but not a new concept; it is being been around for decades. It is being just called differently. It is not different than life cycle impact category indicator global warming potential. However, the term carbon footprint is fashionable these days (Finkbeiner, 2009). The term “Carbon Footprint” has grown in popularity over the last few years and is now has widespread use across the media, government and commercial world. The popularity of this concept is linked to the threat of global climate change (Wiedmann and Minx, 2007).

Despite the long history of carbon footprint concept, uniform and agreed definitions do not existent. It is true that some fields have defined carbon footprint, but these definitions do not necessarily apply at different scales. The field of Life Cycle Assessment routinely calculates carbon footprints and an ISO standard is on the development process. However, this is a product focused definition and can not easily be generalized to the concept of a national carbon footprint. The field of input-output analysis has also routinely calculated carbon footprints of nations, but the definitions do not necessary apply to product based assessments. There are other numerous methods focusing on different scales of carbon footprint, which calculate consumer level, company level, city level, region and so on (Peters and Solli, 2010). Therefore, definition of carbon footprint focuses different level while it is defined by differently.

European Commission focuses product perspective to define carbon footprint which is "*The overall amount GHGs missions associated with a product, along its supply-chain and sometimes including the use phase and the end-of-life recovery and disposal. It is measured in terms of CO2 equivalent*" (Baldo et al 2008).

Peters and solli (2010) defined "*The "carbon footprint" of a nation is the total global long-lived greenhouse gas emissions aggregated using 100-year global warming potentials required to use (direct) and produce (indirect) products and services to satisfy annual national consumption*".

BP (2007) defines "*The carbon footprint is the amount of carbon-dioxide emitted due to your daily activities- from washing a load of laundry to driving a carload of kids to school*." (In Weidmann and Minx, 2007).

Weidmann and Minx (2007) define "*The carbon footprint is a measure of the exclusive total amount of carbon-dioxide emissions that is directly and indirectly caused by an activity and or is accumulated over the life stages of a product*."

The similarities of these definitions are that the carbon footprint is amount of GHG emissions associated with human activities and are threaten to the climate change through global warming impact.

Early GHG measurement efforts began in 1995, when Intergovernmental Panel on Climate Change (IPCC) released GHG inventory guidelines. The Framework Convention on Climate Change (FCCC) requires Annex I countries—those with binding targets under the Kyoto Protocol—to report annually on their emissions in six sectors: energy, industrial processes, solvents, agriculture, land use and land use change, and waste. The IPCC guidelines are to be used by Annex I countries when calculating their national level emissions. These guidelines are widely used for calculating emissions within a national territory (Green, 2010).

Thus, by 1997, there were considerable activities associated to GHG measurement. Moreover, these efforts were focused almost exclusively on the national and project-levels, and developed very basic tools. The first efforts to undertake GHG accounting at the corporate level began in 1997, when BP announced an ambitious plan and system for measuring and reporting with a goal to reduce BP's emissions by 10% below 1990 levels by 2010. As a result, other business communities are also encouraged towards accounting GHG. BP along with Monsanto, General Motors and the World Resources Institute (WRI) published "*Safe Climate, Sound Business: An Action Agenda*" in October 1998. This laid the foundation for Greenhouse Gas Protocol (Green, 2010). Some other efforts for GHG accounting are developed. All these initiatives try to serve an increasing market demand for climate relevant information along supply chains and towards consumers. The standards promote GHG reduction, but are also useful in the development of GHG credit trading schemes.

In the following discussions are made in different initiatives for carbon footprint accounting. While doing so focus is given on upcoming international standard ISO 14067- Carbon footprint of products, which is under the process of final draft.

4.3.1 The greenhouse gas protocol

The World Business Council for Sustainable Development (WBCSD) and the World Resource Institute (WRI) published first edition of an international standard "Greenhouse Gas Protocol - A corporate Accounting and Reporting Standard" in 2001. The protocol provides concepts for dividing up emissions into three scopes. Scope 1: emissions are those that come from sources owned or controlled by the company. Scope 2: emissions that come from purchased electricity and scope 3: subsumes all other indirect emissions such as transportation and extraction of purchased materials. The protocol is comprised of three components: standards, guidelines and calculation tools. The protocol is one of the earliest efforts to develop a firm level accounting tool (Finkbeiner, 2009; Green, 2010; and WRI and WBCSD, 2004). Another standard under Greenhouse Gas Protocol is "A Product Life Cycle Accounting and Reporting Standard", which is not published yet and it's first publication is planned for spring 2011 (ISO , 2010).

4.3.2 British standard (PAS 2050)

The British Standard PAS 2050 specifies requirements for assessing Life Cycle Greenhouse Gas Emissions (LCGGE) of goods and services. This standard is developed by British Standard (BSI) in cooperation with Carbon Trust and the Department for Environment, Food and Rural Affairs UK. It is an independent standard. It provides methods to industries for assessing product carbon footprint during product's life cycle. PAS 2050 follows principles and requirements of ISO 14040 and ISO 14044 for LCA methods. The standard allows comparison of GHG emissions between products and enables communication of this information. PAS does not specify requirements for communications (PAS 2050, 2008).

4.3.4 ISO 14064, ISO 14065 and ISO 14066

The latest standards in the ISO 14000 have been developed following some standards related to greenhouse gas accounting. These standards are illustrated in Table 4-3.

Table 4-3: Greenhouse gas related ISOs (www.iso.org, 2010)

ISO 14064-part 1: 2006: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory. ***ISO 14064-part 2: 2006: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements***. It includes requirements for planning a GHG project, identifying and selecting GHG sources, sinks and reservoirs relevant to the project and baseline scenario, monitoring, quantifying, documenting and reporting GHG project performance and managing data quality. ***ISO 14064-part 3:2006: Specification with guidance for the validation and verification of greenhouse gas assertions***. ISO 14064-3 specifies principles and requirements and provides guidance for those conducting or managing the validation and/or verification of greenhouse gas (GHG) assertions. It can be applied to organizational or GHG project quantification, including GHG quantification, monitoring and reporting carried out in accordance with ISO 14064-1 or ISO 14064-2. ***ISO 14065: 2007: Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition***. It specifies principles and requirements for bodies that undertake validation or verification of greenhouse gas (GHG) assertions. ***ISO 14066: Competence requirements for greenhouse gas validation teams and verification teams***. ISO 14066:2011 complements the implementation of ISO 14065. ISO 14066:2011 is not linked to any particular greenhouse gas (GHG) program. If a particular GHG program is applicable, competence requirements of that GHG program are additional to the requirements of ISO 14066:2011

4.4 ISO 14067: Carbon footprint of products

ISO 14067 is still in the form of committee draft. The information related to this ISO in this study is complete depend on committee draft version. The feature of ISO 14067 is discussed following.

4.4.1 Background of ISO 14067

International Organization for standardization is currently developing a standard called ISO 14067 for measuring carbon footprint on product (goods and services). The aim of this ISO 14067 is to develop internationally acknowledged system to account carbon footprint of the products. ISO 14067 - Carbon Footprint ofPproducts will provide requirements for the quantification and communication of greenhouse gases (GHGs) associated with products. This ISO is still not available for public. First committee draft of this ISO was launched in February 2010. At the beginning it consisted of two parts; one on quantification and another on communication. Recently, with the latest discussion, the working group purposed a combine version standard. The target for combine version of committee draft for comments and voting scheduled for March 2011. It is being targeted for publication in 2012 (Skaar, 2011).

The role of carbon footprint standard is the calculation of greenhouse gas (GHG) emissions associated with the lifecycle of a product or service. It could be a tool for managing GHG emissions along with product supply chain and is hoped to safeguard the survival of companies in changing regulatory and economic business landscape.

4.4.2 Basic features of ISO 14067

Following ISOs are reference material for the ISO 14067.

ISO 14040 and ISO 14044, Life Cycle Assessment
ISO 14020: Environmental labels and Declarations – General principles
ISO 14021 Type II: self declared environmental claims
ISO 14024 Type I: environmental labels
ISO 14025 Type III: environmental declarations
ISO 14065 and ISO 14066 on validation and verification related to GHG

According to committee draft version ISO 14067, carbon footprint of a product is the net amount of greenhouse emission and removal expressed in CO2 equivalent. The CO2 equivalent is calculated using mass of a given GHG multiplied by its global warming potential published by the Intergovernmental Panel on Climate Change. GHGs include among others carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6.)

The ISO 14067 aims to provide clarity and consistency for quantifying, communicating and verifying the carbon footprint of product to organizations, governments, communities and interested parties. The main goal of this ISO is to provide principles and requirements for studies to quantify and communicate carbon footprint of a product based on life cycle assessment specified in ISO 14040 and ISO 14044. This ISO is applicable for cradle to grave studies, which covers all life cycle aspects of a product. It is defined as Carbon Footprint of a Product (CFP).

This ISO is also applicable to partial carbon footprint, which means cradle to gate or gate to gate studies. During communication, there should be clear message on carbon footprint of the product life cycle or partial carbon footprint of a product. The quantification of GHG allows for the individual study, comparative study, assess CFP reduction over time. Method for the allocation, recycling and reuse of materials considered to account carbon footprint of product and methods applied according to ISO 14044 are described.

ISO 14067 also recommends that the carbon footprint of a product shall include quantitative or qualitative assessment on uncertainties. CFP shall include emissions for electricity, but renewable energy source is excluded from the mix to avoid double accounting. Significant GHG emissions and removals as a result of direct land use change, indirect land use change and use of biogenic and fossil shall be considered for CFP. Soil carbon change, carbon storage in product, technology for carbon storage and capture shall be reported separately with verification.

For the communication purpose, ISO 14067 recommends to adopt principles and requirements of product category rules (PCR) in accordance with ISO 14025 and need to be verified by a third party verification team. The plan is not intended to support comparisons. In addition, it provides requirements and guidance to ensure comparability, reliability and comprehensiveness of the communication. Carbon footprint communication shall make clear statement on carbon footprint of a product life cycle or partial carbon footprint. It is noted that the carbon footprint of a product is only comparable to similar product category.

ISO 14067 provides guidance and principles for the communication of carbon footprint on following levels*:*

- Business to business communication
- Business to business communication that is publicly available

- Business to consumer communication
- Performance tracking that is publicly available

4.4.3 Basic requirement for carbon footprint of a product

Requirement for carbon footprint (CF) quantification and communication is discussed on the basis of ISO committee draft 2 -14067 - Carbon footprint of products.

Requirement for CF quantification

Carbon footprint of a product can be quantified considering either all stages of the life cycle of a product from raw material acquisition to final disposal or one or more stages, processes or modules from the life cycle of a product. CF covering all stages of a product is called carbon footprint of a product (CFP) and later one is called as partial CF.

The quantification of CFP or partial CF shall be based on Life Cycle Analysis (LCA) methodology according to ISO 14044.

Biogenic carbon, fossil carbon, land use carbon, soil carbon change, carbon storage in products, carbon capture and storage and air craft emission shall be assessed and presented separately.

The relative principles of CF quantification are iterative and follow scientific approach. Collected data, methods and results should be having relevance, completeness, consistency, accuracy, transparency and avoidance of double counting.

There are some considerations while accounting carbon footprint of product. All GHG emissions and removals arising from the use stage or from end of life occur within ten years after the product has been brought into use may be treated and accounted at the beginning of the assessment period and included in the Carbon footprint of a product. Emissions over more than ten years shall be included but reported separately. Inventory data for electricity, land use, soil carbon change, carbon storage, carbon capture and air emission are needed for complete accounting of carbon footprint.

Requirement for CF communication

Carbon foot print of a product can be communicated through product declaration, claim and labele following certain principles and requirements of ISO standards (ISO 14020 series and ISO 14067). General principles of ISO 14020 - Environmental Labels and Declarations shall be used as principles for CF label and declarations. Requirement and principles of ISO 14024 Type I: environmental labeling, ISO 14021 Type II: self declared environmental claims and ISO 14025 Type III: Environmental declaration shall be used for the purpose of carbon footprint label of a product, self declaration claim of carbon footprint of a product and CFP declaration, respectively. Carbon footprint communication process and program shall follow similar process and program as ISO 14020 series. For example, similar product categories rules and program of ISO 14025 is applicable for the carbon footprint program. Instead of these three communication processes, option of other two communication processes is included in ISO 14067, which are carbon footprint report and carbon footprint performance tracking report. Table 4-4 shows options of reporting for EPD documentation and Carbon footprint of product documentation

Table 4-4: Reporting and documentation options for EPD and CFP

Environmental product declaration and labeling (EPD)	Carbon Footprint of products (CFP)
1. Environmental label 2. Environmental claim 3. Environmental declaration	1. Carbon footprint label 2. Carbon footprint claim 3. Carbon footprint declaration 4. Carbon footprint report 5. Carbon footprint performance tracking report

PCR is very important in communication process, while a product is compared to other comparison requires calculation according to similar carbon footprint product category rules (CF-PCR). This consist identical functional unit, equivalent system boundary, and equivalent description of data and so forth. PCR requirements and contents include clauses of ISO 14025, which are given in Table 4-2. CF - PCR document and result of carbon footprint study of a product or communication document should be verified by verification team. Carbon footprint communication program should be participatory and should have significance and fairness. Detail information regarding different five communication mechanisms and required specification and principles are described in ISO 14067.

Following information shall be provided on the website or at the point of sale when carbon footprint communication is directed to the consumer.

- The methodology used
- The results of the third party verification
- The involvement of interested parties
- Background information on GHG emissions e.g.
  - Emissions and removals deriving from different life cycle stages
  - Total emissions and removals for the single product
  - Total emissions and removals for the functional unit
  - Storage time period for biogenic carbon in the product
  - Information on data quality requirements fulfilled

Chapter 5: System model of road transportation

5.1 System of transportation

Transport refers to an activity that facilitates physical movement of goods and individuals from one place to another. It supports trade and industry by transporting raw materials for production and finished product for consumption. Individuals, industry and business sector that engage in such activities are collectively called transportation. Transportation sector has a major role in this globalized world. It is a mean of service that connects social economic activities around the world. Even though, transportation sector is contributing for economic development, it also has many environmental and social consequences in regards with sustainable transportation, both from local to global perspective. According to Han and Naeher (2006) one of the major issues is global emission and air pollution. Emission of carbon dioxide (CO2), Nitrogen oxide (NOx), Carbon mono oxide (CO), Particulate Matters (PM), Nitrogen dioxide (NO2) Polycyclic Aromatic Hydrocarbons (PAHs) and Volatile Organic Compounds (VOCs) are major emissions that come from transportation and are responsible for both air pollution and degradation on human health. More importantly, CO2 is degrading climate because of increasing greenhouse gases in the atmosphere and is a global issue.

Different transportation modes contribute different intensity of emission. For example in the UK direct emission of CO2 from personal vehicles raised from 59 million tones in 1990 to 63 million tones in 2002, which is 6 percent increase. In the same period, emission from shipping is increased by 25 percent. Aviation transport is increasing world wide and has also large effect on the climate change. According to Intergovernmental Panel on Climate Change (IPCC) estimation made in 2001, aviation caused global warming amounts to 3.5 percent of total human induced global warming, which may rise to 15 percent by 2050. Carbon emission from transportation has direct/indirect impacts on climate and on human health (Woodcock et al 2007).

Hence, transportation sector has considerable challenges that need to be taken care to convert it to sustainable transportation. Reduction of emission while developing infrastructures (construction of road way, rail way, airports etc.), reduction in fuel consumption, seeking for alternative energy, energy efficiency technologies, change in travel mode and change in behavior are some of the major ways that may help to achieving sustainable transportation. Extend of emissions may be different for different form and mode of transportation. From an environmental perspective the issues are not simply the amount of transport and associated infrastructure but also who, how and it is used. For example, one ton of cargo moved by rail to the destination likely to have different impact than one ton moved over by a truck since different mode of transportation have different emission impacts. While considering sustainable mode of transportation issues need to be broken downed into different elements or stage of the transportation system as indicated in Figure 5-1

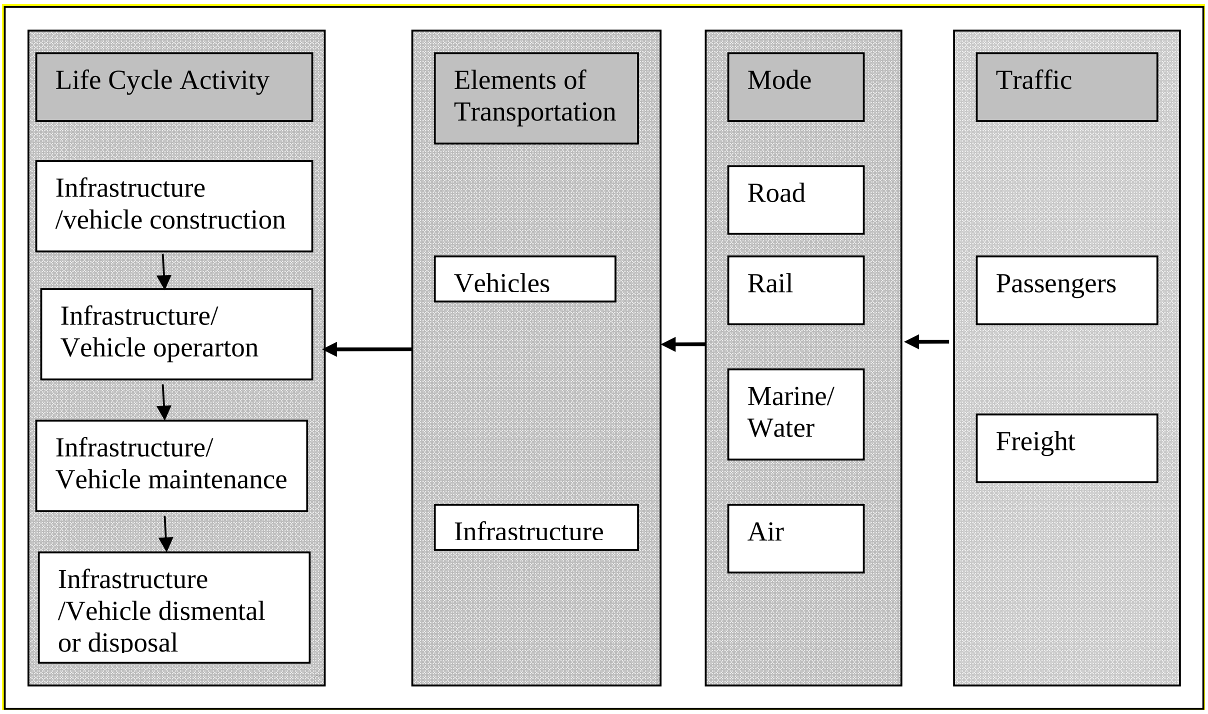


Figure 5-1: Elements of different mode of transportation for sustainable decision making (modified after Button, 2009).

Figure 5-1 shows major elements of the system of whole transportation sector. Transportation provides service to carry people (passenger), goods and raw material (freight) from one place to other. Four modes of transportation in Figure 5-1 are main means to provide service of transportation in modern era. Function of each mode of transportation is possible with the help of two major elements, i.e. infrastructure and means of carriage or vehicle. Life cycle activities of elements of transportation mode should be considered for the sustainable decision making so as there is minimum chance of environmental problem transformation. The decision over best option in the sense of environmental performance is more rational if environmental performance of the mode of transportation is analyzed through life cycle perspective.

Carbon footprint with each transportation mode should be looked through whole life cycle of a system. In this way it is more logical to compare mode of transportation to each other. Consideration of all activities of the life period of transportation is important to know actual carbon footprint from each mode of transportation. It is the requirement of ISO 14067 that recommends considering life cycle activities of product and service to calculate Carbon footprint of the products and services. These activities in the case of transportation consist of infrastructure development and vehicle manufacturing, their operation (travel), maintenance and disposal. Among two major elements, life period of the road infrastructure is considered in this study that will later lead to describe carbon footprint of road construction.

5.2 Mode of transportation: Road

According to Figure 5-1, road is one type of transportation mode among other three. Road is the mode of transportation that connects one place with another by surface on the land. There are varieties of road transportation vehicles like cycles, motorcycle, cars, trucks, buses etc. Before motor driven vehicle were developed animal and man driven vehicles were in use. Development of motors revolutionized transport system and is one of the important parts of socio economic activities in the world. Road system of both developed and developing countries represents significant part of the country's infrastructure development and plays important role in improving socio-economic condition of the country in concern. The road transportation is very flexible in comparison to other modes of transportation because it provides house to house services where other means of transportation are not connected. Because of this flexibility, extension of road infrastructure and use of road vehicles are very common in each corner of the world.

Roads have direct influence on the natural environment through their physical encroachment on the landscape, emission and pollution during life cycle function. Through the life span of a road, traffic causes number of environmental impacts, the major one is the air pollution effect both locally and globally. However, the construction and reconstruction of roads and road maintenance activities also contribute to air pollution (Lindgren, 1998). This study is focusing on infrastructure of road transportation and their environmental implication in the view of carbon footprint. Following chapters are focused on road infrastructure and it's system, which are responsible for the carbon footprint.

5.3 Life cycle system for road transportation

Infrastructure for the transportation service is a key element of the transportation system. Highways, city roads, rural roads etc. are sort of road infrastructures. Various type of roads like black topped road, earthen road, gravel road etc. exists, which are categorized depending upon vehicle intensity and maximum load to be transported (Watson, 1994).

Infrastructure for road transportation system increases with increasing economic development of the country. Road infrastructure is needed for the economic growth and development.

Development of industries means more supply and demand of products and increasing economic status of people means more personal vehicles. Hence, there are two way relationships between road and infrastructures (Nijkamp, 1994).

From system thinking perspectives, each life cycle phases of road infrastructure is responsible for carbon emission. Therefore, it is necessary to understand system model of the road transportation infrastructure through life cycle perspective. Figure 5-2 presents system of the road through life cycle perspective. The figure shows four major phases of life of the road. It starts from planning and ends with disposal or removable of road. Each phase comes into action with the input of materials, resources and energy. Arrows in and out of the system illustrates input and out flow of the materials. Outputs are the functions of phases as well as different environmental impacts. Environmental impacts could be greenhouse gas emissions and other environmental impacts. Outputs that interact with environment are the matter of interest for the environmental analysis. For example greenhouse gas emission shown in Figure 5-2 is of interest for analyzing carbon footprint of the road.

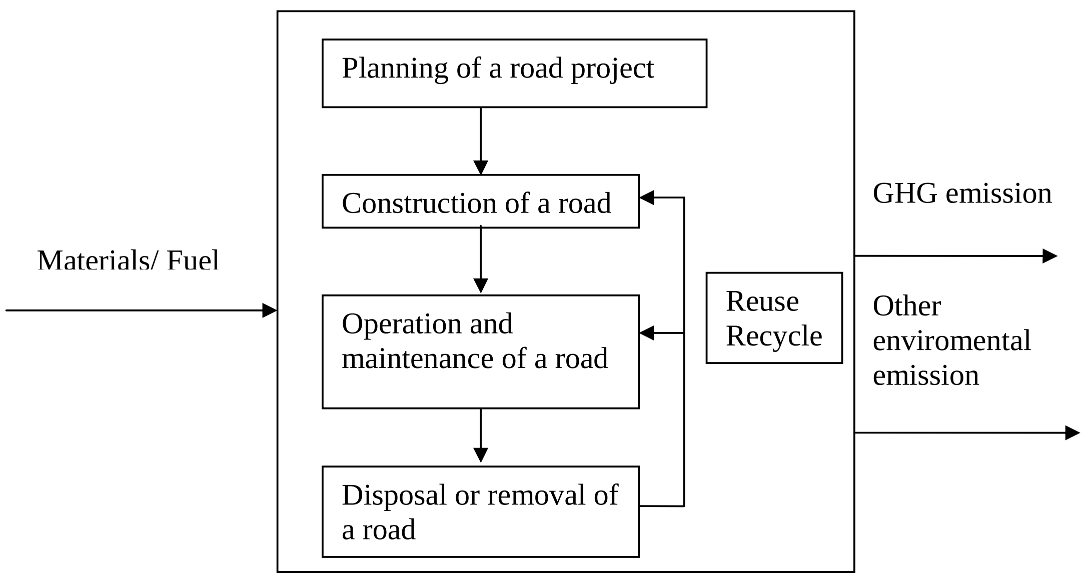


Fig 5-2: System model of a road through life cycle perspective

5.3.1 Planning and design of a road

Planning phase is important for decision making to build specific type of a road. Selection of road alignment, detail design of the road, material and cost estimation, bidding process etc. are the activities during planning phase of the road. Therefore, many actors like designer, owner, experts, material suppliers, investor and contractors are involved during planning phase. Type of road and standard of the required road materials are decided on the basis of national standards, geological settings and topography of the area. Rajgopal (2007) highlighted that many literatures have not accounted this phase as life cycle phases of the road. The reason could be due to insignificant emission at this early stage of planning. But this phase is important phase for choosing environmentally friendly construction materials and process by all related stakeholders.

Length and width of the road, thickness of different construction layers of the road and supporting structure are defined during design process. Decision is also made on the construction materials among several available alternatives. Construction time and work of the project are decided and maintenance and operation aspects are also described in this stage in many cases (Birgisdottir, 2005).

5.3.2 Construction of a road

The construction phase includes mobilization of all materials, machinery equipment and manpower to construction site till the road comes in operation. Road construction constitutes several work elements such as excavation in order to obtain desired road alignment, foundation reinforcement, construction of embankment, construction of base and sub-base courses, wearing course and other supporting elements. Cutting, filling and embankment construction are major activities. Most of the big road projects may also consist of bridges and tunnels, which are also part of the road system. Owners, contractors, engineers, material suppliers and skilled manpower are the key actors who play key role during construction phase of a road. The construction camps are needed in different places if the road project is large in scale, which is also a part of road construction system that contributes to emission. Road construction may last from few months to several years depending upon it's scale (Watson, 1994). Birgisdottir (2005) states that the road construction work can be divided into major three stages that are;

(i) earthworks that can vary due different geological and topographic features of the area. Earth work consists of clearance of vegetable and humus soil from the area, mass removal, excavation of trench for drainage, excavation in the hill side slope and filling in the valley and so on.

(ii) construction of pavement, bridges and tunnels.

(iii) additional works that include different supporting structures like fences, trenches, road side lamp, road marking and drainages.

5.3.3 Operation and maintenance of a road

Operation phase of the road begins after the completion of road construction. During operation phase periodic maintenance of the road is required, which is called operation and maintenance phase of the road. This phase includes (i) winter road maintenance in terms of road salting and snow clearing. (ii) regular maintenance by clearing and moving waste and vegetations from and near the edges of road, (iii) pavement maintenance by replacing wearing course on the carriageway and road structure in the life time of the road.

The purpose of road maintenance during operation is to keep the road as safe and acceptable condition as possible during its service life. Both operation and maintenance reoccur several times during the lifetime of the road. The operation and maintenance occurrence and periods are determined by the desired road standard, density of traffic, weather pattern of the area and so on (Brigisdottir, 2005 and Stripple, 2001).

Road is one of the major infrastructures of every country, which needs significant investment to build the structure. Therefore, it is important for regular maintenance of the existing road, which extend the life of the road and saves investment by avoiding new construction.

5.3.4 Disposal or removal of a road

Normally a road does not have end of life. The road is built and thereafter used year after year with improvement. If the existing road is not enough for vehicle density, generally the existing road is expanded. If the road reaches the stage of removal or demolition, these are often left without being demolished or recycle the demolished material in other road projects or decomposed (Brigisdottir, 2005 and Stripple, 2001).

5.4 System elements of road project

In general, road projects include not only pavement but also associated structures such as bridges, tunnels and retaining walls together with other structures and are part of the road system. Bridges, tunnels and other highway structures are fundamental to the road transport infrastructure because, they form essential links in the road network. A road network contains many different components from materials in the road itself to peripheral equipment such as lighting, traffic lights, game fences, road signs, bridges, tunnels etc. Bridges and tunnels are fundamental elements of a large road infrastructure system because, they are essential in many places to link the highway across the obstacles along the road alignment. Road system and it's elements and sub elements are presented in Figure 5-3.

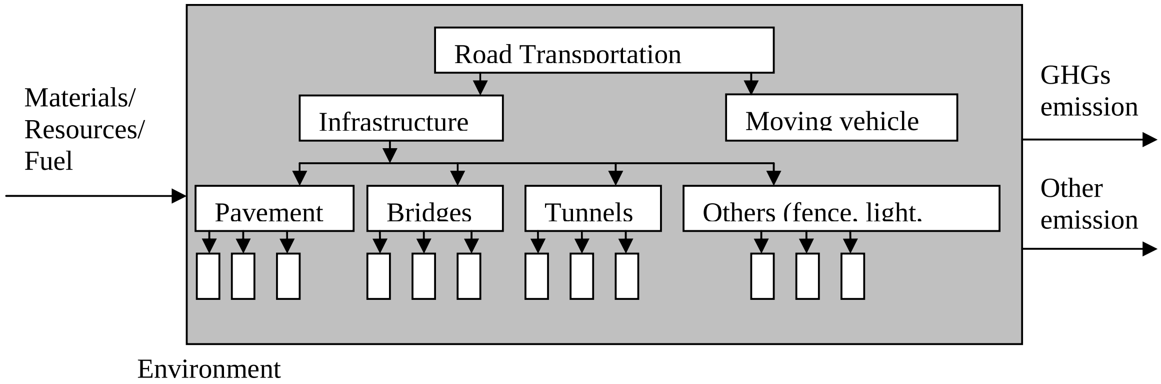


Figure 5-3: System elements of road transportation.

The figure 5-3 shows that the road transport system has two major elements, which are vehicles and infrastructure. The figure also shows input flow of materials, resources and fuel for the construction of each elements and output flow in the environment. As an example, greenhouse gas emission is shown in the figure, which is an environmental impact dealt in this study. Infrastructure and vehicle have their own sub elements. Here, road infrastructure is discussed. Generally, the large scale of road infrastructure covers bridges, tunnels along pavement and other physical structures like fence, electricity and sign boards. Every structure is made of different elements. As an example, a road showing main element in the road is presented in Figure 5-4.

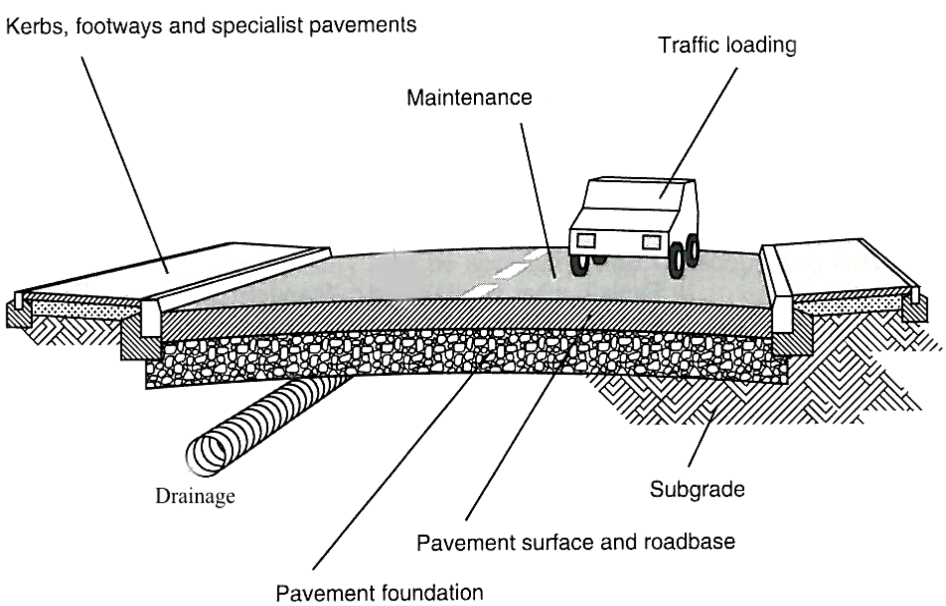


Figure 5-4: Elements of road (source: Watson, 1994)

The figure shows different elements of road like pavement, drainage, footways and vehicle. Maintenance is also a phase of a road which is also indicated in the figure.

Every structures or elements of the road need different materials and products. Each and every products and materials have their own life cycle from extraction to production until the end of their use. For example we can take wearing layer of pavement, which needs bitumen. Life cycle of bitumen starts from the extraction of crude oil process followed by oil refinery, asphalt plant, use for wearing course and some time waste handling. Figure 5-5 shows the life cycle of materials for the end product and service. The figure indicates that life cycle of a product starts from extraction of raw material from the nature then it moves to the stage of material production and to main product production. After the production process the product inters into the use phase of life cycle and ends with waste handling. Waste handling could be reuse, recycle or decomposition in nature.

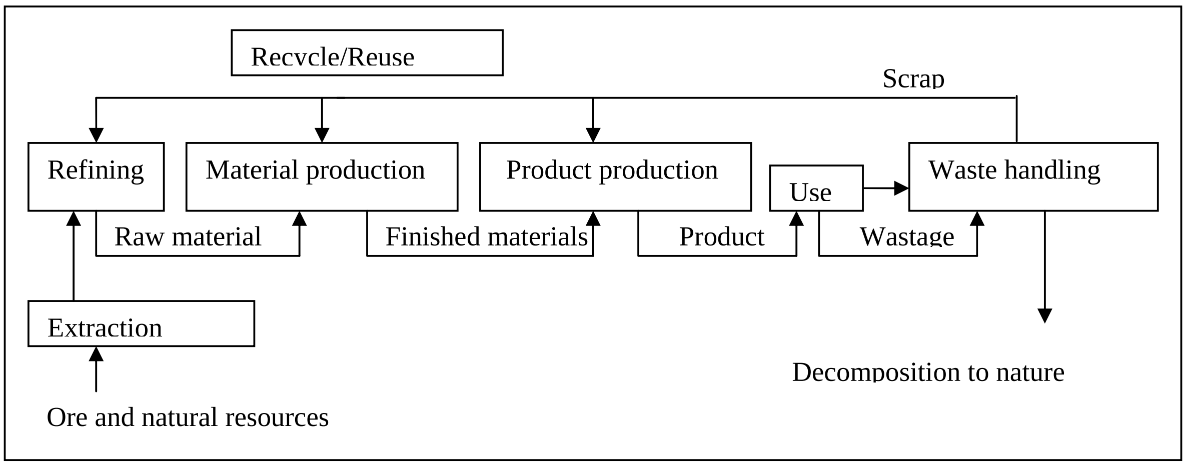


Figure 5-5: Life cycle of material production needed for road construction.

Environmental consequences due to road construction cover broad system boundary in the case if environmental impacts are accounted through life cycle system perspectives. Every material and product that is used for road construction is produced due to demand for road construction. Therefore, environmental consequences of all these products required for road construction are counted in life cycle system thinking.

5.5 Environmental aspects and impacts from road construction

Road construction needs large amount of construction materials, considerable area of land and energy. Stripple (2001) states that the construction, operation and maintenance of road network have in many cases, from an environmental point of view, been regarded as less significant compared to the impact of vehicles using the road during its lifetime. Any unambiguous evidence of this or any quantification of the conditions have not been presented, especially not seen from a life cycle assessment perspective, which includes a system of direct road work, materials, transportation and peripheral equipment, etc. Mroueh and et al (1999) mentioned that extraction of materials, product manufacturing and transportation of material for road construction has different environmental impacts. These environmental impacts are atmospheric emission, dust emission, substances leaching into the soil and water, noise and land use.

The atmospheric emission originates from machinery movement, resource extraction, product process and delivery of materials. Dust is released during aggregates production process and handling. Leaching is one of the major environmental impacts from road construction. Water soluble substances present in the materials is transported by run-off water and contaminate ground water, soil, river and sea. Noise emission are usually reported as sound level from different machine work like excavation, crushing plant, blasting stone, paver and roller etc, which are sources of noise in the road construction. Land use causes different environmental consequences in the landscape, soil, water, fauna and flora. For example, excavation of soil for road structures alters the landscape, loss of habitat of animals and on valuable plants and many ecological settings (Mroueh and et al, 1999; Horvath, 2004 a.; Spellerberg, 1998).

Choice of materials makes difference in environmental impacts. In recent years crushed concrete from demobilized buildings and municipal solid waste are being used for road pavement purpose. Reuse of materials gives positive impact on non renewable natural resource depletion, energy consumption. However, other environmental impacts such as leaching of hazardous or toxic substances to soil and water and degradation of human health are environmental problems from waste material handling (Petkovic and et al, 2004; Horvath, 2004 b).

5.6 Carbon footprint and road construction

Atmospheric emission, greenhouse gases from the road construction process are calculated for the case in this study. Accounting greenhouse gases is important to deal with the growing risk of climate change. ISO 14067 Carbon footprint of products refers greenhouse gases as carbon footprint.

According to the Asian Development Bank (ADB) (2010) "*Carbon footprint of a road can be defined as the total amount of CO2, and other GHGs (direct and indirect) emitted over the full life cycle of a road. Life cycle includes construction, operation and maintenance phases. Its life ends when the road needs to be completely reconstructed or when it is abandoned*."

It is the responsibility of every sector in carbon footprint accounting, reporting and taking action for reduction. Therefore, it is advantageous to reduce risk of climate change by carrying out carbon footprint accounting of road construction.

As have been discussed, one large road project covers broad system boundary. Through system thinking and life cycle perspective tone should look every materials used for the completion of road project and carbon emission during their life cycle phases. This means that materials for the road system represents quite large industrial sector of the economy due to the need of varieties of materials for the road construction. According to carbon footprint ISO 14067 there is a need to consider every material input and greenhouse emission in each life stage of the materials for carbon footprint of product and service.

Hence, road construction and maintenance has significant impact in producing GHGs potentials while analyzed every materials and phases of road through life cycle perspective. CO2 emission on the choice of materials, mode of transport and transportation distance, alternative design options are necessary to be analyzed to have better understanding concerning the extent of GHGs production from the road construction.

The framework of carbon footprint accounting and documentation methodology for road construction with the view of system approach is discussed in next chapter.

Chapter 6: Framework for carbon footprint documentation

Upcoming international Standard ISO 1406 emphasizes carbon footprint of the products should cover all embodied carbons in materials and activities. As discussed in previous chapters, the most debated issue at present is climate change caused by environmental exchange between production, construction and the nature. System thinking is one of the approaches to deal with all elements of the system related to the product and their interaction with the environment. Therefore, in the case of road all connected elements should be analyzed to understand its interaction with environmental systems and effect on different faces of environment. Life cycle phases of the road and it's elements are discussed in Chapter 5, which needs to be modeled for carbon footprint of a road.

The scope of carbon footprint documentation should satisfy the need and requirement of stakeholders. The system and system boundary is decided on the basis of stakeholder's feedback and their needs. Similarly, environmental performance indicator should also fulfill the demand of stakeholders. In the case of carbon footprint of road construction, performance indicator is CO2-euivalent emission, which could be the demand of any of stakeholders. Therefore, possible stakeholders and their needs and requirements are briefly discussed below before describing step by step process for documentation of carbon footprint of road construction,

6.1 Stakeholder and demand

The need and requirement for carbon footprint accounting is defined or demanded by stakeholders. Stakeholders demand to the responsible organizations to perform carbon footprint accounting. Stakeholders and their demand regarding carbon footprint of road is briefly mentioned in Table 6-1.

Selection of the system for carbon footprint analysis and documentation depends on demand and requirements of stakeholders who involve directly and indirectly in road system. If the requirement of stakeholder is to provide carbon footprint of whole road project from planning to construction and operation and end of life, all life phases of the road should be accounted. If stakeholders want carbon footprint of road only from construction phase then all materials, resources and fuel for the construction phase and GHG emission from these processes should be considered. Study system and system boundary should satisfy the requirements of stakeholders. Possible stakeholders of road construction, their requirements and how the need can be satisfied are tabulated in Table 6-1.

Table6-1: Possible stakeholders for road construction and their need & requirements

Possible stakeholder of road construction	Need and requirement	Why it is needed	How the need can be satisfied
Owner (for example Statens Vegvesen in Norway)	Optimize the efficiency of road construction with less GHG emission. Documentation of carbon footprint of road according to ISO 14067. Carbon footprint declaration of the road	Because there is emission of GHG during road construction from different process. Because it is useful for the organization's performance improvement. Because other stakeholders demand to provide carbon footprint information.	Changing the construction process, material type & amount, fuel source & quantity and technology. Documentation of all input materials and their contribution in GHG emission Providing information of carbon footprint of the road to consumers and stakeholders.
Contractor	Submission the estimation of carbon footprint from the road construction project along contractual procedure	Because there is demand from owner to present the carbon footprint performance from owner	Providing information of carbon footprint of the road to owner
Society / consumers	Want to know the carbon footprint performance of the road	Because society are aware toward climate change environmental problems	Providing information of carbon footprint of the road through documentation or product declaration
Local and national governmental authority	Document the national carbon footprint. Reduce the national GHG account.	Because it is responsibility of every nation to document. Because there is national commitment (for example in Copenhagen Accord)	Applying national and local law regarding carbon footprint performance documentation.

6.2 Step by step process for carbon footprint documentation

Calculation and documentation framework can be made using system engineering approach on road construction. System engineering approach makes it easy to define the problem of the case system. In this chapter, application of system engineering approach in carbon footprint accounting and documentation for road construction is discussed step by step. This step by step process is the combination of system engineering (SE) principles and life cycle analysis (LCA) methodology as illustrated in Figure 6-1. System engineering principle helps to understand associated problem clearly, while LCA methodology assists to account carbon footprint of the system quantitatively. The combination approach is proposed to account and document carbon footprint of road construction. The concept of LCA and system engineering are already discussed in Chapter 2 - Research methodology.

Figure 6-1 is the illustration of the framework for carbon footprint documentation. The figure shows step by step process and it's connection with principle of system engineering steps and life cycle analysis methodology. System engineering steps are denoted by SE 1 to SE 6 and arrows show the link to step by step process in Figure 6-1. Decision in every step is made to satisfy the need and demand of the stakeholders.

6.2.1 Decision making stage

The need for carbon footprint accounting of the road is identified with the demand of people, industry or the government who are the stakeholder of the road .Defining carbon footprint as performance of the road is the reflection of step 3 of system engineering. Step 3 of system engineering is to specify the performance of the road. Therefore, in the decision making stage, decision maker should be cleared that which type of road they are going to consider for the analysis stage to show the performance of the road. In addition, the analysis may cover either whole life cycle phase or only construction phase and should be decided. Performance of the road may present either whole life phase or only one phase of the road. Steps in decision making stage influence on the analysis results. Four main steps in decision making stage are described following.

Step I: Select the type of road

In this step, if road is under planning process, the decision makers should know, which road they are going to take for the analysis. The selection of road should satisfy the interest of the stakeholders. The interest of stakeholders could be in any type of road such as highway, city road, rural road or agriculture road. For example, government of the country may desire carbon footprint performance documentation of the national highway.

If road is already constructed then there is no need for further work in this step. If the analysis is connected to the road under planning then size, type and location should be optimized, which makes it easy to define the sub-systems and elements of that road. This is done based on the purpose of the road, vehicle density and geographical character of the area in concern. Various type of road such as earthen road, gravel road, asphalt road and concrete road are in function.

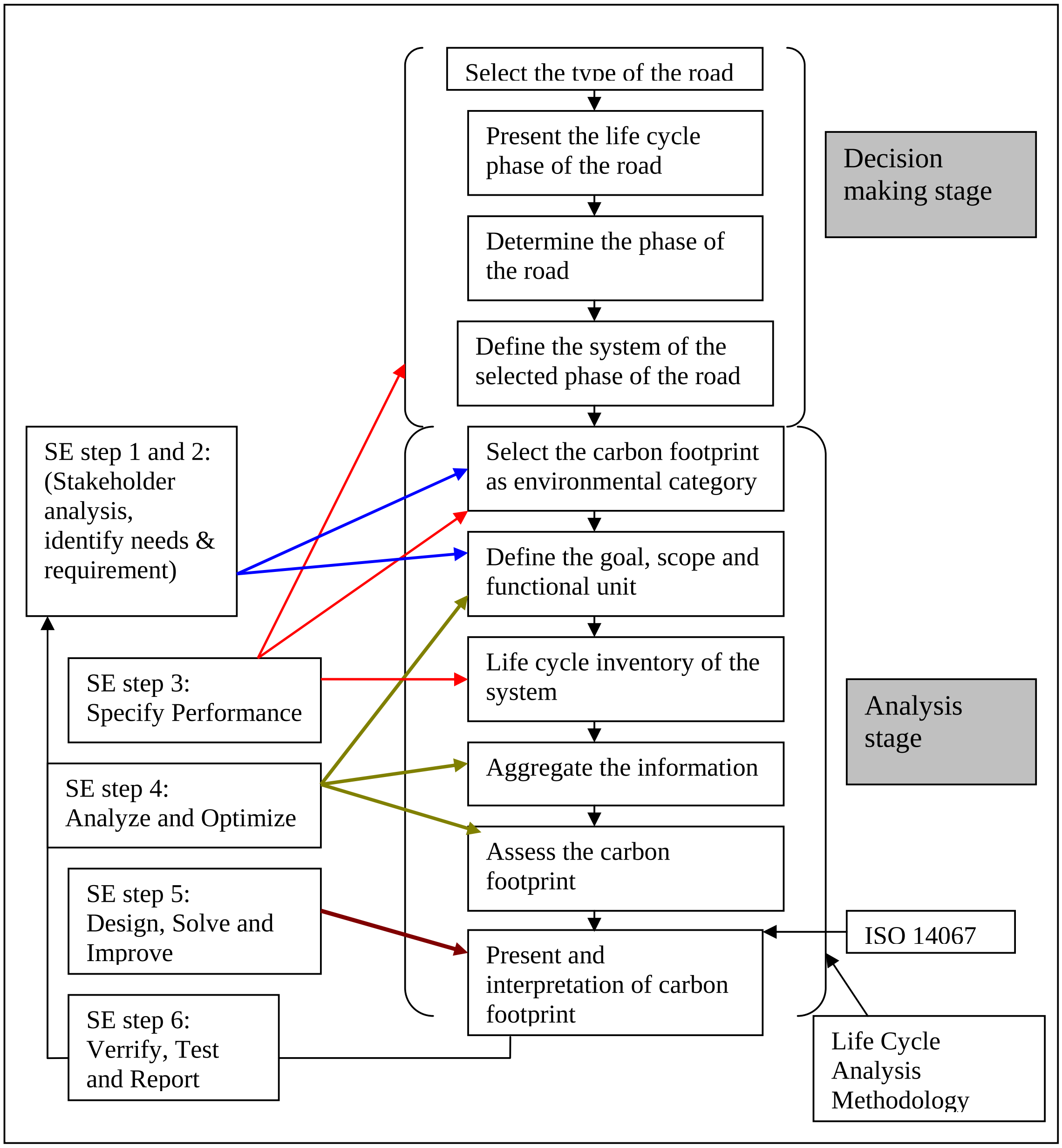


Figure 6-1: Framework for Carbon footprint documentation of road construction (inspired by Fet et al, 2008)

In case of highway concrete and asphalt road are common pavement materials. These roads have different size like one lane to several lanes depending upon traffic density. Type and size of road makes different in the extent of environmental impacts. If the road is narrow and traffic density is high there is possibility of high GHGs emission from vehicles during operation. Referring to the International Road Federation the Asian development bank (2010) has indicated that improving traffic fluidity and reducing contestation will lead to the reduction in fuel consumption and is an effective way in reducing GHG emissions in total.

Hence, the type of road should be decided before the start of next step. Depending upon involved parties different road alternatives can be looked upon during planning phase for comparative study and best alternative can be selected. If there is demand for carbon footprint of the already built road then just defining the type of road is made in this step.

Step II and III: Life cycle phase and study phase

It is the second step for decision making. In Chapter 5 four life phases of road system is discussed. Among four phases of the road, first phase (planning) is generally not considered for environmental accounting since it gives insignificance GHG contribution at this early stage. Step II and III are decided to fulfill the system engineering step 3. The decision should reflect stakeholder need, which is step 1 in system engineering principles. In system engineering principles there is always reflection from every next step to first steps (see Appendix A). If stakeholder requirement is to know the carbon footprint of all phases of road then these should be considered for the study and documentation. Decision of this stage makes difference on the selection of system and elements of the road for the analysis.

Step IV: Defining system of selected phase of the road

The whole road construction project consists of the construction of pavement, bridges, tunnels, waterways (drainages), electricity distribution etc. Therefore, at system defining stage the decision is made on which system is to consider for the environmental analysis. It also depends on stakeholder demand and owner's ability to pay for. For example if any authorities wants to document carbon footprint of a road project according to ISO 14067 Carbon Footprint of product, they need to consider all system and every elements and materials flow for all life phases of the road; i.e. construction, operation, maintenance and even decomposition. Therefore selection of phase and system of the road is reflection of the need.

6.2.2 Analysis stage

This stage is divided into different six steps (see Figure 6-1). Life cycle analysis methodology is applied for carbon footprint analysis of the road. Different steps of this analysis stage and it's link to LCA and system engineering is discussed below. The steps discussed below are the continuation of the steps discussed above.

Step V: Selecting carbon footprint as environmental category

This step accounts for selecting environmental performance indicator of the system. This step fulfills the objectives of system engineering steps 1, 2, and 3. Performance indicator is selected according to the need of the stakeholders. Different environmental performances can be analyzed and documented. Some of the examples are percentage of recycle material used during constructions, use of renewable resources, non renewable resources, emission and other pollutants,

In the case of carbon footprint, the performance indicator is CO2- equivalent per functional unit. In this step decision should be made for the consideration of either all GHG emissions recommended by Kyoto Protocol or else. If the purpose of carbon footprint calculation is to fulfill the norms of ISO 14067, another decision that needed to be made in this step is documentation of carbon footprint of the product with the consideration of biogenic carbon, fossil carbon, land use carbon and so forth. Decision maker should be clear on whether all aspects of carbon footprint like GHG emission, GHG storage and capture should be accounted or not.

Step VI: Defining goal, scope and functional unit

Decided phases and system of road will define the goal of the analysis. This step is first step of LCA methodology that satisfies step 4 of system engineering principle (Figure 6-1). If the phase and system of the road is construction phase and only pavement or street is considered then goal, functional unit and system boundary of the study may be defined as carbon footprint performance of the system;

Goal: The goal of LCA methodology is to find the carbon footprint of pavement during road construction phase.

Functional Unit: The functional unit is either per km road construction or complete project.

System boundary: Decided materials input and output are the system boundary for the carbon footprint calculation. If material transportation is not considered for the carbon footprint calculation then transportation process within the system should be out of system boundary even though it is a part of the system.

Step VII: Life cycle inventory of the system

Step VII is carried out in LCA methodology and it is the requirement of system engineering step 3 - specify performance. Life cycle inventory covers collected input and output of every material that goes for the system boundary of the road construction. Different types of material and their production process are inputs. If specified performance in SE step 3 is carbon footprint, GHG emission, storage of carbon and carbon capture from these processes are output for the carbon footprint accounting during construction of road.

The needed information and data for the inventory stage is obtained from the actual field data as well as from secondary sources. Material information is generally collected from documentation record, if maintained. In this stage there is a need of expert specialist who knows every elements of the whole system of the road. List of input and output are tabulated or listed on the basis of specialist knowledge. In LCA process generally flow chart with material input and output is prepared in this step For example, if fuel is one of the inputs for the road construction, carbon emission per unit fuel combustion (for example per liter diesel) is emission output . How much carbon is embodied in per unit fuel is further needed for life cycle point of view, which means carbon emission due to oil extraction, refining and transportation. Therefore, all these foreground and background processes should be presented in flow chart of fuel consumption.

Step VIII: Aggregate the information

Step VIII is the aggregation of all material input, process and carbon emission, capture, storage per functional unit according to the flow chart made in step VII. As shown in Figure 6-1, information is aggregated in system engineering step 4 - Analyze and optimize. If the carbon footprint per km road construction is objective of the scope of the study, then GHG emission from every process and material production for one km road is aggregated. For example, requirement of material for one km road construction and carbon footprint from these materials should be aggregated in first step. It is called foreground information in LCA methodology. In LCA methodology background information is also needed that give information about how much resource and energy is needed to produce products that require for one km road construction. Through life cycle perspective and system thinking principles system boundary goes back to resource extraction. Therefore, information needed to be aggregated from foreground system and background system depending upon defined system boundary. It is the major work for the quantitative analysis of the carbon footprint. Input and output of every process is relevant for the result accuracy.

According to upcoming ISO 14067 Carbon Footprint of Product, other information related to GHG should be collected. These are (i) change in soil carbon due to modification of land use, (ii) carbon removable from nature for example extraction of trees and shrubs, (iii) carbon storage in the materials for example in bitumen and (iv) carbon capture. So, carbon footprint accounting process demands multidisciplinary team work with knowledge and experience in different discipline.

Step IX: Assess the carbon footprint

As indicated in Figure 6-1, this step also has connection with system engineering step 4 - Analyze and optimize. In this step amount of defined GHG emissions per functional unit are tabulated if the carbon footprint is the objective of the analysis. Global warming potential is the impact category for carbon footprint. Therefore, all GHGs should be multiplied by respective characterization factor to get CO2 equivalent emission. Table 2-1 (Chapter 2) gives conversion of different GHG to global warming potential. In this way GHG emission are converted to kg CO2 equivalent and added altogether to get carbon footprint per functional unit within defined system boundary. In this step carbon emissions, removed, stored and captured, all are documented if these aspects are considered while analysis.

Step X: Presentation and interpretation of carbon footprint

In this step results are presented in the form of report. Interpretation of the results is made and feedback and recommendations are given in the report. Presentation and interpretation is the process for system engineering step 5 - design, solve and improve (Figure 6-1). Report with presentation and interpretation is prepared on the basis of objective of analysis. If the analysis is carried out for documentation purpose then presentation and interpretation of results are important. If the analysis is carried out for the future improvement then feedback and recommendations are made in addition to the results. Hot spots of carbon emissions are pointed and possible suggestions are recommended.

As indicated in Figure 6-1 the results in the report is verified and tested following system engineering principle step 6. If the purpose of the analysis is to follow the ISO 14067 then report or documentation should be made as per the requirement of ISO and it should be verified by the third party to check the validity of the report according to the ISO norms. If carbon footprint analysis and documentation process is not enough, the process again repeated with adding lacking requirements. Carbon footprint of product or service can be reported in the form of partial carbon footprint or total carbon footprint. Partial carbon footprint of product covers only part of the product's life phases, while total carbon footprint of product covers all parts of the products life phases. System boundary should cover from cradle to cradle product process for the total carbon footprint reporting. Five different options for the Carbon footprint communication process are mentioned in ISO 14067. These options are Carbon footprint declaration, Carbon footprint label, Carbon footprint claim, Carbon footprint report and Carbon footprint performance tracking report. The detail process and aim of this documentation are available in ISO 14067. As shown in Figure 6-1, step X is connected to system engineering step 6 and provides feedback to system engineering steps 1 and 2.

Chapter 7: The study case – E6 Kroppan – Tonstad

The carbon footprint documentation framework is discussed in Chapter 6. First stage of frame work is decision making stage where decision is made for the analysis of road system and system boundary. The discussion made in this chapter is related to the decision making stage of Figure 6-1. The selected case road and the selected construction phase and its systems and elements are discussed in sub-chapters 7.1 to 7.4.

The case is selected based on the communication made by this researcher with Statens Vegvessen officials. The Statens Vegvessen is the owner of this road case, who is one of the important stakeholders. After discussion the owner became interested for carbon footprint analysis of road construction case. Being ready for construction the E6 Kroppen – Tonstad case was found to be appropriate for such assessment.

7.1 Introduction of the case

The case is the extension of bus lane in E6 between Kroppan and Tonstad, which is located about 8 km south of Trondheim (Figure 7-1). The owner of road project is *The Norwegian Public Roads Administration*. The project name is given as "E6 Kroppan – Tonstad - New Bus Lane". The project construction will start in middle of May and will be finished by the end of August 2011. The information related to case is obtained from personnel in Statens vegvessen, Trondheim through direct discussion and e-mail corresponding. According to design this extension of lane is 815 m long and has 5 m widening.

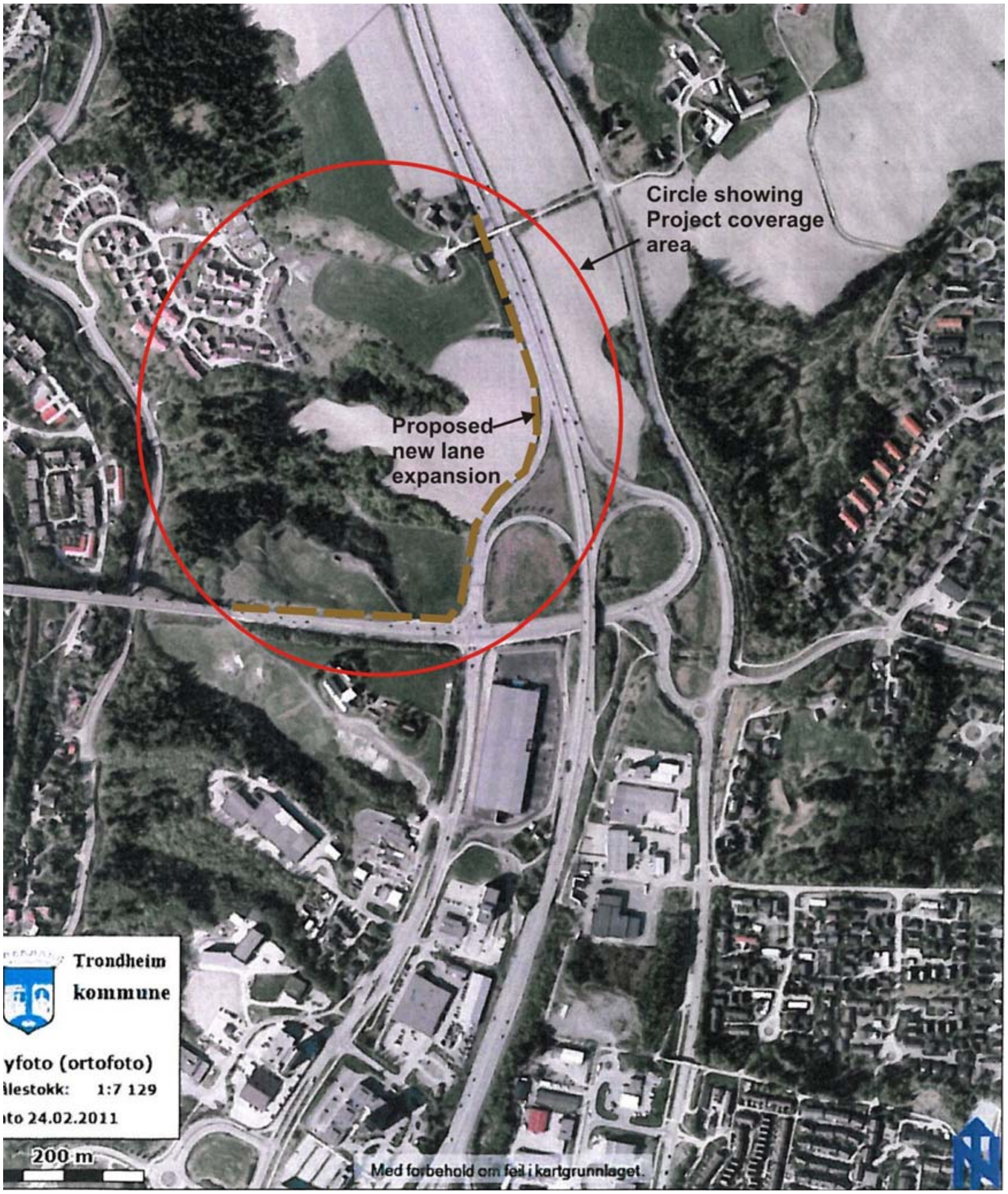


Figure7-1: Proposed new bus lane extension in E6 between Kroppen and Tonstad.

7.2 Life cycle phase of the road

The life cycle phases of the road and selected phase of road for the analysis is developed and illustrated in Figure 7-2. Among four phases shown in the Figure, construction phase of road is selected for the analysis.

7.3 System of the selected phase of the study

Generally, length of the road, width and thickness of different layers of the road and supporting structures and elements are defined during pre-construction phase, which is called design phase of a road project. Based on road design a decision is made on the types and sources of different construction materials. Since this case is extension of a lane, the main construction work consist of expansion of existing pavement, new water drainage system, relocation of electricity cable, relocation of lighting columns, erection of barriers, and removal of mass (Figure 7-1). The construction works are divided into three major parts consisting removal and transfer of existing structures, construction of new structures and waste or residual management. The functional system of the case study road and link between them are illustrated in the Figure 7-2.

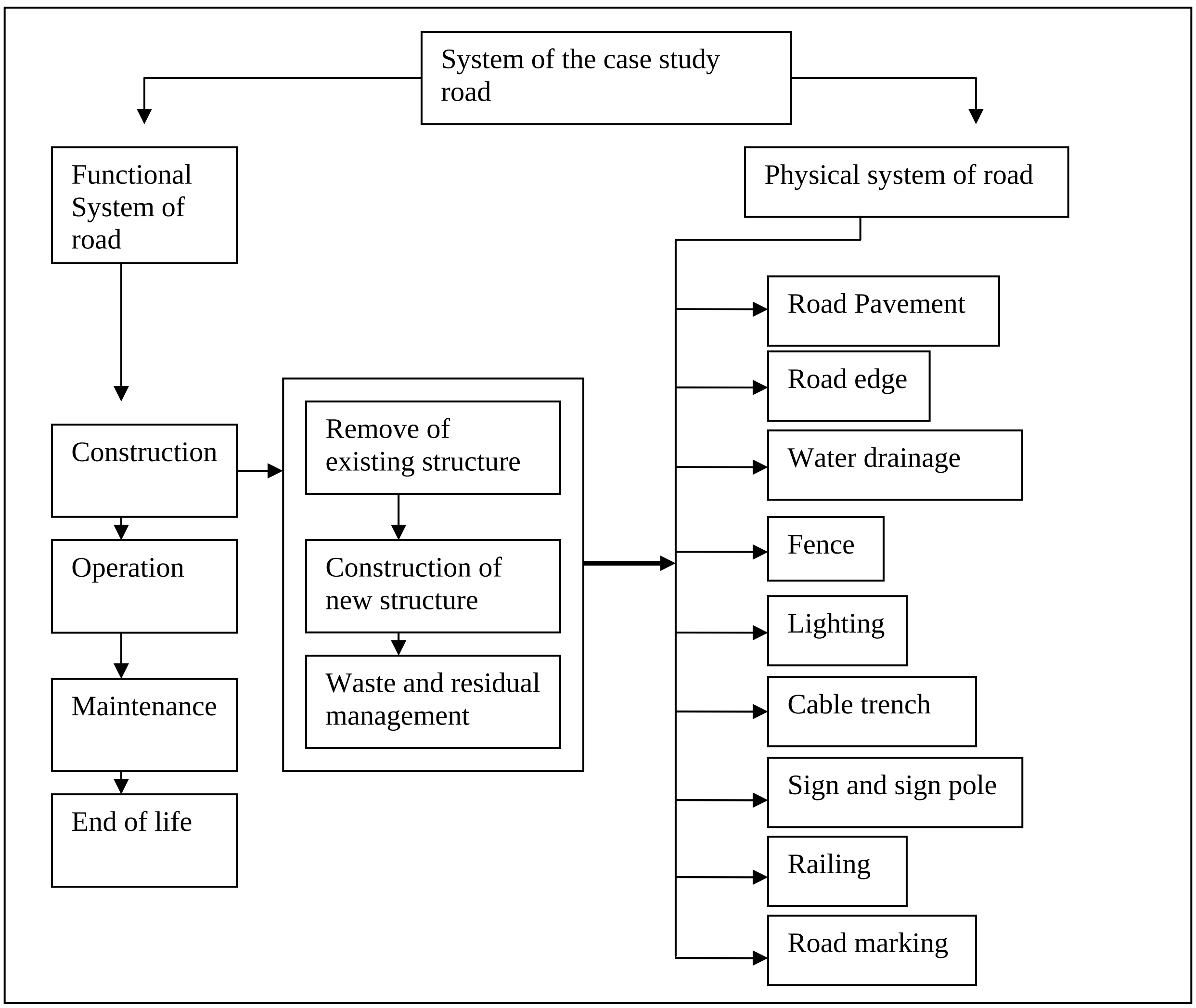


Figure7-2: System of the case study road.

As illustrated in Figure 7-2, like every product and service, road system has also construction, operation, maintenance, and end phases. These functional phases are carried out to execute the physical system of the product or service. This case has major physical system consisting are road pavement, water drainage, cable trenches, fence and lighting system.

As the case is an extension of lane, construction phase of the system has three sub-functional phases. Those are removal and transfer of existing structures, construction of new structures and waste or residual management. Different physical structures are required for the case road construction, which are also illustrated in Figure 7-2. All three sub-phases are carried out until new road lane is ready for operation.

The construction of a road follows certain steps. This extension of existing road lane has following major steps during its construction phase.

7.3.1 Removal and demolition of existing structures

Since it is an extension of existing road lane there will be a need for the removal of existing railings, electricity poles, wearing asphalt, asphalt base course, old cables, fences, tanks and pipelines before completely new lane is constructed. According to Statens Vegvesen, following are the structures to be removed before the start of new lane construction.

Demolition structures	Estimated quantity
Railing	130 meter
Electricity pole	16 pieces
Sign post	3 pieces
Asphalt milling	360 m2
Asphalt demolition	800 m2
Old cables	750 meter
Fences	245 meter
Manholes and pipe lines	4 pieces

Most of the structures can be reused if these are in enough good condition. For example; electricity pole, sign post, railing and fences may be re-used. Reusing and recycling point of view these structures help reducing environmental impacts as well as carbon footprint due to product and service. Information received from the project indicated that the old asphalt will be reused for the construction of layer of pavement of new construction.

Sources of carbon footprint on site from removal and demolition of existing structures are mainly fuel combustion by the vehicle equipments used to remove and to transport.

7.3.2 Construction of new structure

Following are main activities should be carried out for construction and installation of new structures of the case road.

7.3.2.1 Earth works

A. Clearance of area

Before the start of construction it is necessary to prepare the road foundation for construction work. It starts from removal of shrubs, trees and tree roots from the foundation area. The next is the removal of first layer of soil from foundation area from where road alignment passes. First layer of soil is in general rich with organic matters and is not suitable for the road foundation. This is because, organic matters in the soil will be decomposed quickly, which will affect on the road stability. In general, the layer below top soil is suitable for the road foundation.

The total surface area that needs to be cleared for the extension of extra lane for this road case is 3600 m^2. The area is covered mainly bye shrubs and very few trees (only about five six numbers). The removed vegetation is not used for another purpose and will be decomposed near by area.

B. Bulk transfer

In many places of this road alignment there is a need to cut bulk of land to maintain road gradients, level and alignment. During this process large area with vegetation needs to be removed. At this particular case it is estimated that approximately 7200 m3 soil mass needs to be removed. The bulk soil will be removed from the area and part of this mass will be used as vegetation cover in area, as filling material for road construction and backfilling in the trenches.

C. Digging of trenches

Digging trenches is one of the important activities of road construction. Two types of trenches are generally found. First one is trench excavated for water drainage structure, which is common for all type of roads. Water drainage structures are important to protect pavement from premature failure. If mechanism for water run-off is not made, penetrated water weakens the sub-grade of the pavement that may cause settlement and washing away of fine materials from unbound sub-base and base courses (Watson, 1994). Second one is the trench for electricity and telecommunication cables, which is in general aligned along the edge of the road. A cable trench is a shallow trench that holds cables, conduit lines, or piping. For this road 1730 m3 excavation for water trench and 900 m3 excavations for cable trench is estimated.

7.3.2.2 Construction of pavement

The structure intended for traffic movement is called pavement. Pavement consists of number of elements or layers of processed materials, which provides risk-free traffic movement with protection of land. These numbers of layers are made of different treated materials and have various functions to keep road safe, stable and durable for a period of time. The pavement should be maintained, and kept uniform during all weather conditions. This means drainage system should be well functioning and good. The pavement is generally made up of number of layers of bound and unbound materials and is placed one over another. The pavement layers of this case are illustrated in Figure 7-3.

As shown in Figure 7-3, different layers of the pavement and construction material details and thickness. The case road consists of three layers of sub-base course, three layers of base course and surface layer with wearing course. Total thickness of layers above geo-textile is 1.55 meter.

Elements of the pavement:

Bottom layer: Bottom layer will cover area with 5860 m2. Bottom layer is just road embankment. The bushes and first layer of soil is removed and level of layer is maintained by cutting and filling the soil. This bottom layer of the road is called sub-grade in road construction terminology on which the pavement rests.

Geo-textiles: 5860 m2 area is designed to be covered by geotextile layer over the bottom layer of sub-grade of the case. Geo-textile is used for the protection of soil from erosion, for soil stabilization, for embankment reinforcement and for making road pavement durable. The purpose of the use of geo-textile in this road construction is embankment reinforcement and to allow water and air to pass through permeable soil.

Non oven geo-textile fabric is used to increase the strength and stability of the underlying soil in a roadway (www.geotextile.com, 2011). One of the important uses of geo-textile fabric is to maintain separation between layers of different sized soil particles. The fabric essentially restricts upward flow of water and fin soil particles into the gravel, which would otherwise drastically reduce strength of the gravel.

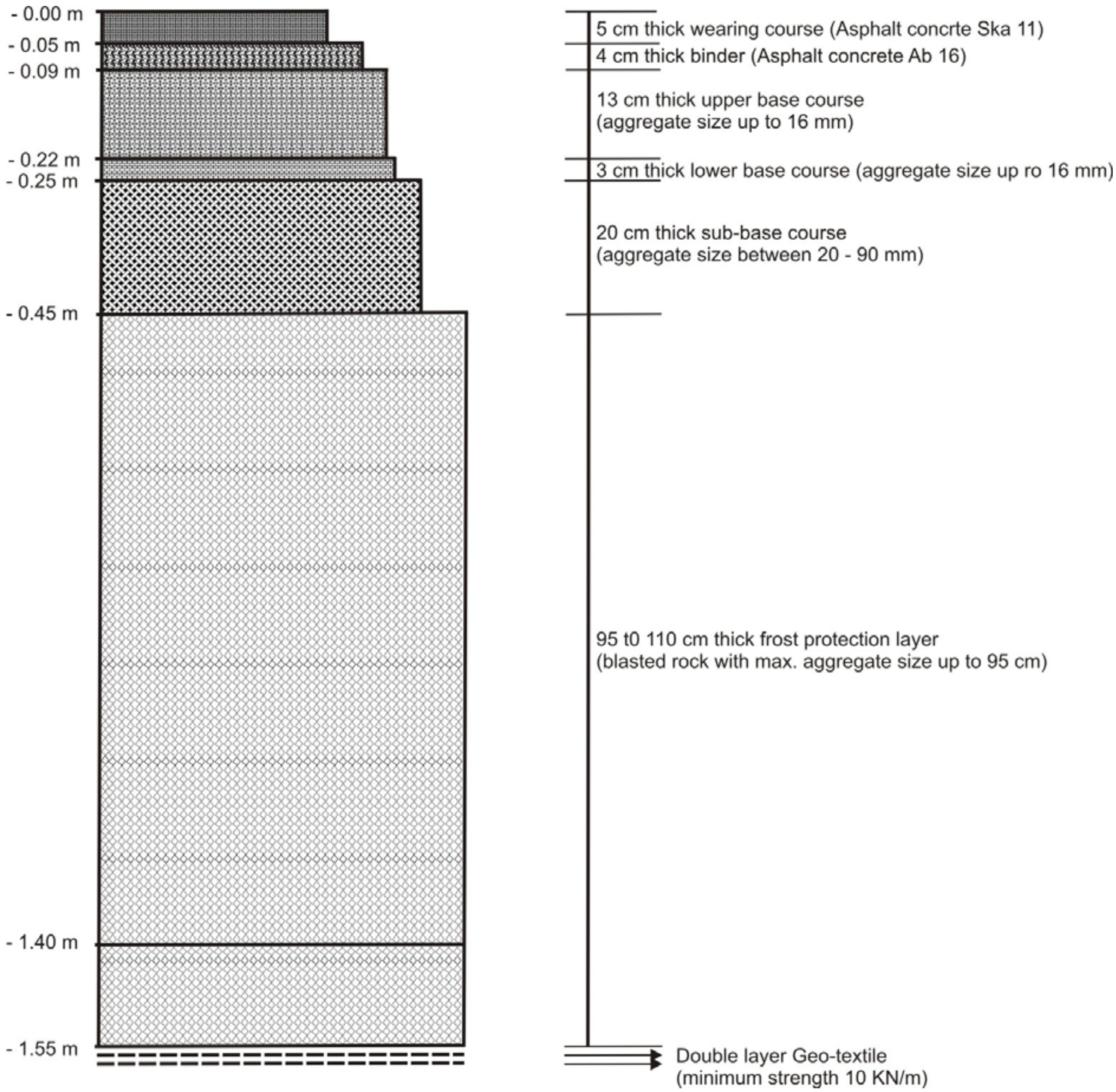


Figure 7-3: Cross-sectional layer of the case road re-drawn based on the designed drawing.

Sub-base and base course: Sub-base course of the pavement consists of number of layers of unbound materials. Unbound materials for the case are different sized blasted rock and crushed stone. Sub-base course is laid above the geo-textile. Sub-base course provide platform for the base course. Base course consists of bitumen bound materials and graded granular aggregates. Contribution of the base course on road construction is to add strength to the pavement and transfer load to the foundation. The top layer of the road consist wearing course that is provided above the base course. Wearing course keeps the stability and durability of the road.

7.3.2.3 Additional supporting structures

Additional work covers activities related to the supporting structures of the road. Installation related to trench for water drainage and trench for cables (electrical and telecommunication). Similarly, sign boards, road lighting system, fences and railing are also part of the system of the road. Most of these installations are industrial products and have indirect carbon footprint or embodied carbon footprint. Carbon footprint during installation is accounted as direct. This road case consists of different additional elements, which are illustrated in Figure 7-2. Information regarding product and quantity used in this case is presented in Appendix E.

7.3.3 Disposal of residues

After the completion of road construction there are always materials that are not used or left over. These materials should be managed properly to improve esthetic of the road and to improve surrounding environmentally. For example, if remains of asphalt are not managed properly there will be leakage of bitumen, which may lead to soil and water pollution. Therefore, it is environmentally wise to use this leftover construction material for another road construction. For this case it is planned that all leftovers of the construction material will be reused for another road construction.

Chapter 8: Analysis of Carbon Footprint of the Case

As discussed in Chapter 6 - carbon footprint documentation framework, there are two main stages. First stage is decision making stage for the case, which is presented in Chapter 7. The second stage is analysis stage. Figure 6-1 shows that carbon footprint analysis is carried out with the application of LCA methodology. Analysis stage with LCA methodology is a supporting environmental analysis tool for system engineering step 3 to step 6. As discussed in Chapter 2, LCA methodology is flexible tool that can be used to account different environmental impacts at various phases of the product as well as to the whole life cycle of the product. Therefore, LCA methodology for carbon footprint analysis of the case is applied and discussed in this chapter.

8.1 Goal definition

The application of LCA methodology for this study is to provide Carbon footprint of a road construction case. This study is carried out to fulfill one of the objectives of this MSc thesis with a goal to test carbon footprint documentation methodology in road construction case example. As a case example “E6 Kroppan – Tonstad - the extension of a new lane” is taken. For details reference is made to Chapter 7. The aims of application of LCA methodology for the study are to:

- apply LCA methodology for road construction phase of the case
- develop a system model of the road construction case based on identified sub-systems and elements in decision making stage discussed Chapter 7.
- identify and quantify the materials of sub-system and elements of the road construction that are responsible for carbon footprint of the system boundary
- adopt LCA software tool GaBi to model material flow to the system and find carbon footprint of the modeled system.

It is practiced that LCA results are presented relating to functional unit. In the case of road, functional unit could be carbon footprint per year per km road length or carbon footprint per passenger per km road length. However, in this case all life cycle phases of the road is not considered for the analysis and only construction phase of the road is selected. Therefore, result of the case analysis is the presentation of CO2- equivalent emission from the construction of whole case road. Carbon footprint of single product (case) that is the extension of a 5 meter wide and 815 meters long extra lane of road, which is the study unit for this analysis.

8.2 Scope and limitation

Complete LCA of road must consider all phases of the road and every material and product process during the life period of the road and environmental consequences. However, the scope of this study is limited to the application of LCA methodology only for road construction phase.

All materials input and product process for the construction of the road is modeled in a system in Figure 8-1. The system is modeled on the basis of "cradle to gate concept" that means all process from the raw material extraction to production phase or construction phase for the case road. Following are limitations that restrict consideration of whole system elements for the study.

- The first limitation of this study is that unavailability of complete material data and limitation of time margin for the collection of data in detail. Hence, partial system elements are considered to account the carbon footprint of the case. Processes that are included within the system boundary are marked with the shaded color in system model Figure 8-1.

- While considering construction process of the road, fixed capitals and its carbon footprint for the system is neglected and only operation process is included in foreground system boundary. For example, CO2- equivalent emission for the operation of machine during filling for the pavement is considered but not machine production.

- Limited primary data information for the input material for the case was received from Statens Vegvesen, who is the owner of the case. Due to limited information it was not possible to get complete data sets, as an example number of electrical pole are provided but no detail specification of the pole. The required quantity of steel for one pole can be estimated on the basis of available information in internet or written materials if detail specification of material is available. Lack of product material specification forced to omit some system elements from the system boundary.

- Another limitation of the LCA methodology is the use of educational version of GaBi LCA tool. Educational version of LCA tool is available for the research work which seems has limited data base. "***The data set contained in this educational version of GaBi, GaBi Education, is a small fraction of the available data within PE***" (GaBi education, 2010). Therefore, in some cases materials input are assumed with similar type of other materials available in the data base. For example, blasted rock required for the base course layer of the pavement is assumed limestone directly from mountain mining.

- According to upcoming ISO 14067 – Carbon footprint of products, In addition to the total number of CO2- equivalent of product, carbon footprint of product should be presented in the form of (i) removed carbon from nature, (ii) carbon storage on product, (iii) carbon capture, (iv) treatment of electricity, (v) land use change, (vi) soil carbon change and (vii) aircraft emission. But the scope of this study is to present total number of CO- equivalent emission (carbon footprint) from the defined system boundary.

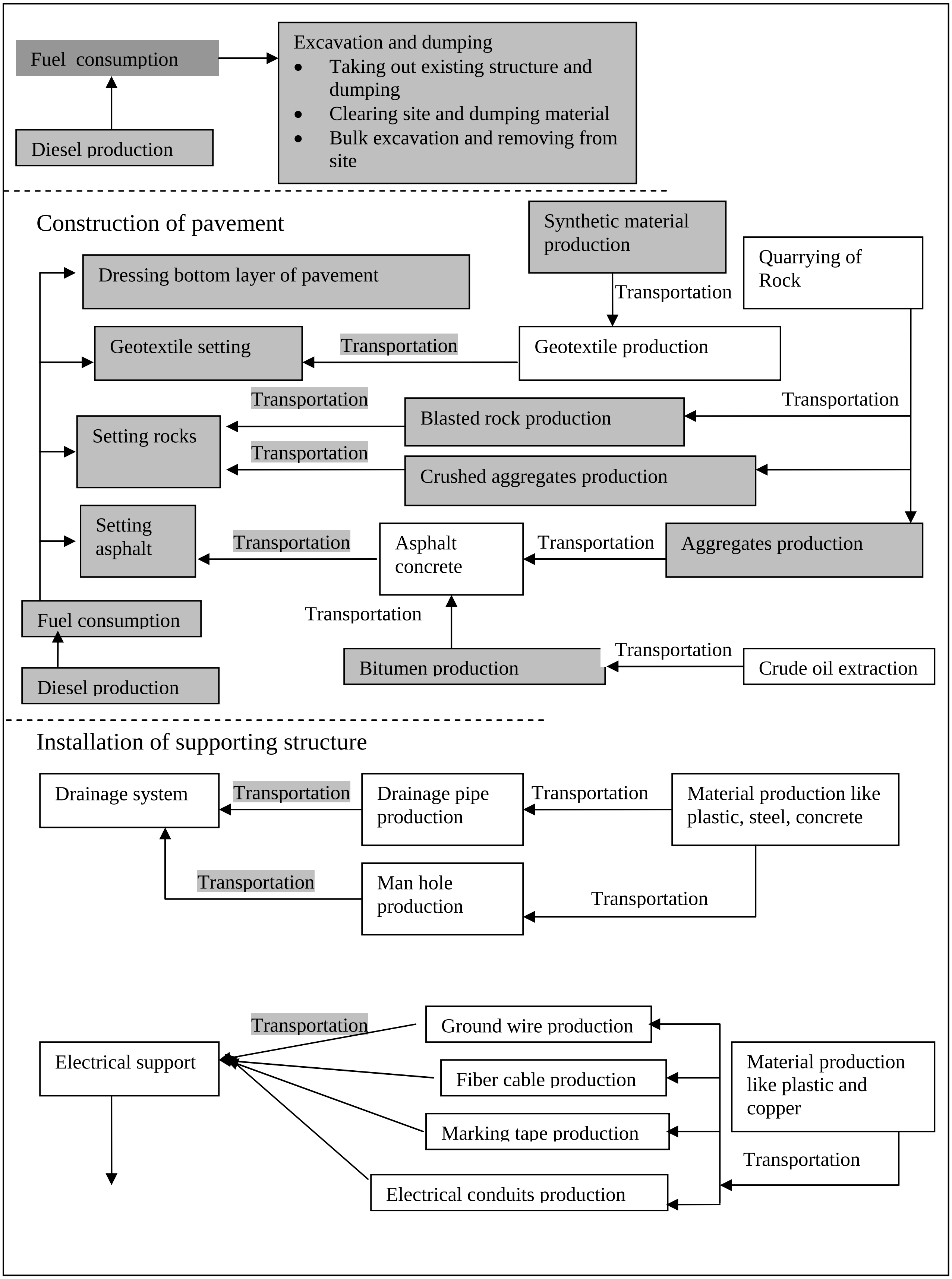
8.3 System and system boundary model

Required materials for the construction of the road and extraction of materials from nature, processing of raw materials and transportation to the production / construction site are included into the system model. The system model (Figure 8-1) shows different processes that interact with environment. Carbon footprint among many environmental impacts of the system boundary is the scope of this study. System boundary of the case, which is considered for the analysis is marked with shaded color within the system model of the case. Material transportation to the site is considered but transportation distance is only from local distributor to construction site.

The Figure 7-2 shows three different sub-systems of the case. Among these two sub-systems "*remove of existing structure*" and "*construction of new structure*" are breakdown into three different activities in Figure 8-1. These activities are (1) excavation and dumping, (2) construction of pavement, and (3) installation of supporting structure.

Carbon footprint is analyzed mainly into three different activities within the system boundary. (1) First activity is carbon footprint of the pavement materials, which cover cradle to site. (2) Second activity is carbon footprint from material transportation. (3) Third activity is carbon footprint on the construction site, which includes excavation and dumping, laying pavement materials and installation of other structures of the road. Furthermore sensitivity of activities is discussed.

In Appendix B1 carbon footprint of pavement covering cradle to construction (material production, transportation and laying on site) is illustrated in GaBi plan and also discussed briefly. Similarly transportation and site activities are also modeled in GaBi and illustrated in Appendix B2 and B3.


Fuel consumption
Diesel production
Excavation and dumping
Taking out existing structure and dumping
Clearing site and dumping material
Bulk excavation and removing from site
Construction of pavement
Synthetic material production
Quarrying of Rock
Transportation
Dressing bottom layer of pavement
Geotextile setting
Transportation
Geotextile production
Transportation
Transportation
Blasted rock production
Setting rocks
Transportation
Crushed aggregates production
Setting asphalt
Transportation
Asphalt concrete
Transportation
Aggregates production
Fuel consumption
Transportation
Diesel production
Transportation
Bitumen production
Crude oil extraction
Installation of supporting structure
Drainage system
Transportation
Drainage pipe production
Transportation
Material production like plastic, steel, concrete
Transportation
Man hole production
Transportation
Transportation
Ground wire production
Electrical support
Fiber cable production
Material production like plastic and copper
Marking tape production
Transportation
Electrical conduits production

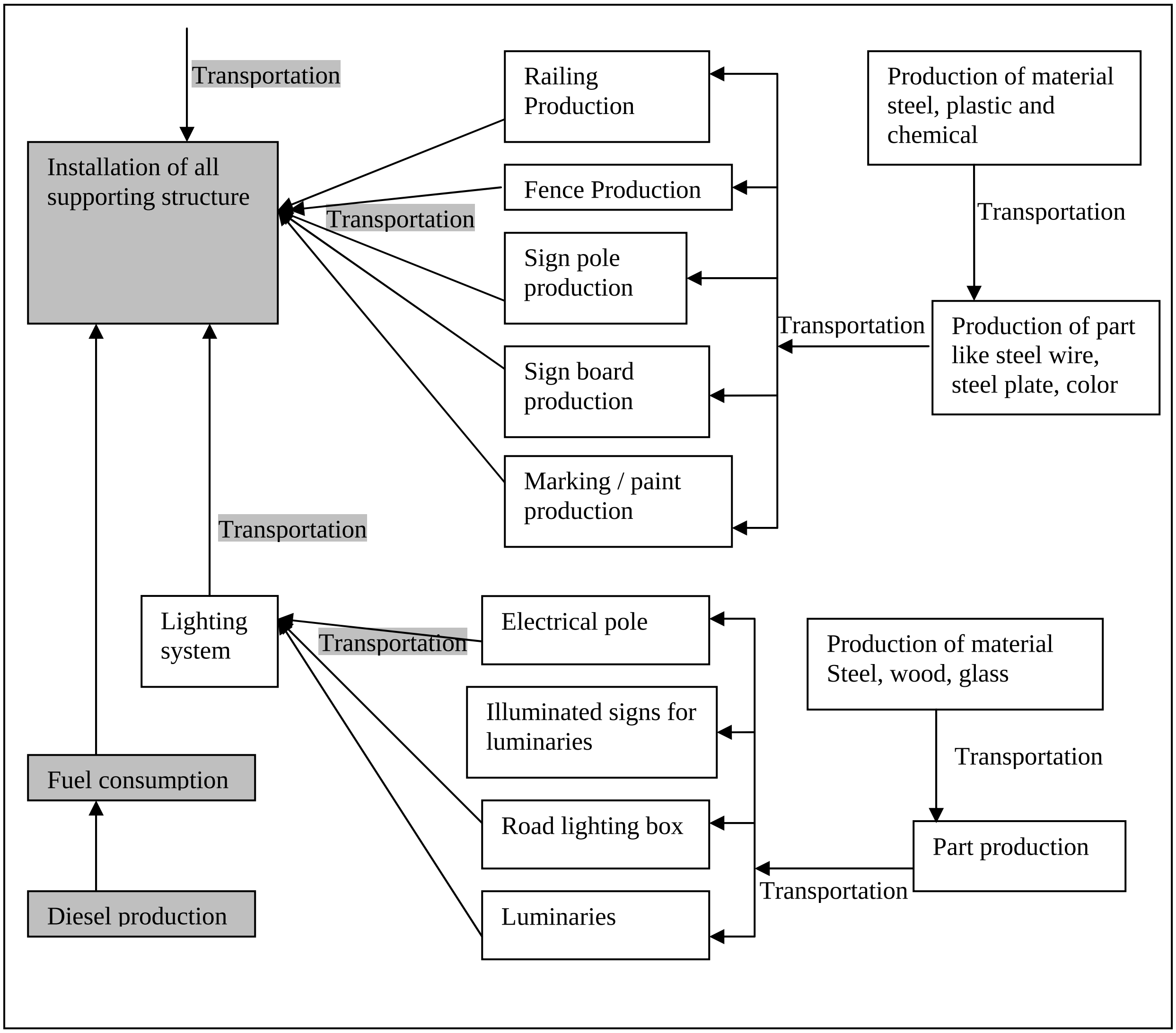


Figure 8-1: System and system boundary of the case road construction

8.4 Inventory analysis and aggregation of information

This is step VII and VIII as illustrated in Figure 6-1 (Chapter 6). Inventory analysis and information aggregation is made from the defined system boundary even though system of the case is large. Due to limited available data, system boundary is defined only for the available data. Inventory analysis includes resource, energy (fuel) and travel distance, which are measured mainly on mass (kg or ton), volume (m3 or liter) and length (kilometer), respectively. In some cases it was necessary to make assumptions where only partial information are available. Assumptions are based on information retrieved from internet and discussion with Statens Vegvesen personnel. Inventory information for pavement material, transportation and site activities are tabulated in Table 8-1, Table 8-2 and Table 8-3, respectively.

Greenhouse gas (GHG) emission is considered since carbon footprint of system is aim of case analysis. Among many gases that are potential for greenhouse effect, major six GHG gases are purposed by Kyoto protocol to account global warming potentials (GWP) of a product. The information for input resource quantity for the foreground system boundary is based on site specific data received from Statens Vegvesen. The details of the data sets obtained from Statens Vegvesen are attached in Appendix E. Primary emission data from the site are not available for the case. Hence, all emission information due to resource extraction / product process is abstracted from within the process database available in GaBi LCA tool. Emissions due to per unit fuel combustion at site by equipments are collected by secondary sources and GaBi database.

GWP impact category is selected for the case. The reference substance for GWP is CO2 and the reference unit of GWP is defined as kg CO2- equivalent. Each GHG emission is multiplied by it's global warming potential characterization factor suggested by the CML. Global warming potential for GHG emissions are expressed for different time horizon. ISO 14067 requires "Global warming potential for 100 years time horizon". GHGs and their characterization factor on GWP for 100 years time horizon is converted to CO2 – equivalent and shown below. The example is for 4 kg CO2, 2 kg CH4 and 0.5 kg N2O. Factor information is achieved from draft version of ISO 14067.

greenhouse gas emission		**GWP factor relative to CO2 (kg CO2-eq/kg emission)**	**Total carbon footprint** (kg CO2-eq)	
CO2	4kg	1	4 x 1 = 4	→ **203 kg CO2-**
CH4	2kg	25	**eq**	
N2O	0.5kg	298	2 x 25 = 50	
			0.5 x 298 = 149	

In this study, CML (2001) global warming potential for time horizon 100yrs is selected. The CML method is the methodology that was proposed by the Center of Environmental Studies (CML) of the University of Leiden

GaBi tool automatically gives total CO2- equivalent of available process and resource material from its data base. Even though, it is possible to break down CO2 – equivalent gas into different GHGs emission categories through GaBi balance table, the total CO2–equivalent information is only used.

Inventory data are analyzed in following headings. First resource and material input flow is analyzed and then carbon footprint of the resources is calculated.

8.4.1 Construction materials

The quantity of construction materials needed for the defined system boundary is analyzed and tabulated the in Table 8-1. It is noted that the transportation of materials and fuel requirement for the construction site are accounted differently in separate headings in Chapters 8.4.2 and 8.4.3.

A. *Geo-textile*

Non woven geotextiles are used for road construction purpose to increase the strength and stability of the underlying soil in a roadway. A geotextile is a textile material that is permeable and is made of synthetic or natural fibers (www.geotextile.com). The road case has used the non woven geotextiles made of synthetic materials called polypropylene fibers.

The density of geotextile ranges from 100 to 575 grm/m² (www.geotextile.com), which is depend on thickness of the geotextile strings. For this study a density of 500 grm/m2 is considered. This is due to the fact that heavy weight geotextile is required for road construction purpose. It means 500 grams polypropylene fibers are needed for each square meter of surface area. Hence, this case needed 5860 m2 geotextile that gives total weight of 2.93 tons polypropylene fiber (refer Table 8-1)

B. *Blasted rock*

Blasted rock is laid over geotextile layer. It is assumed that the blasted rock is transported directly from the rock quarry. It is specified that the blasted rock has a density of 1.8 t/m3. The total required volume of the blasted rock is 4200 m3 which is equivalent to 7560 tons of blasted rock (Table 8-1).

C. *Crushed stones*

Stones are processed through crushers to get crushed stones. For this case 980 m3 crushed stones are needed, which also has density 1.8 t /m3. Hence, required total weight of the crushed stone is 1764 tons (Table 8-1).

D. *Asphalt concrete*

Asphalt concrete is one of the important construction material needed for the upper layer of the road. Asphalt concrete is made mixing bitumen and stone aggregates. Total quantity of asphalt needed for this case is 2668 tons. According to provided information (Appendix C) the mixing ratio used to produce asphalt concrete is 5% bitumen and 95% crushed aggregates. So, 134 tons bitumen and 2534 tons aggregates are required to produce 2668 tons of asphalt concrete (Table 8-1). The estimated total construction material for this road construction is presented in Table 8-1.

Table 8- 1: Inventory of road construction materials of the case

Materials	Unit	Amount
Geotextile	kg	2930
Blasted rock	ton	7560
Crushed stone	ton	1764
Asphalt		
• Bitumen	ton	134
• Aggregates	ton	2534

8.4.2 Transportation

In general, different transportation mode may be used for the transportation of materials for road construction such as road transport (cargo truck), ship, rail and air cargo. Hence, means and mode of transportation is dependent on the geographical location of the construction site, type and size of the road construction project. Emission rate for different means of transportation depends on factors such as size of means, efficiency of engine, fuel type and so on. Emission per 1 km per ton transportation using specified trucks, ships and rails are presented in Appendix C. Used emission information is obtained from GaBi data base.

For this case transportation distance for trucks from local supplier of material to construction site is available. In the life cycle inventory of truck transport, fuel consumption during operation of the trucks and production of fuel are taken into account. However, LCA of truck production is not allocated for the road construction. Trucks with different load carrying capacity are assumed for the case. The capacity of the trucks is estimated using provided number of trips and quantity of materials to be transported. Mainly three categories of trucks with different load carrying capacity are selected for various construction purposes. Since this road is going to be constructed soon the truck category with euro standard 4 is selected which means less emission than by older standards. However, it needs to be emphasized here that Euro standards do not make any difference in CO_2 emissions.

Following trucks category having following load carrying capacity are considered for the analysis. The trucks are classified as category I, category II and category III.

Truck Category I = 7 tons total load capacity with 3.5 ton payload capacity
Truck Category II = 12 to 14 tons total load capacity with 9.3 ton payload capacity
Truck Category III = 34 to 40 tons total load capacity with 27 ton payload capacity

Payload capacity
The payload is the difference between the total weight of the vehicle at its capacity (the gross vehicle weight rating, or GVWR), and the weight of the empty vehicle (sometime called the curb weight). Subtract the full weight from the curb weight to get your payload.
http://www.ehow.com/how_7500799_calculate-payload.html#ixzz1JZlv5fjD

Empty truck return

Transportation trucks return empty after every trip to accomplish scheduled next transportation trip. Empty truck transportation also consumes considerable amount of fuel and emits GHG. Hence, CO2 – equivalent emission should be counted on fuel consumption during empty transportation. In GaBi educational version only two types of empty truck process are available having capacity of 28 tons, which are not reasonable to use for material transportation in this case. On the other hand, the information found about empty truck return the home webpage of Volvo gives distribution truck with different capacity that consume 20 to 27 liters diesel per 100 km. It is assumed that the trucks used are of good quality and road condition is also good. Hence, the minimum value of 20 liters per 100 km (0.2 liters per km travel) is selected for the calculation of GHG emission from empty truck return. . Using this unit diesel consumption, i.e. 0.2 liters per km travel for each category truck, back calculation of equivalent weight transportation for empty truck is performed by GABi. GABi calculation process gave equivalent weight for different category empty trucks are:

Truck category I = 4 tons
Truck category II = 6 tons
Truck category III = 12 tons

Then, this empty truck equivalent weight is additionally added to the loaded trucks assuming that this will account carbon footprint for transportation trucks fo different categories for both ways transportation.

8.4.2.1 Transportation of construction materials

Available transportation of material information is considered in the system boundary of the study. Transportation of materials are analyzed and tabulated in Table 8-2.

A. Transportation of geotextile

Transportation distance from production site to construction site is not available. Hence, 6 km distance from local distributor to construction site is used. Since calculated total weight of the geotextile is 2.93 tons, Category I truck is selected for the transportation of geotextile. Since the weight of the geotextile is less then 4 tons, fuel consumption by empty truck return is counted by doubling the weight of geotextile (Table 8-2).

B. Transportation of blasted rock

Provided information indicated that the transportation distance of blasted rock is 6 km. Hence, it is assumed that the blasted rock mine is at 6 km from construction site. Total 180 truck trips are estimated for the transport of blasted rock. Total weight of blasted rock is 7560 tons that gives 42 tons per trips. Therefore, Category III trucks, i.e. 34 to 40 tons total capacity truck with euro standard 4 is selected for the transportation (Table 8-2). This is the maximum capacity transportation and cargo truck given in GaBi data base.

C. Transportation of crushed stone

Like Blasted rock, total 45 trucks trips are estimated for crushed stone transportation. About 39 tons per trip is needed for total 1760 tons crushed rock. Same truck as for blasted rock is defined for crushed stone. The transportation distance is also similar, i.e. 6 km (Table8-2).

D. Transportation of asphalt concrete

Transportation distance for asphalt is only considered from local asphalt concrete manufacture to construction site, which is about 10 km away from the construction site. 400 special truck trips are mentioned in provided data, which means 6.67 ton per trip for 2668 tons asphalt. Therefore, Category II truck is selected for the transportation of asphalt concrete (Table 8-2).

8.4.2.2 Transportation of supporting sub-structure

The distance information for transportation of products from production site to construction site is not available. Therefore, transportation distance from local supplier to construction site is considered in the analysis. Most of the materials are transported from local suppliers within short distance. Material transportation are analyzed and illustrated in Table 8-2.

A. Transportation of filling materials

Filling material is soil, which is transported for greenery vegetation purpose around the new road. 900 tons soil from 6 km distance in 40 trips is estimated. It accounts 22.5 tons per trip. Therefore, Category III truck is defined for filling material transportation.

B. Railing and some lighting support structure

Railing and lighting support structures include hand railing, electrical pole and foundations. Products related to railing and lighting structures are transported from 330 km distance. Length of railing and number of other products are available and estimated 3 trips of trucks. Therefore, the material weight per trip is assumed 20 tons and altogether 60 tons is assumed. This means Category III truck should be defined for the study purpose.

C. Cables and accessories

Transportation of cables and accessories are planned from 200 km distance. Length of material is available but not the weight. So, it is assumed that the cable has 2 kg weight per meter cable based on the information given in Appendix E, row first that gives 200 kg per 100 m for old cable. (In this case total cable length is 2225 m (1325 m lighting cable and 900 m fiber cable, respectively). This will give total weight of the cable of 4.5 tons. The length of other supporting materials (binding tape, marking tape etc.) is 1800 m long and considered one kg per meter. All together 6.3 ton are needed for the case. Therefore, vehicle capacity is selected with Category II truck.

D. Other miscellaneous materials

Other 150 tons miscellaneous materials are accounted for the study purpose, which are transported for the supporting structures. These miscellaneous materials are manhole, conduits, side stones, road marking and materials related to different concrete structures. Most of these are bought from local suppliers and only transportation distance from supplier to construction site is considered. Around 22 truck trips are estimated, which means 6.8 ton per trip. Therefore, truck Category II is selected for this heading.

Table 8-2 gives overall material transportation details used in this analysis.

Table 8-2: Inventory of material transportation details of the case

Transported materials	Mass (ton)	No. of trips	Quantity per trips (ton)	Truck	Equivalent Quantity for empty return	Total quantity for both way transportation	Transportation distance (km)	Total truck travel (km) Distance x number of trip
For pavement								
Geotextile	2.93	1	2.93	I	2.93	5.86	6	6
Blasted rock	7560	180	42	III	12	54	6	1080
Crushed stone	1764	45	39	III	12	51	6	270
Asphalt	2668	400	6.67	II	6	12.67	10	4000
For other structure								
Filling materials for slope repair	900	40	22.5	III	12	34.5	6	240
Railing and lighting support	60	3	20	III	12	32	330	990
Cables and accessories	6.3	1	6.3	II	6	12.3	200	200
Other miscellaneous materials	150	22	6.8	II	6	12.8	6	132

8.4.3 Fuel consumption at site

Different type of equipment and vehicles are used for the purpose of road construction. These equipment and vehicles performed different functions. All vehicles are diesel engine. Diesel production and combustion are the system boundary of the site activities of the study. Material input for the manufacturing of these equipments and vehicles are not allocated. It is assumed that engine for every vehicle is efficient having low emission factor. According to Strippel (2001) diesel engines of high emission type release greater amount of emissions and it may be double in some inefficient engines.

Road construction equipment with two types of model are defined for the case, which are CAT 323D and Volvo FH12. Information for working hour of CAT 323D for different activities are provided (see Appendix E). From the home page of Caterpillar it is found that this type of vehicle engine uses diesel in the range of 6.5 to 24.5 liter per hour for different application. For this study, typical mean value of 15 liter per hour is considered. Volvo FH16 is to be used for installation purpose. From the home page of Volvo it is found that the machine uses 31 liter diesel per 100 km travel at normal speed of 60 km per hour. Since the construction site is confined within one kilometer, it is unlikely that Volvo will have speed exceeding 30 km per hour. Assuming that 50% reduction in speed may increase consumption of oil by almost double, and then the diesel consumption per hour will be around 18.5 liters.

For pavement laying different machine are needed. According to (Stripple, 2001) different equipment which are used for the purpose of pavement laying, consume different quantity of fuel during operation and it ranges from 18 to 22 liters per hour. For simplicity an average value of 20 liters per hour fuel consumption is used for carbon footprint calculation of pavement work.

CO2 emission factor per liter diesel consumption is obtained from the home page of Norwegian Climate and Pollution department (Klif). It is assumed that engine has high efficiency; total CO2 emission from one liter diesel is 2.66 kg. The calculation by GaBi for one liter diesel combustion indicated total CO2 equivalent emission (other GHGs are also included) of 2.68 kg. Similarly, the production process for one liter diesel will give emission to 0.33 kg CO2 equivalent. Hence, all together (from cradle to use) approximately 3 kg CO2 – equivalent per liter diesel consumption is considered.

A. Excavation

Excavator is used to excavate the earth material. During road construction excavation work is necessary to remove upper layer of soil, to remove bulk material and to dig trench for water drainage and cable work. Efficiency of excavation is dependent on material that needs to be excavated. Here working hour of excavator for each activity is available and fuel consumption is estimated to 15 liter per hour based on (Stripple, 2001). On the basis of this excavation work is analyzed and data are tabulated in Table 8-3.

Excavation activity for the case:
Demolition of existing structure will require 50 hours machine work. Clearing of shrub and trees with a surface are of 3600 m2 requires 60 hours machine work. Excavation of bulk consisting 7200 m3 requires 180 hours machine work. Excavation for the water drainage and cable trench consisting 1730 m3 and 900 m3, respectively requires 200 hours machine work together (Refer Appendix E).

B. Filling and paving

Different construction activities must be carried out to complete the road construction. Some of the important tasks with total machine hours required are for instance 600 m3 of filling of earth masses for greenery purpose require 8 hours machine work. Laying down of pavement materials for sub-base, base and top wear requires different types of special vehicles like asphalt paver, roller, and loader. In Table 8-3, altogether 380 machine hours for paving is mentioned, which is required for pavement work that consists 20 machine hours for dressing embankment, 60 hours for laying down the blasted stone, 60 hours for laying down the crushed stone and 80 x 3 = 240 hours for laying down asphalt concrete.

C. Loading and dumping

The function of loading and dumping is to remove excavated soil, bushes, trees and bulk materials from the construction site. Generally, materials are removed by loading into dumper. According to Statens Vegvesen trucks are used for the dumping of unused materials. For this case it is assumed that excavated soil for trench and drainage are not loaded because most of the excavated soil is used for filling and sealing trench. Therefore, excavated bulk material consisting soil, existing old structure and cleared vegetation are loaded and dumped at the specified location within possible near distance. Truck Category III with 34 to 40 ton total loading capacity is defined for this purpose. The details are as follows;

Dumping old structure: 14 truck trips and 16 m3 per truck are estimated. In average 1.3 ton per m3 is considered, which will give per truck 20.8 ton. Dumping site is located at a distance of 6 km.

Dumping of bulk soil: Mass of bulk soil is estimated to 10800 tons that need 500 truck trips, which gives average weight to 21.6 ton per trip. Dumping distance is located within 3 km.

Dumping of vegetation and trees: Dumping area is decided in 3 km distance for excavated vegetation and trees. Total volume of excavated vegetation is 1080 m3 which give 14.4 m3 per trip. It is assumed that green bushes and trees have density of approximately 1.1 t/m3 which gives per trip 15.84 ton.

Because all dumping materials need about 20 ton per truck, truck with 32 to 34 loading capacity having 22 ton pay load capacity is used for dumping purpose. This truck uses 0.2 liter diesel per km at empty returning which is equivalent with 12 ton quantity when modeled in the truck process in GaBi. Therefore this quantity is added to truck load for dumping material to account load and empty truck transportation.

D. Installation of supporting structure

Supporting structures needed are available in number of pieces or length. Other detail like used material for the product and weight of materials of the product were not available. Therefore, carbon footprint of these materials for production are not calculated and considered outside of the system boundary. However, per unit production of different materials are provided in Appendix C on the basis of information available in GaBi data base.

Machine hours for the installment of supporting structure are available, which altogether is 143 hours. Vehicle Volvo FH16 is planned to be used for the installation work. This information is used to develop system boundary of the case. The table 8-3 below illustrates the fuel consumption in different site activities. The Table 8-3 is based on above analyzed information.

Table 8-3: Inventory of fuel consumption on site activities

Site activities	Working hours	Specification of vehicle	Diesel/ hour		Total consumption of diesel (liter)
Excavation of					
existing structure	50				750
Shrubs & trees	60	CAT 323D	15 liters		900
Bulk	180				2700
Drainage &trench	200				3000
Filling & setting					
pavement		CAT 323D	15 liters		120
Greenery purpose	8	Different vehicle	20 liters		7600
Setting pavement	380				
Installation of other structure	143	Volvo FH16	18.5 liters		2645.5
Loading and dumping	Truck travel (trip x distance)		Quantity per trip (ton)	Equivalent quantity for empty truck (ton)	Total quantity per trip which count both way transportation
Old structure	14 trip x 6 km = 84 km		20.8	12	32.8
Bulk	500 trip x 3 km = 1500 km		21.6	12	33.6
Vegetation	75 trip x 3 km = 225 km		15.84	12	27.84

8.5 Assess / calculation of carbon footprint of the case

This is step IX in Figure 6-1. As presented above, different materials are estimated for the extension of 815 m long and 5 m wide lane of the road construction case. These materials are projected for the construction of pavement and other supporting structures like lighting system and drainage system. Total Carbon footprint of the case should include greenhouse gas emission for each material and product process, which is estimated for the completion of road project. This study gives only partial carbon footprint of the case of available data and information. To calculate partial carbon footprint of the case the road construction work are divided into three major activities consisting; 1) carbon footprint of materials for pavement construction, 2) carbon footprint for the transportation of the material and 3) carbon footprint on site activities. Carbon footprint of each unit is achieved by using LCA software program GaBi. The system boundary is also modeled in GaBi with total material and details are presented in Appendix B.

8.5.1 Carbon footprint of materials for pavement construction

Different materials are used for the road construction. These materials are divided into two parts. First part includes materials for the pavement structure and second parts include materials for the other structures. Estimated quantities are already described in Chapter 8.4.

Emission information of polypropylene fiber process is used EU 27 process from GaBi data base. Emission data are obtained from GaBi data base which gives the cradle to gate emissions. Transportation of goetextile and fuel needed for laying down at the construction site is counted differently. Energy need and other requirement during geotextile production is not considered since no process data are available

Information regarding type of rock was not available and hence the limestone option available within GaBi is used considering that exactly similar process is needed to quarry the blasted rock from the mountain. Emission data is used from US based process industry.

Emission information available within GaBi for crushed stones is used for the analysis. The emission data covers from cradle to production of crushed rock. The process available in software is DE process which is German based industry process.

GaBi data base that covers from cradle to gate meaning crude oil extraction to bitumen production is selected for the assessment. The selected process is based on EU 15 process from

GaBi. Crushed stone is used as aggregates. Process for aggregate and bitumen mixing is not included in system boundary.

Table 8-4 gives total carbon footprint of the construction materials calculated by GaBi software using assumption discussions above. Total amount of CO2- equivalent from pavement construction material product process is 148.7 ton.

Table 8-4: Carbon footprint of pavement construction material.

Material used for pavement	Unit	Material quantity	Kg CO2 - equivalent per unit	Total kg CO2-equivalent	Percentile CO2 – equivalent (%)
Geotextile (polypropylene fibres)	kg	2930	2.32	6782.95	4.56
Blasted rock	ton	7560	5.77	43606.08	29.32
Crushed rock	ton	1764	13.96	24623.68	16.56
Asphalt (5% Bitumen and 95% aggregates)	ton	2668	27.62	73690.16	49.56
Total CO2 – equivalent				148702.87 kg **149 tons**	

8.5.2 Carbon foot print from transportation of materials

Three categories of trucks with euro standard 4 are selected for transportation. Emission value per km per ton is modeled using information discussed earlier and GaBi data base. The calculated values of emissions are tabulated in table 8-5, which covers whole transportation activities. Total CO2 –equivalent from transportation of material to the site from distributor is 10 ton. The same result found when modeled in GaBi too (Refer Appendix B2).

Table 8-5: Carbon footprint of transportation

Transported materials	Truck category	kg CO_2-equivalent per km per ton transportation	Quantity per truck which account both way transportation (ton)	Total truck travel (km)	Total kg CO_2 - equivalent
Pavement					
Geotextile	I	0.134	5.86	6	4.71
Blasted rock	III	0.0499	54	1080	2910.16
Crushed stone	III	0.0499	51	270	687.12
Asphalt	II	0.0793	12.67	4000	4018.92
Other structure					
Filling materials for greenery purpose	III	0.0499	34.5	240	413.17
Railing and lighting support	III	0.0499	32	990	1580.83
Cables and accessories	II	0.0793	12.3	200	195.07
Other remaining materials	II	0.0793	12.8	132	133.98
Total CO_2- Equivalent				9943.99 kg **10 ton**	

8.5.3 Carbon footprint from construction site

Carbon footprint from construction activities at site is mainly generated from combustion of fuel. For the construction of road pavement heavy equipment vehicles are used. Estimated machine hours for different activities are discussed earlier. Table 8-6 presents consumption of diesel for different construction activities and emission from them. The value for total CO_2 –equivalent on site is 56 ton. Information from Table 8-3 is used to model In GaBi, which also gives 56 ton CO_2-eq emission from site activities (refer Appendix B3).

Table8-6: Carbon footprint from construction site.

Site construction activities	Working hours	Diesel consumption per Hour	Total consumption of diesel (liters)	Kg CO_2 – emission per liters diesel (production and combustion)	Total kg CO_2-equivalent
Excavation of existing structure Shrubs &trees Bulk Drainage &trench	 50 60 180 200	15 liters	 750 900 2700 3000	3 kg	 2250 2700 8100 9000
Filling & paving Soil filling for slope and green purpose Paving	 8 380	 15 liters 20 liters	 120 7600	 3 kg	 360 22800
Installation of other structure	143	18.5 liter	2645.5	3kg	7936.5
Loading and dumping	Quantity per truck (ton)	Total truck transport (km)		CO_2 per ton per km transport (kg)	Total kg CO_2-equivalent
Old structure Bulk Vegatation	32.8 33.6 27.84	84 1500 225		0.0499	137.4845 2514.96 312.5736
Total CO_2- equivalent					**56111.52 kg equal 56 ton**

8.6 Analysis of carbon footprint of the case

This part of the discussion is step x in Figure 6-1 that is presentation and interpretation of carbon footprint result. In previous chapter carbon footprint of every material for pavement construction, transportation of materials from local distributor and on site construction activities is assessed and presented in Tables 8-4 to 8-6. For the analysis and interpretation purpose information from above tables are rearranged in Figure 8-2, 8-3 and 8-4 and Tables 8-7 to 8-8.

8.6.1 Analysis on pavement material production

The Figure 8-2 below is made from Table 8-4 which is the illustration of carbon footprint of pavement material production process in percentage. The figure shows that contribution of asphalt for carbon footprint is about 50%. Even though the amount of asphalt is less than blasted rock but emission is approximately 20% higher. The main reason is that asphalt concrete has 5% bitumen and bitumen is the byproduct of petroleum product. Therefore, it has high carbon content that emits more CO2 during refining process. Bitumen and stone aggregates are mixed together to produce asphalt concrete. This study has not considered inventory of asphalt mixture process, which is also a process for significant carbon emission because of high energy consumption.

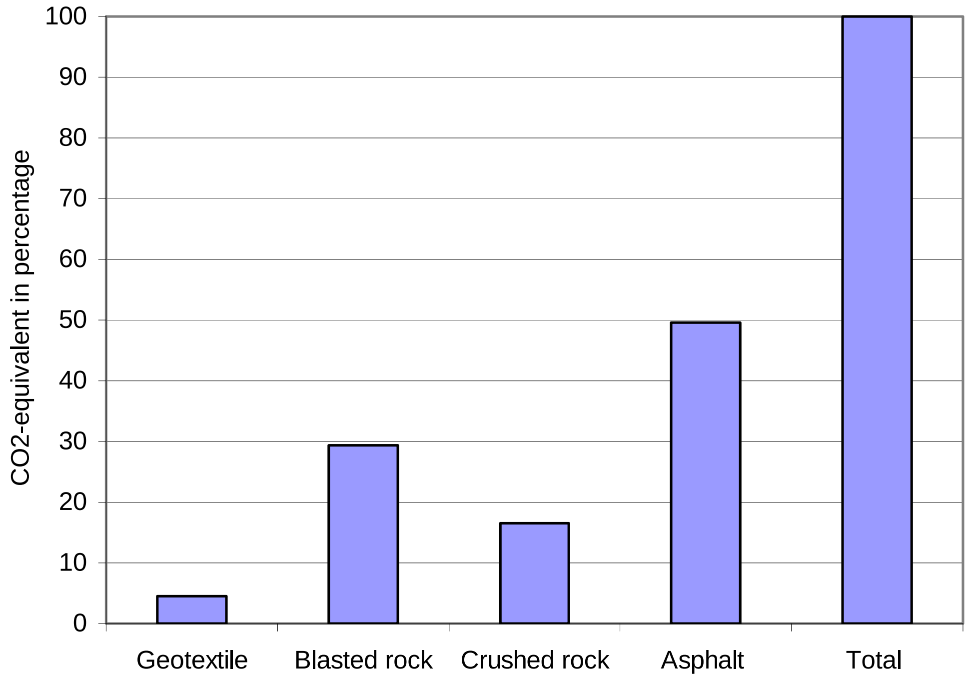


Figure 8-2: Calculated carbon footprint of pavement materials

Total 2.93 tons geotextile has covered approximately 5% carbon footprint of total pavement materials. This value mainly covers plastic production and if emission due to geotextile manufacturing is added, the value will be even higher. The carbon footprint of blasted rock is more than crushed rock because the quantity of blasted rock is considerably higher than to the quantity of crushed rock (Figure 8-2).

8.6.2 Analysis on transportation

Carbon footprint of transportation is directly linked to type of transportation vehicle, transportation distance and quantity of material to be transported. As indicated in Table 8-5 Category I truck has more CO2-equivalent emission than other two. This is due to the fact that the capacity of Category I truck is less, which gives higher per unit CO2 emission. As can be seen, CO2-equivalent per km per ton for truck Category I is 0.134 kg and for truck Category II the CO2-equivalent is 0.0499 kg. Material quantity and transportation distance are other factors that contribute carbon footprint of transportation. Carbon footprint of 6.3 tons cables & accessories transported by truck Category I from 200 km is 195.074 kg CO2-equivalent, while CO2-equivalent of other materials transportation is 133.98 kg due to very short transportation distance of only 6 km. In this respect quantity of material (150 ton) played greater role for emission. The result shows that even though the materials quantity is relatively less for cables and accessories in comparison to other materials, higher emission from cables and accessories is mainly caused by long transportation distance. Therefore, use of local materials and local products reduces transportation distance, which ultimately assists to reduce total carbon footprint. (Table 8-5)

8.6.3 Analysis on site activities

Carbon footprint for site construction activities are mainly from fuel consumption. Table 8-7 below shows the summary of carbon footprint in tons from fuel consumption on site construction activities and Figure 8-3 illustrates CO2 –equivalent emission in percentage using the information of Table 8-7.

Table8-7: Summary of carbon footprint in ton CO2-equivalent on site

Excavation	Pavement construction	Installation of other structure	Loading and dumping	Total ton CO2-equivalent
22.05	22.8	7.9	3.3	56.11
39.30%	40.63%	14.08%	5.88%	100%

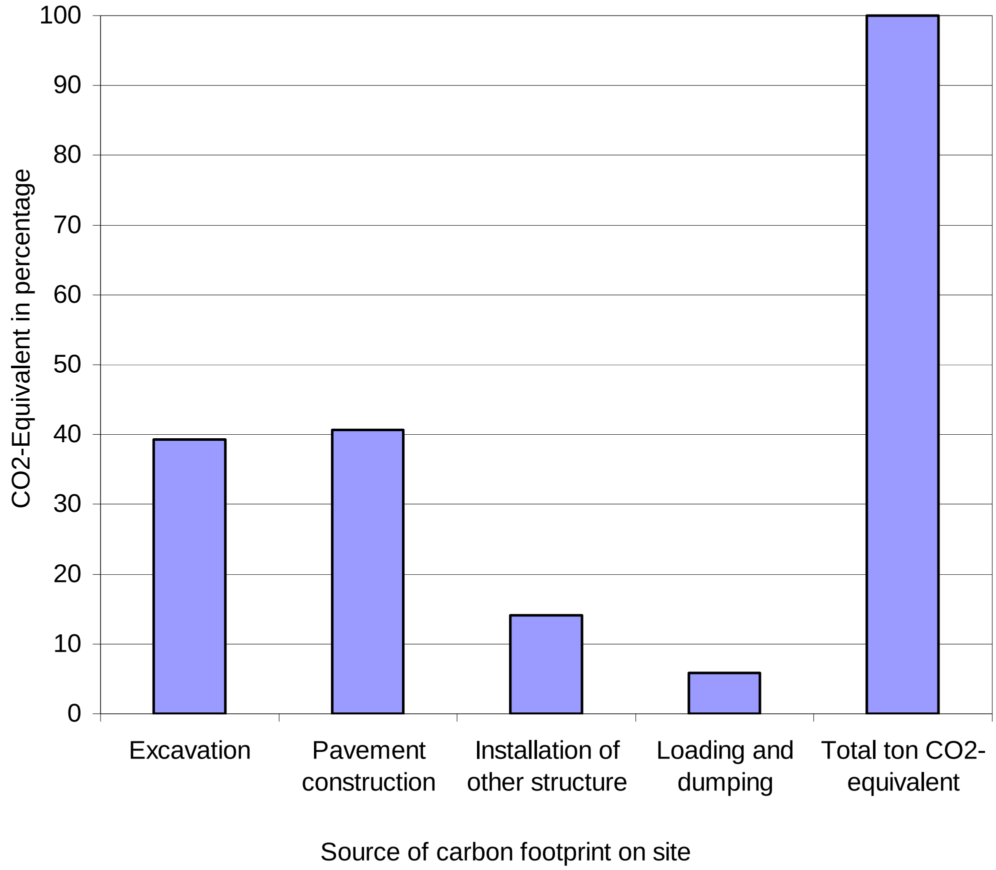


Figure8-3: Carbon footprint from site of the case road.

Out of about 56 ton CO2-equivalent, around 22 tons is contributed by excavation while pavement construction indicated slightly more CO2-equivalent consisting 22.8 ton. Since the road case is extension of the lane, old structure must be removed by excavation, which is extra excavation work than in new road construction. Excavation is also dependent on the characteristics of construction site, i.e. topography and geological set-up (soil or rock). The site of this case is situated on such location where large quantity (10800 tons) of bulk soil needs to be excavated and removed from the area. The emission from pavement construction is second large CO2 – equivalent and it is logic because pavement construction is the major work of the road construction. Different types of vehicles need to be operated to set different layers of the pavements. Loading and dumping is also related matter for carbon footprint. The large area to be excavated and cleared means large quantity of loading and dumping materials, which ultimately adds on the quantity of carbon footprint. In this case 5.88 % carbon footprint is from loading and dumping of excavated materials.

8.6.4 Sensitivity analysis

In this chapter analysis is made in total number of CO2- eq from system boundary and also discussed CO2- eq emission per unit material production that are used for the road construction. Table 8-8 illustrates total amount of carbon footprint of the case road construction. The Figure 8-4 represents the Table 8-8. The table shows that total carbon footprint of the case is about 215 ton CO2- equivalent from the defined system boundary. Please note, this presents the partial carbon footprint of the case because it does not cover all elements of the case.

Table 8-8: Summary of carbon footprint from different activities (ton CO2- equivalent).

Pavement material	Pavement material transportation	Pavement site emission	Other material transportation	Other structure installation	Excavation and site preparation	Loading and dumping filling	Total ton CO2 - Equivalent
148.7	7.62	22.8	2.32	7.9	22	3.32	215 ton
69.27%	3.55%	10.62%	1.08%	3.68%	10.25%	1.55%	100.00%

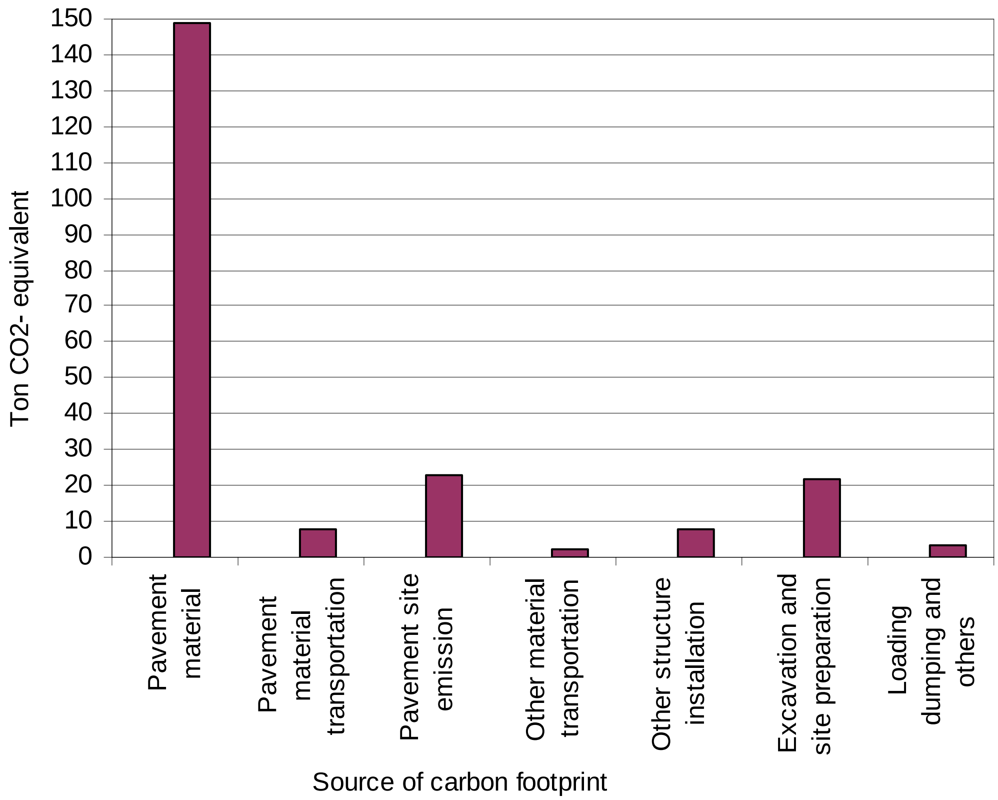


Figure 8-4: Total carbon footprint of the road construction case

Table 8-8 gives total carbon footprint of pavement is 179.12 ton, which cover material production, transportation and fuel consumption on site construction activities related to only pavement. System boundary of pavement is modeled with transportation of materials and site activities in single GaBi plan (refer Appendix B1), which also shows 179 ton CO2- equivalent from pavement. The Table 8-8 shows that pavement material represents high CO2- equivalent emission in comparison to site construction activities emission of pavement. From this it is clear that more carbon footprint is generally produced from production processes. The Figure 8-4 and Table 8-8 also illustrate that there is carbon footprint contribution from transportation. In this case, carbon emission from transportation is only from local distributor to construction site. It is evident that if the transportation is considered from material production site to construction site, there will be more CO2- eq emission from transportation. Therefore, choice of material and location of material production makes considerable difference in carbon footprint of final product and service. For example material, which is processed through clean energy at the nearby area, has less carbon footprint than diesel processed materials brought from longer distance.

More over choice of vehicle efficiency and size also make difference in CO2 emission. Efficient engine consume less fuel in comparison to inefficient engine. Similarly transportation vehicle should be maximized. Category III truck in case study emits about 0.08 kg CO2-eq per km per ton material transportation while category I truck emit 0.13 kg CO2-eq per km per ton (refer Table 8-5). Therefore, for example large amount of material transported at once instead of two times in small vehicles reduce the carbon footprint of transportation of materials.

Other supporting structure installation is also part of road construction like lighting system and drainage system. This work adds CO2- equivalent in site construction activities. This work has added 7.9 ton CO2- equivalent for the case road. Choosing installation process and high efficiency machinery product may help to reduce the carbon footprint of the product.

The amount of carbon footprint from foreground system or site activities can be reduced by selecting proper installation techniques. In the road construction, consumption of fuel is main input during installation of different structures and using less amount of fuel is the best way to reduce carbon footprint form the site. Other factors that makes different in carbon footprint in case of road construction are geological and topographical features of the area. If the proposed road needs to be constructed through forest area, it will make different results in carbon footprint since removable of carbon from nature will be the case. Similarly, if the proposed road construction needs to be excavated through steep hill slopes, it will require extensive volume of soil removal, which will make change in soil carbon and at the same time operation of excavator and dumping trucks will also increase, which will result more CO2- equivalent. In the case study, the result shows (Table 8-8) CO2-eq emission from excavation activity is almost equal to material laying for the pavement (pavement site emission) because of large bulk of soil need to be excavated. Figure 8-5 made with the information from Appendix C shows that consumption of one ton extra diesel for the machine operation means about 400 kg CO2- eq emission from diesel production only. If we add CO2-eq from combustion, all together the amount of CO2- eq is more than 3500 kg. According to Climate and Pollution Agency (Klif), Norway, 1 kg diesel equal 3.17 kg CO2-eq emission from combustion process, which is 3170 kg CO2-eq emission from the combustion of 1000 kg diesel.

It is noted here that the analysis and discussions made previously cover only the material used for road pavement. Materials used for the construction supporting structures also considerably contribute on carbon footprint. Carbon footprint per unit material for supporting structures such as PVC pipes, steel, plastic, copper, pre-cast concrete and wood is also analyzed using GaBi process and is given in Appendix C. Figure 8-5 illustrates kg CO2- equivalent emission per unit material process, which is used for both pavement and other supporting structures of the road construction .

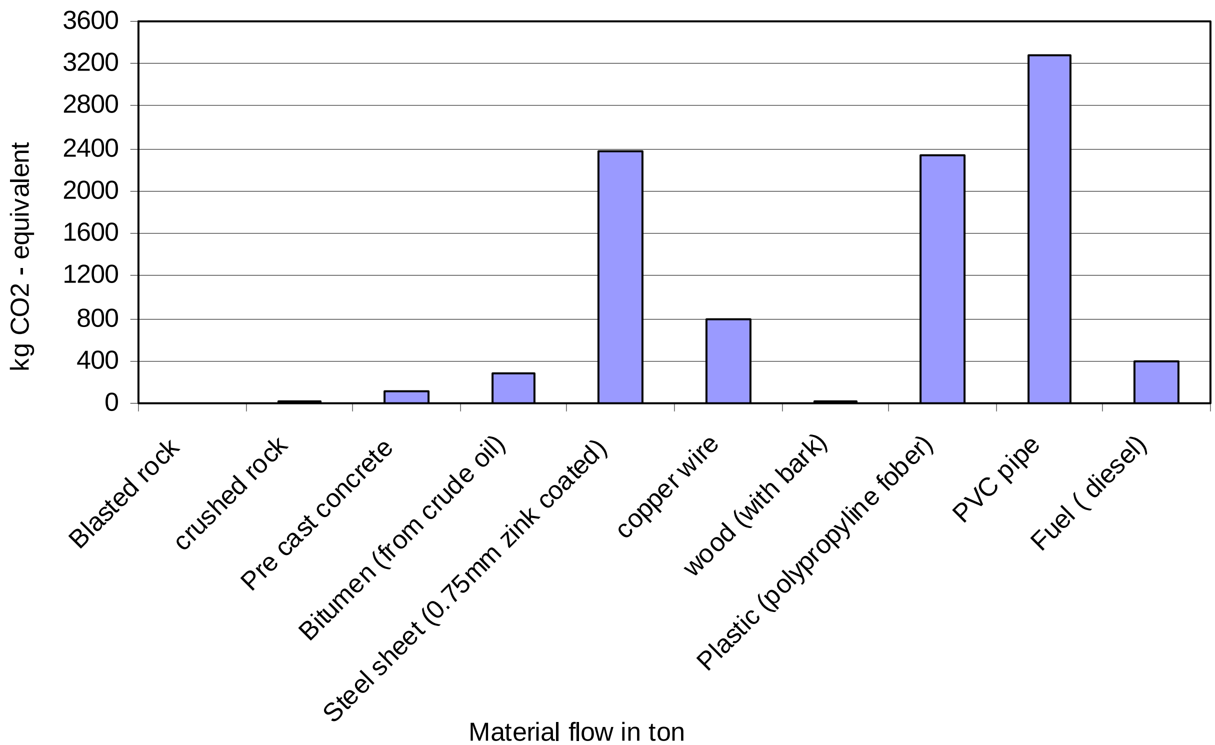


Figure 8-5: CO2- equivalent per unit material production

The Figure 8-5 shows the material used for the road construction and CO2-eq emission per unit extra use of material. Figure 8-5 shows that production of one ton PVC pipe emits more than 3 ton CO2-eq PVC pipe is used for the purpose of road electricity and drainage system installation. Concrete can also be used for the drainage purpose in stead of PVC pipe. Amount of materials and carbon footprint of these products through life cycle perspective should be compared before making decision on the choice of materials.

Similarly, one ton zinc coated steel sheet emits approximately 2.4 ton CO2- equivalent. Steel structures such as railing, electricity pole and manhole are used for the road construction project. This means large quantity of steel is consumed during road construction work. Therefore, use of one ton additional steel will add 2.4 ton more CO2- eq.

8.7 System modeled in GaBi

In case where all input and output material information, product process, energy requirement and emission factor are available, system of the case can be modeled in GaBi. In very few cases GaBi educational version has developed product process data base that can be used to model system. In GaBi, unit process of each product is modeled in separate plan and then all plans are put together with required materials for the case. As an example, asphalt production process system boundary is modeled in GaBi and presented in Figure 8-6 below.

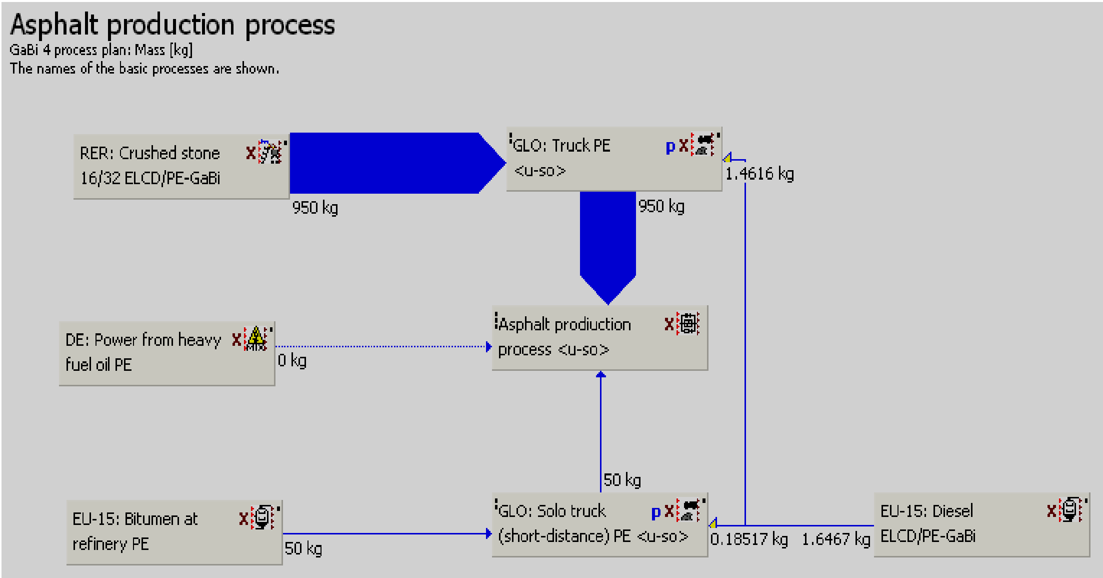


Figure8- 6: A model example in GaBi.

This Figure8-6 is the example of data processing method in GaBi. The data process in this example is not related to case study. Case study has no information for transportation of aggregates and Bitumen. The Figure 8-6 shows that Asphalt is produced with the mixture of stone aggregates and bitumen. Bitumen production process and aggregates as crushed stones process is already available in GaBi process data base. These available processes in GaBi are set in Asphalt production plan. New process for asphalt production should be self made in Asphalt production plan. Flow of crushed stone and bitumen are linked to asphalt production through transportation. Asphalt mixture plant needs power, which can be given from different source. Power from heavy fuel is used in this case example. Another flow is diesel, which is supplied to the transportation mode.

This example is for 1000 kg asphalt production. Bitumen and crushed stone are transported from 100 kilometers. 1.64 kg Diesel is allocated self by GaBi for 1000 kg materials.

After model is finished, carbon emission from each flow can be found in GaBi balance table. Gabi balance table for above example is presented in Figure 8-7 below, which is copied from GaBi. Total kg CO2- equivalent according to CML (2001), Global warming potential, 100years is 46.972 kg for this example process. This figure may be broken down in every flow steps. One can read that CO2- equivalent for power production form heavy fuel oil is 13.45 kg. There should be emission while asphalt is produced mixing bitumen and aggregates. This emission comes from bitumen burning and fuel combustion. The emission factor for this process should be collected from other secondary information or site inventory. This emission factor is an output of asphalt production process. Supposition is that there is no emission information available for this process and output flow for this process is left blank during modeling in GaBi. So, there is no result in balance table during asphalt production. Hence, this asphalt concrete production case gives only partial carbon footprint of the product since it lacks carbon footprint of asphalt mixing.

CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]									
	Asphalt production process								
			Asphalt productio n process <u-so>	DE: Power from heavy	EU-15: Bitumen at refinery PE	EU-15: Diesel ELCD/PE-GaBi	GLO: Solo truck (short-distance)	GLO: Truck PE <u-so>	RER: Crushed stone 16/32
Flows		46.972	0	13.4583	14.36641	0.639048	0.592373	4.655349	13.26058
Resources		0	0	0	0	0	0	0	0
Emissions to air		46.972	0	13.4583	14.36641	0.639048	0.592373	4.655349	13.26058
Emissions to fresh water		0	0	0	0	0	0	0	0
Emissions to sea water		0	0	0	0	0	0	0	0
Emissions to industrial soil		0	0	0	0	0	0	0	0

Figure 8-7: Balance table figure copied from GaBi

In this way every product process flow is modeled and put together in main process plan in GaBi. This GaBi methodology is used for system boundary of the pavement, material transportation and site activities of the case and illustrated in Appendix B1, B2 and B3.

8.8 Carbon footprint as part of environmental product declaration

From ISO review it is known that both ISO 14020 series and ISO 14067 recommend LCA methodology to declare environmental impacts and carbon footprint of product, respectively. The study of carbon footprint is important to contribute in the area of climate change. In addition, according to ISO 14020, environmental label and declaration systems (EPDs) include other environmental impacts. Aggregation of all material input flow is required for both EPD system and carbon footprint analysis. Aggregating material input flow information is same for every environmental impact performance analysis. Only output flow information for different impacts are different. Information on output flow for carbon footprint analysis is greenhouse gases.

Hence, in addition to carbon footprint, all environmental performance of the product can be declared with some extra effort related to the collection of output flow of environmental consequences. Moreover, there already exists many developed LCA computer tools, software and process data base of several environmental emissions. Consideration of all environmental impacts reduces the chances of shifting problem from one to other environmental impact. For example, the road case studied above demonstrated that road construction need large amount of non renewable natural resources. Bitumen, blasted rock, crushed stone and aggregates, and fuel for machinery work are non renewable resources. Resource depletion could be another significant impact in the case of road construction besides carbon footprint.

As an example, EPD of asphalt declared by epd-norge is attached in Appendix F, where environmental impact global warming potential (kg CO2-eq), depletion of ozone (kg CFC-11-eq), Acidification (kg SO2-eq) and so on are documented and declared. From the definition of carbon footprint, it is understood that carbon footprint is the amount of greenhouse gas emissions associated with the life cycle of the product. Amount of greenhouse gases is presented as global warming potential (GWP) impact category in environmental product declaration (EPD) system (refer appendix F).

EPD example of asphalt in Appendix F illustrates that number of acidification value is higher than global warming potential. Giving importance on carbon footprint of asphalt means to neglect the acidification environmental impact. ISO 14067 is en effort to deal with alarming environmental impacts; climate change, while EPD system considers other impacts. According to ISO 14067, extra works need to be considered to declare carbon footprint. In addition to total number of CO2-eq emission from the product process, treatment of fossil and biogenic carbon, change in soil carbon, carbon storage in product, carbon capture and aircraft emission should be treated separately and communicated in carbon footprint declaration of the product. Therefore, Carbon footprint of product in reference with the requirement of ISO 14067 can be declared in single EPD system along with other environmental declarations. Global warming potential impact category in EPD system can be changed with carbon footprint. In this way other environmental impacts can be treated at the same time and reduce the possibility of shifting environmental problems.

Chapter 9: Discussion

In this chapter, discussion is made on the basis of finding in the previous chapters. Findings related to EPD, carbon footprint documentation system and in the case road study are discussed and presented below. Findings of part 2 - literature review are discussed in heading 9.1 and 9.2. Part 3 – case study analysis is discussed in heading 9.3 and 9.4. Discussion is also made on the fulfillment of objectives of this thesis at the end of this chapter.

9.1 Environmental declaration and carbon footprint

Environmental documentation system is adopted to contribute sustainable development. Documentation process highlights environmental consequences of industrial and development activities, which are main causes for the environmental impacts in the nature. Therefore, it is the responsibility of business community to reduce environmental impacts and at the same time it is the responsibility of consumers to force industries to declare environmental impacts caused by their industrial activities. In the process of developing environmental protection, attention is made to system thinking from site specific solutions. Educational discipline like industrial ecology, analytical tool like LCA, concepts like system engineering are developed to deal environmental issues with holistic system approach.

Environmental documentation and communication of environmental impacts through environmental product declaration (EPD) and new system of carbon footprint documentation is continuously applied and becoming acquainted. EPD system, which includes environmental product labeling and declaration mechanism, is being adopted since 1990s with a goal to account all types of environmental aspects of a product. On the other hand, carbon footprint accounting is new and emerging system, which accounts only single issue of environmental impact; i.e. Global warming potentials. The aim of carbon footprint accounting system is to control increasing world climate change risk. Different systems are developed by varieties of organizations to account carbon footprint. The system suggested by International standards ISO 14000 series provide a single, globally accepted standards, which help to keep harmonization around the world. *ISO 14020 series* (environmental labels and declarations ISOs; ISO 14024, ISO 14021 and ISO 14025) and incoming *ISO 14067- Carbon footprint of products* are the outcome of the effort laid by International organization for standardization for the declaration of environmental consequences of the product.

Increasing global warming and possibilities of negative climate change consequences in future humbled different organizations to develop different system for greenhouse gas accounting. Moreover, consumers are also becoming aware about carbon footprint of their choice. As a result, assisting tools such as greenhouse gas protocol, PAS 2050 are developed and many online services are available to calculate personal carbon footprint. The up-coming standard ISO 14067 – Carbon Footprint of Products is scheduled to be published soon.

Both ISOs 14020 series and 14067 are product oriented. The aim of these ISOs is to facilitate producers and consumers to choose environmentally friendly product process. Both ISOs provide LCA based information in accordance with ISO 14040. LCA procedure and environmental declaration system process given in these ISOs encourages industries to account direct and indirect environmental impacts caused by production and to improve environmental performance of products over life cycle. Similarly, the mechanism of environmental product declaration given in these ISOs also assists purchasers and users to make environmentally friendly decisions by allowing choosing environmentally best products. ISO has proposed different five means for communication of carbon footprint of product on ISO 14067 and three means for environmental product labeling and declaration on ISO 14020 series (Table 4-4).

Communication of environmental and carbon footprint information of a product help organizations to be environmentally responsible in the area of green procurement, environmental reporting and communication (for example, sustainability reporting and global compact reporting), environmental product design, research and development of environmental friendly technology and environmental management system of the organization.

9.2 Issues of ISO 14067-Carbon footprint of products

The main limitation of carbon footprint is accounting of single environmental issue; i.e. global warming potential, while environmental label and declaration encourage industries to account all sort of environmental impacts.

The requirement of ISO 14067 is that carbon footprint of a product shall be based on LCA methodology. The procedure for carbon footprint calculation is same as ordinary LCA used for environmental declaration and labeling. There could be possibility for a question on why no additional effort to get a broader environmental analysis like in ISO 14021, ISO 14024 and ISO 14025 where industries are obliged to quantify information on environmental impacts and also give qualitative information. Environmental product declaration according to ISO 14025 covers all other impacts along global warming potentials.

In broad view there will be a chance of problem shifting of environmental impacts. Now, popularity of the term carbon footprint is growing due to heightened awareness on climate change. If focus is given only for climate change, a problem of the world from all sectors, there will be possibility for the emergence of another environmental problem such as acidification, toxicity of air, water and soil, depletion of resources and so on. Therefore, one may say that there is possibility of revised environmental declaration program according to ISO series 14020 with added new clauses for carbon footprint as mentioned in ISO 14067, which may allow treating other environmental impacts along with carbon footprint as seriously.

Another issue related to ISO 14067 is that carbon footprint program may be costly for small sized industries to perform assessment and verification procedures. Time consuming data aggregation and verification process are cost factors. Besides decision making, on the basis of only one environmental performance, carbon footprint is not fair sometime. If so, according to Finkbeiner (2009) recycled paper should be stopped because compared to virgin paper with carbon footprint close to zero. Similarly, waste water treatment, which increases carbon footprint also need to abandoned. This shows both opportunities and threat if considered only carbon footprint. Right now, it is true that global warming is most threatening environmental issue and reduction on greenhouse gases (carbon footprint) is only one single solution indicating carbon footprint accounting and documentation.

9.3 System of road and data aggregation for carbon footprint analysis

While looking through system perspective, road is a sub-system of transportation service. Road system itself consists of sub-systems and many elements.

Industrial ecology, which is a broad system thinking approach, treats the environment as part of product system. Analyzing whole system of a product process from life cycle perspective and it's interaction with environment makes it possible to find critical environmental spot, which may provide feedback for environmental improvements. The combination of system engineering and LCA is found helpful approach to visualize system of product from life cycle perspectives during this research work. The method is equally valuable to account carbon footprint of the products.

The main effort for carbon footprint accounting of a road is data aggregation for life cycle analysis methodology. LCA methodology needs all product process information from cradle to cradle. Moreover, life phase of the road should also be considered through life cycle perspective. Life phase of a road starts from planning to demobilization.

Road as a product consists of different engineering structures such as pavements, bridges, and tunnels. Water drainage system, lighting system, railing and fencing are supporting structures for a road. Many suppliers and production industries are involved or connected during the process of road construction. Hence, data inventory and analysis process is time consuming and has long process for LCA of a road to account carbon footprint. Collecting all materials and product process information is important to keep the consistency on the carbon footprint of a road. Material and emission flow information is possible to get, if all related organizations keep flow of material information in their data system. Therefore, good coordination among them is important.

Emission data are possible to achieve from scientific data base that are maintained generally by specific data base organization or national and from international publication.

Modeling of life cycle phase of a road consists of some challenges in data aggregation. The matter of discussion for carbon footprint of a road is that whether greenhouse gas emission from vehicle during operation of a road should be allocated to road or not? Further more, how to document carbon footprint of use of vehicle? Average information on types and number of vehicle running through the road and their carbon footprint factor should be collected.

Modeling end of life of a road in LCA is also not easy. Generally, constructed road has no end life; it is maintained for many years. If road is constructed for temporary purpose, waste management after end of life of a road must not be excluded from modeling The material flow for maintenance phase is major part for greenhouse gas emission. For example, if life period of road is decided for 50 years, material flow for the maintenance and operation phase for 50 years should be accounted for the carbon footprint of a road.

Another challenge for accounting carbon footprint of a road construction is the allocation of emission for recycled materials. From literature review it was understood that now a day there is a trend to use construction wastage for road construction. For example, if remains of building materials are used for road construction than the allocation criteria for the recycled materials need to be included.

A road is different from other industrial products. Consumption of materials and energy differ for different road projects even though type of materials and road are same. Factors that make difference are geo-physical and topographic conditions. Amount of material flow may vary in different geographical, geological and topographical conditions. Due to varying conditions it is not possible to use constant material quantity for all conditions.

9.4 Discussion on case study

This case was proposed by Statens Vegvesen (Norwegian public road administration), Trondheim. The system of the case is construction of extra road lane, which consists of pavement and supporting structure like drainage, light, railing, and fencing. During case study many environmental aspects are noticed like removing bulk soil, clearance and cutting of some vegetation, possibility of noise pollution because of machinery work, local air pollution because of dust and so on. However, the main focus of the case study was carbon footprint of road construction. Hence, the case is used for carbon footprint accounting through life cycle analysis (LCA) methodology.

Since the case study is a road and focus is carbon footprint of road construction, many product process that flow to the construction of road was modeled and data related to these process were collected. As discussed, inventory process in LCA of road construction is time intensive step and co-ordination among all actors of road construction is essential for accuracy and trustworthy results. Because of limitation of time and data information, life phases of every elements was not possible to include in the system boundary. Limitation of this case is that the input flow of materials and resources for LCA methodology are relied on the information that were provided by the owner of the case and emission information are calculated by the use of GaBi educational LCA tool.

The need is recognized to document carbon footprint information of the case by organizing discussion meetings between Statens vegvessen personnel and the researcher. Mainly pavement elements of the case system are selected for the analysis. Carbon footprint performance of the case is greenhouse gas emission from system boundary of the case. The performance indicator is CO2-equivalent emission form the case. The case analysis covered performance of material process, transportation and site specific processes.

Process model of material, transportation and site specific activities are developed with LCA methodology. All three aspects of the case are vital for carbon footprint analysis of the case. All together carbon footprint of the defined system boundary of the case is 215 ton CO2-equivalent. Result of the case analysis is that material product process for the end product is most significant for carbon footprint of the case. In addition, transportation and site specific process are also important in adding carbon footprint to the case. The case is studied applying system thinking approach and is discussed relating to system engineering principal.

The environmental performance of the case is partial carbon footprint because it has not cover whole element process of the case road. The information of this analysis can be used for documentation purpose. The analysis is carried out based on estimated information and some assumptions. The results can be verified after the completion of the case road with actual field data.

9.5 Fulfillment of objectives

The main purpose of this study was to look environmental burden of a product focusing carbon footprint based on life cycle assessment. As a case road is taken a product and LCA methodology is applied in the construction phase of the road. It is argued that the carbon footprint of the road construction can be documented as requirement of ISO 14067 or ISO 14025.

Six objectives were set to achieve main purpose of the study. Objective 1 and 2 were covered in Chapter 4, where discussion was made on the development of environmental documentation system from site specific priority to holistic attention. Existing environmental documentation system like environmental reporting in national to international level such as Sustainable Reporting, Global Compact Reporting were synthesized and presented in Chapter 4. Environmental declaration through requirement of ISO 14020 and new ISO 14067 to declare carbon footprint of product are important systems that assist business and service sector to declare environmental impact of their product and consumer have choice to make environmentally friendly decisions. Hence, ISO 14020 and ISO 14067 were discussed in detail in Chapter 4. The relation between these two ISOs and issues related to ISO 14067 are discussed at the begging of this chapter.

Road construction is selected as case product. In Chapter 5 system theory is applied to define the road product to achieve objective 3. Looking through system theory road is a part of transportation service and road has four life phases from planning to end of life. Every phases of a road consist of many physical elements. Carbon footprint of road accounts CO2-eq emission from product process of all elements of whole life phases of the road.

Combination of system engineering principle and LCA methodology is purposed for carbon footprint mapping methodology in Chapter 6. 10 steps framework has covered the principle of system engineering and LCA methodology. Discussed framework is the coverage of objective 4. Data aggregation and system modeling issues discussed in the heading 9.3 of this discussion Chapter.

Proposed carbon footprint mapping framework for road is applied in road construction case study and discussed in Chapter 7 and 8. LCA methodology is applied to calculate carbon footprint of the case study. Carbon footprint may be a part of EPD and hence is discussed at the end Chapter 8.

Chapter 10: Conclusions and recommendations

10.1 Conclusions

The world will suffer from different impacts in near future if the development pattern of the world continues at the existing rate of growth and with similar pattern of technological processes. The solution is to become responsible in environmental consequences of the activities mankind makes for the economic growth. At present climate change and its consequences in global society is most alarming.

As a result, technology, standards and regulations are being developed to deal the risk of climate change. One of the recent developments in climate change regime is upcoming ISO 14067- carbon footprint of products. This ISO is guiding document for every good and service provider to account changes in greenhouse gases on environment due to their production system.

Following the principle of ISO 14067, case study is carried out on carbon footprint of the road construction in transportation service. While, case study is carried out for small road project with less than 1 km road length with only for one lane extension. Total carbon emission of defined system boundary was calculated to approximately 215 ton CO_2-equivalent.

From the study it is concluded that road has four phases in its life cycle and has large time span in its life. Many elements of the life phases of road may change greenhouse gases in environment considerably. The result of case analysis shows that production process in background system of foreground system of road construction has major impacts in the emission of CO_2 - equivalent and hence consuming one unit of material increase carbon footprint of the road considerably.

It is also concluded that accounting carbon footprint following coming ISO 14067 is important to deal the risk of global warming and climate change impacts. However, at the same time other environmental impacts should not be neglected. Therefore, it is suggested to include environmental indicator “carbon footprint of product” as requirement of ISO 14067 instead of global warming potential (GWP) indicator in EPD system of ISO 14020. By doing so, it will help to reduce the possibility of shifting environmental issues in the future.

10.2 Recommendations

This research is carried out on the estimated data of planned road construction case and the use of LCA tool GaBi educational version. Hence, following recommendations are made:

- It is expected that some degree discrepancy between estimated and actually constructed material flow data will occur. Hence, actual material flow data should be collected during the construction of the road and should be compared with the estimated one to achieve more accurate CO2- equivalent.

- Carbon footprint of the case is calculated with the help of GaBi educational version, which lacks Norway based product processes. Therefore, it is recommended to also apply actual country based product process to check the validity of the results.

- LCA needs material flow from cradle to cradle of product process. This is possible if all related sectors or material provider keep material flow information in their data system. Therefore, it is recommended to establish a system that allows co-ordination between all product and service providers so that all material flow information is possible to get of the calculation of carbon footprint of the road through life cycle perspective.

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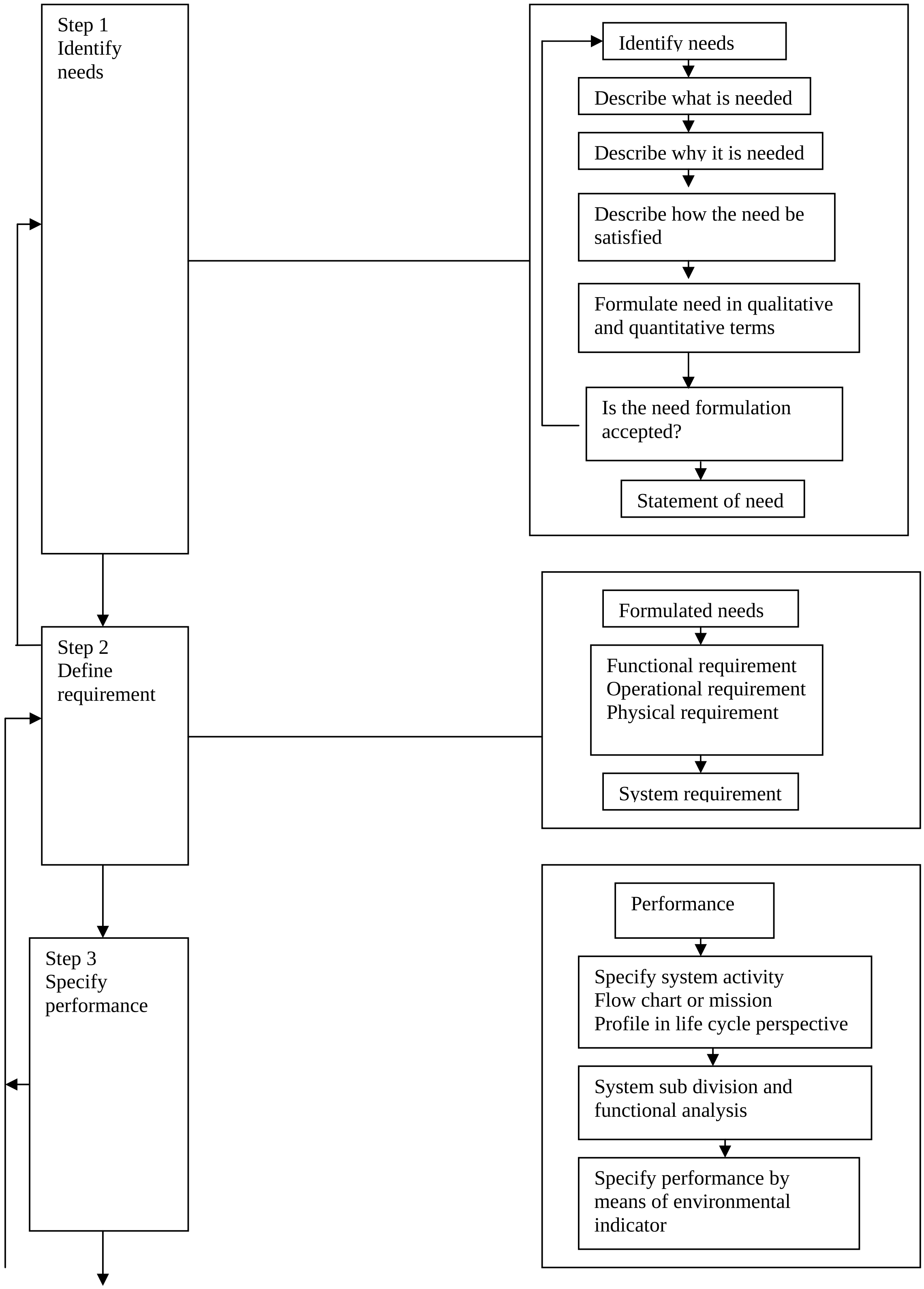
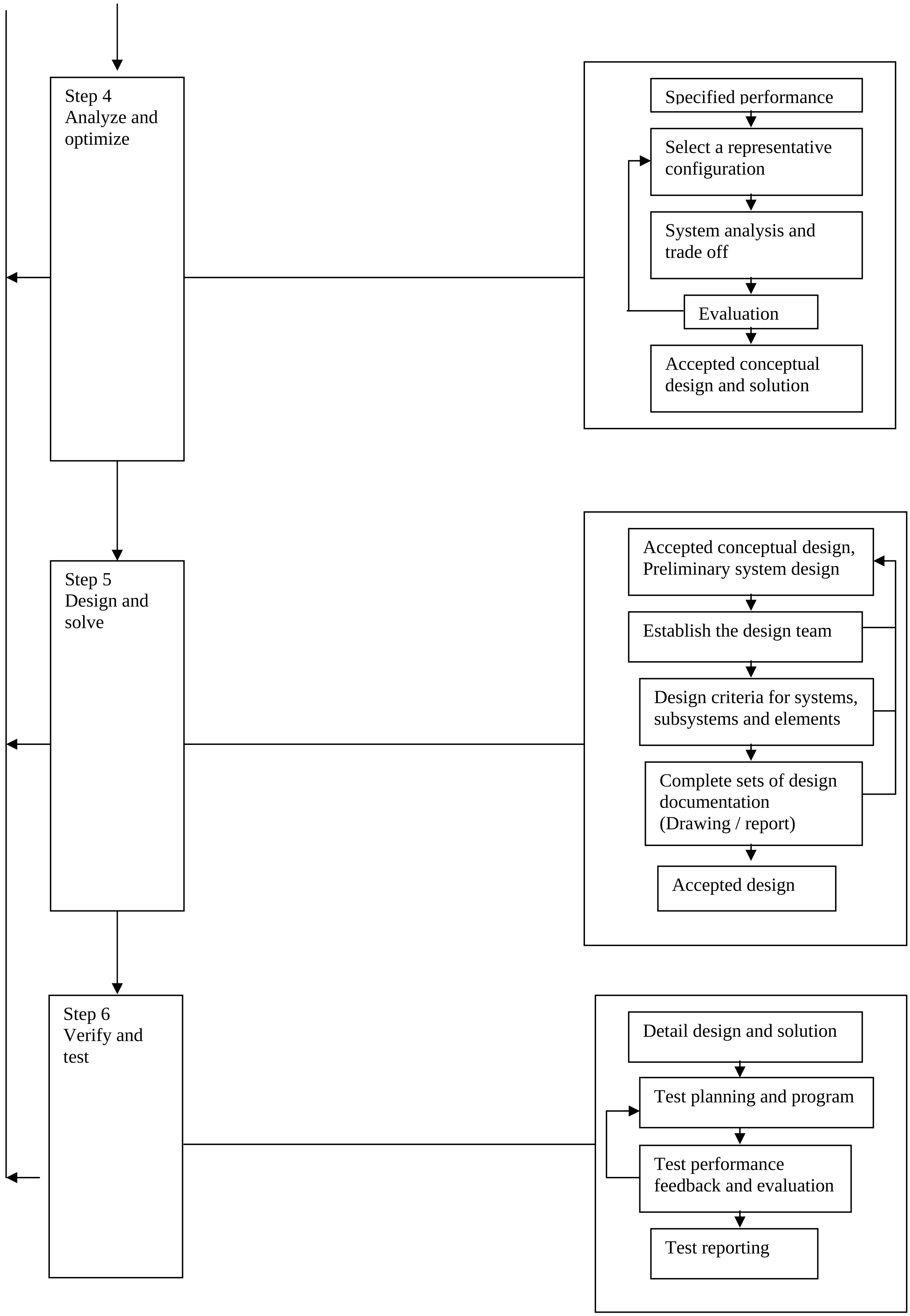
Appendix A: Illustration of system engineering process

Illustration of activities in each step of the System Engineering process (Fet, 2009)





Step 4
Analyze and optimize
Specified performance
Select a representative configuration
System analysis and trade off
Evaluation
Accepted conceptual design and solution
Step 5
Design and solve
Accepted conceptual design, Preliminary system design
Establish the design team
Design criteria for systems, subsystems and elements
Complete sets of design documentation (Drawing / report)
Accepted design
Step 6
Verify and test
Detail design and solution
Test planning and program
Test performance feedback and evaluation
Test reporting

Appendix B: Different activities of case modeled in GaBi and presentation

Appendix B1: Carbon footprint of pavement of the case

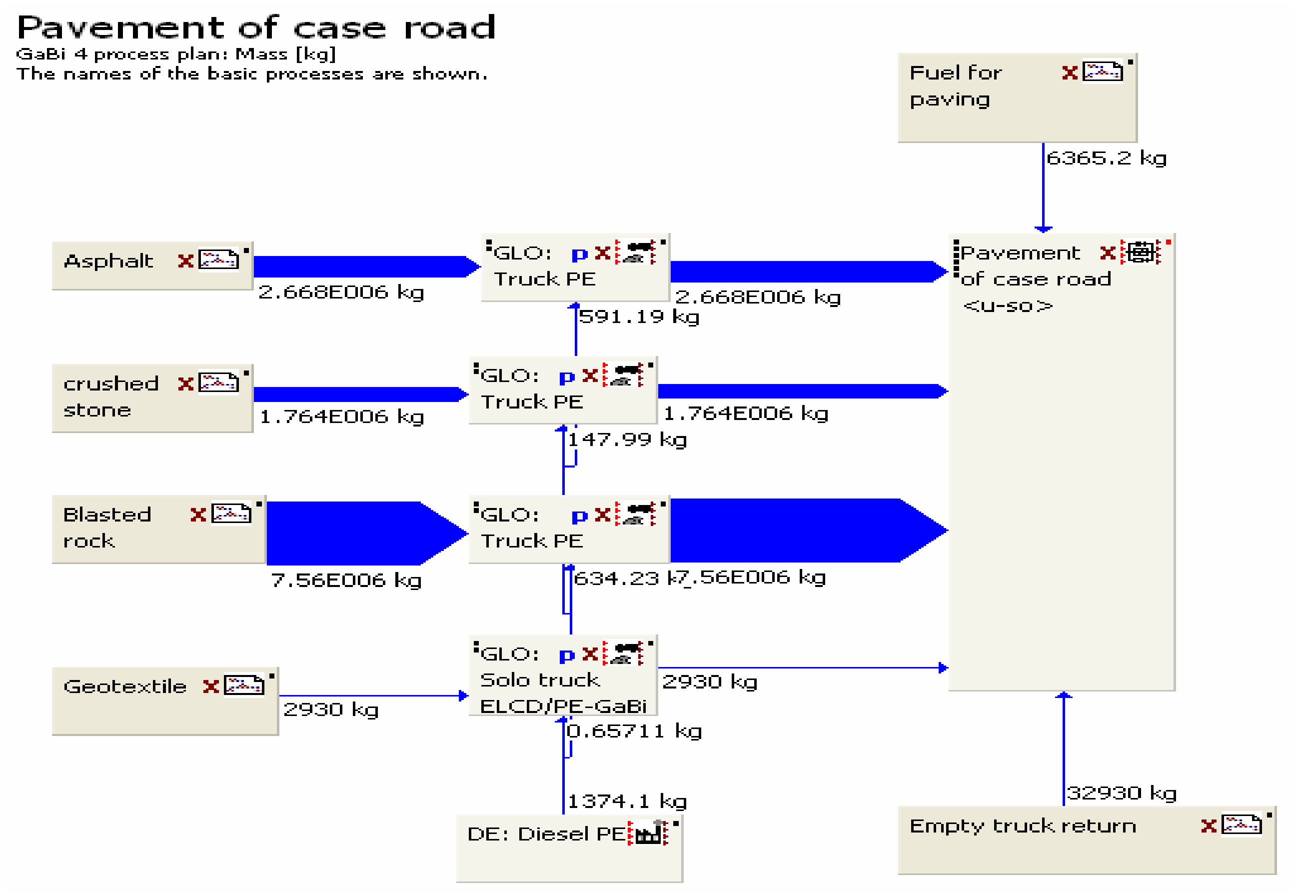


Figure B1-1: Material flow diagram for pavement construction of case road (modeled on GaBi)

The Figure B1-1 is copied from GaBi. This figure is the system boundary of pavement of the case, which is modeled in GaBi and is based on the information of data inventory. The system boundary covers material production, transportation and fuel consumption for the construction of pavement at site. Plan of each material process is develoed and connected to main process. For example, plan of *Blasted rock* is developed with the flow of blasted stone from the mountatin. This plan is connected to main process *Pavement of case road* through transportation. Carbon euiavalent of the system boundary is presented in Table B1-1.

In the case of empty truck return, certain quantity is loaded in the GaBI truck process system to make equivalent 0.2 liter diesel per km. Alltogether it counts about 33 tons equivalent quantiy for the empty truck.

Table B1-1: kg CO2-equivalent of pavement of case road

	CML2001 - Nov. 09, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]								
					Fuel for paving and labeling		Transportation		
	Asphalt	Blasted rock	crushed stone	Geotextile	Diesel for site vehicle	Combustion on site	Transportation with load	Transportation with empty	Total CO2-Eq (Pavement
Emissions to	73708.80	43742.36	24622.79	6837.47	2498.08	20368.00	4915.31	2713.03	179406.11

Table B1-1 and Figure B1-2 show resuls of modeled Figure B1-1. The result shows that Asphalt production process has singinificant impact in comaprision to other material production. Considered system boundary of the asphalt production is bitumen and aggregates production. Energy during mixing bitumen and aggregates is not considered. The asphalt mixing process could add more carbon footprint.

Combustion on site and transportation are also major factor for the carbon footprint of the product.The table shows that carbon footprint of fuel combustion on site is about 20 ton, 2.5 ton CO2-eq from production of diesel for site machinary work. Hence, all together it counts more than 22 ton CO2 -eq from site. Both way transportation, load and empty return contributing around 7.6 ton CO2 -eq.

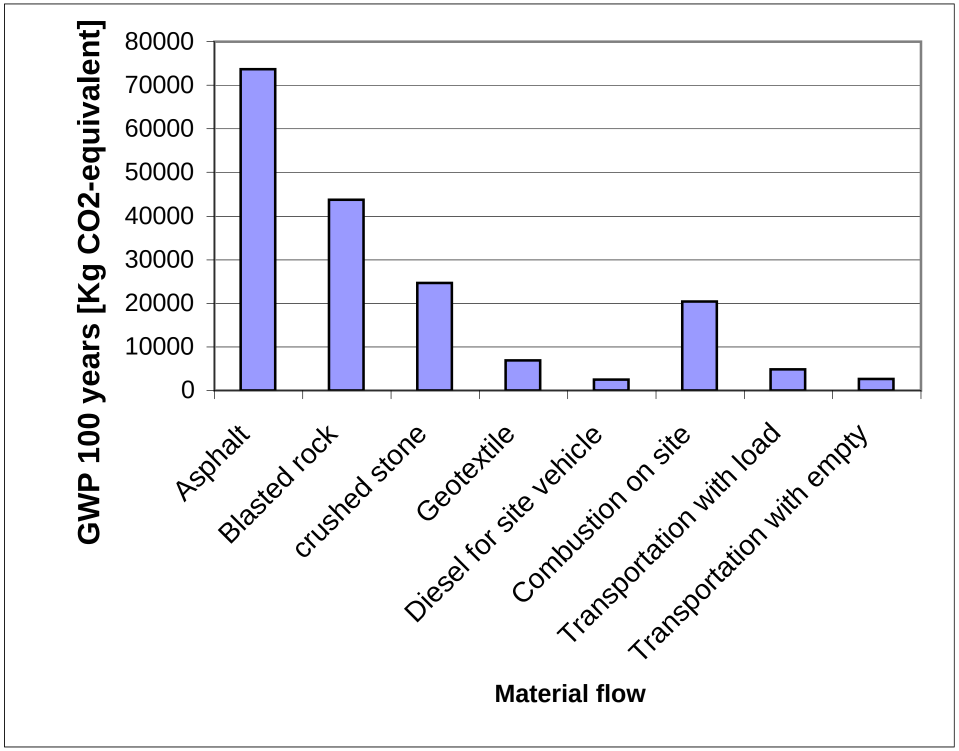


Figure B1-2: Carbon footprint of the pavement of the case

Appendix B2: Carbon footprint only from transportation of materials in case road

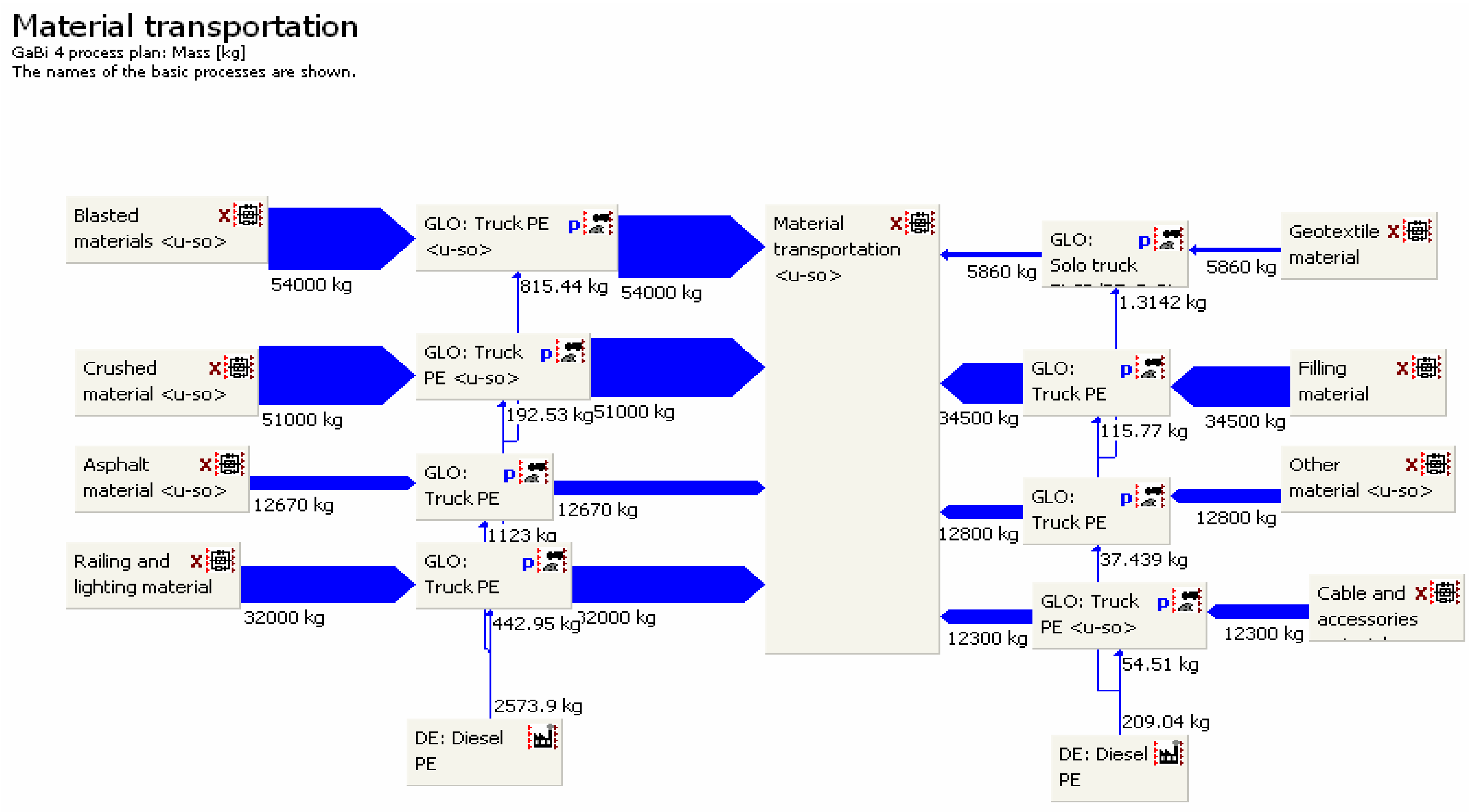


Figure B2-1: Material transportation flow daigram (modeled on GaBi)

Figure B2-1 is a model for transportation only. Material flow quantity for each material is per truck transportation, which counts both load and empty return transportation. Total number of truck is multipled with distance to get total truck transportation distance and defined it while processing the truck. For empty transportation, 0.2 liter per km is assumed and equivalent weight for 0.2 liter diesel is added to loaded truck to consider carbon footpritn of the empty truck return. For example, railing and lighting material is transported 20 ton per truck and 0.2 liter diesel can transport 12 ton per km. Therefore, 32 ton per trip is considered to account both way transport. Other materials are also adjusted in the same way The carbon footprint of transportation is tabulated in Table B2-1 and B2-2 .

Table B2-1: kg CO2-equivalent of materail transportation for case road construction (copied by GaBi balance)

CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]										
DE: Diesel PE	DE: Diesel PE	GLO: Solo truck	GLO: Truck	GLO: Truck	GLO: Truck	GLO: Truck	GLO: Truck	GLO: Truck	GLO: Truck	Total
1010.02	82.039	4.2015148	1409.4443	612.6278	2594.6588	368.37748	173.804422	119.37396	3580.6537	9955.2

Table B2-2: Rearanged balance of kg CO2-equivalent from table B2-1

Flow	kg CO2-equivalent
Diesel Production	1092.059
Diesel combustion	8863.1419
Total	9955.2009

Table B2-2 shows carbon footprint from diesel production and diesel consumption. Diesel production cove about 1 ton CO2 -eq, while combustion from truck engine gives 8.8 ton CO2 -eq. Form this figure it is cleared that diesel contribute more CO2 -eq by combustion than production. Therefore, less use of diesel helps to decrease carbon footprint of the product.

Appendix B3: Carbon footprint from site activities

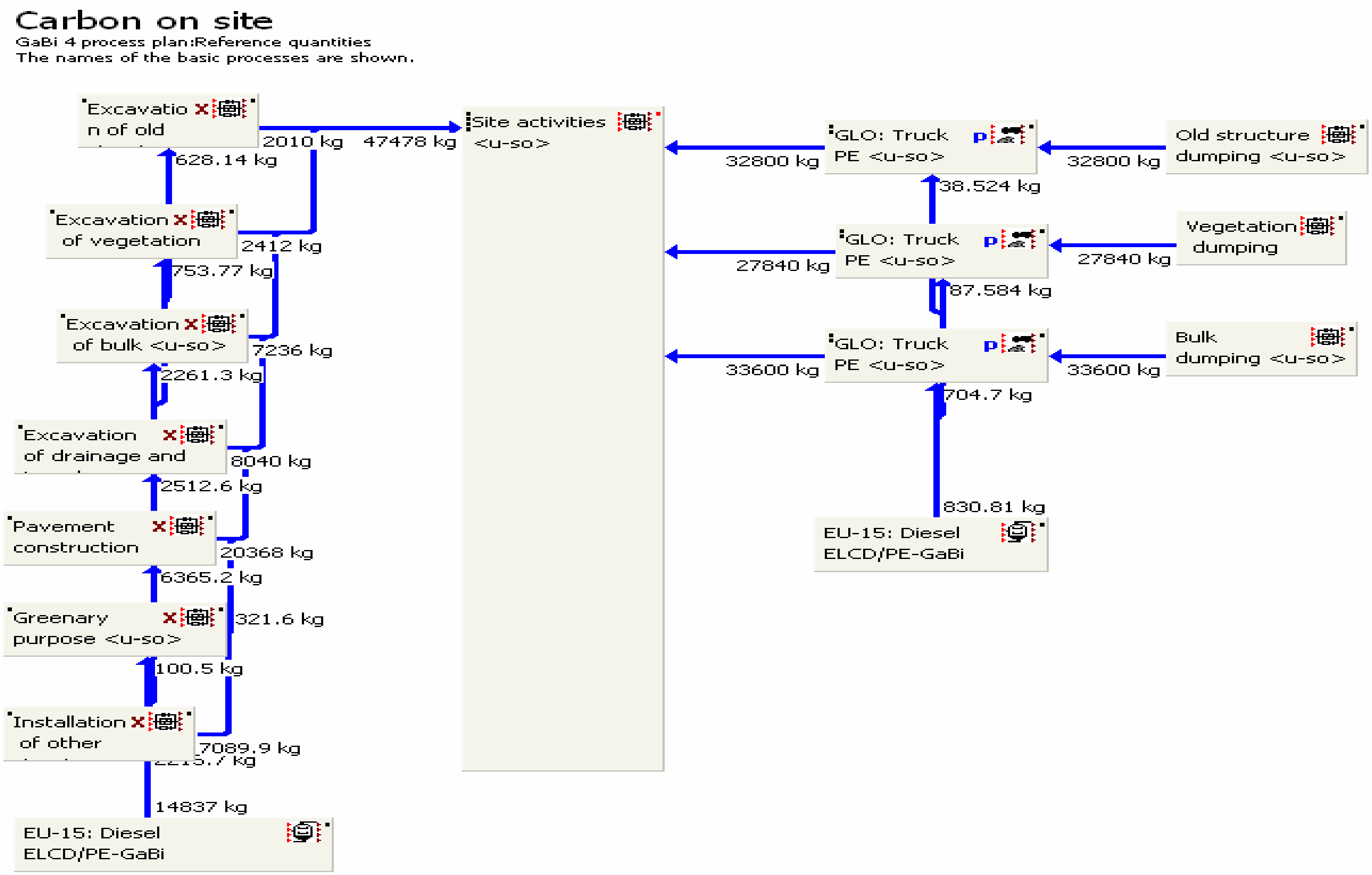


Figure B3-1: Flow diagram of diesel and fuel combustion on site activities (Modeled on GaBi)

Figure B3-1 is the flow of diesel and combustion from different site activities. Flow of diesel is the amount of diesel for each activities and the flow to the right in the figure is carbon equivalent flow. In Figure B3-1 machinary work is shown to the left side and dumping is shown to the right side, which represents transport. Flow of dumping material is quantity for each truck, which accounts both load and empty truck. Diesel is input for the truck engiene. The carbon footprint on site is tabulated in Table B3-1 and B3-2 in next page.

Table B3-1: kgCO2 equivalent balance on site activities of case road construction
(copied from GaBi balance)

EU-15: Diesel ELCD/PE-GaBi	EU-15: Diesel ELCD/PE-GaBi	Excavation of bulk <u-so>	Excavation of drainage and trench <u-so>	Excavation of existing structure <u-so>	Excavation of vegetation <u-so>	GLO: Truck PE <u-so>	GLO: Truck PE <u-so>	GLO: Truck PE <u-so>	Greenary purpose <u-so>	Installation of other structure <u-so>	Pavement construction <u-so>	**Carbon on site (Total)**
322.4152	5757.896	7236.00	8040.00	2010.00	2412	2242.3	278.686	122.5789	321.60	7089.94	20368	**56201.41**

Table B3-2:Rearranged balance of kg CO2 equivalent from table B3-1

Diesel (dumping)	Combustion (dumping)	Diesel (Excavation & construction)	Bulk excavation (combustion)	Drainage and trench excavation(combustion)	Excavation of existing structure(combustion	Vegetation excavation (combustion)	Greenary purpose (combustion)	Other structure installation (combustion)	Pavement construction (Combustion)	**Total kg CO2 -eq**
322.4151	2643.562	5757.896	7236	8040	2010	2412	321.6	7089.94	20368	**56201.414**

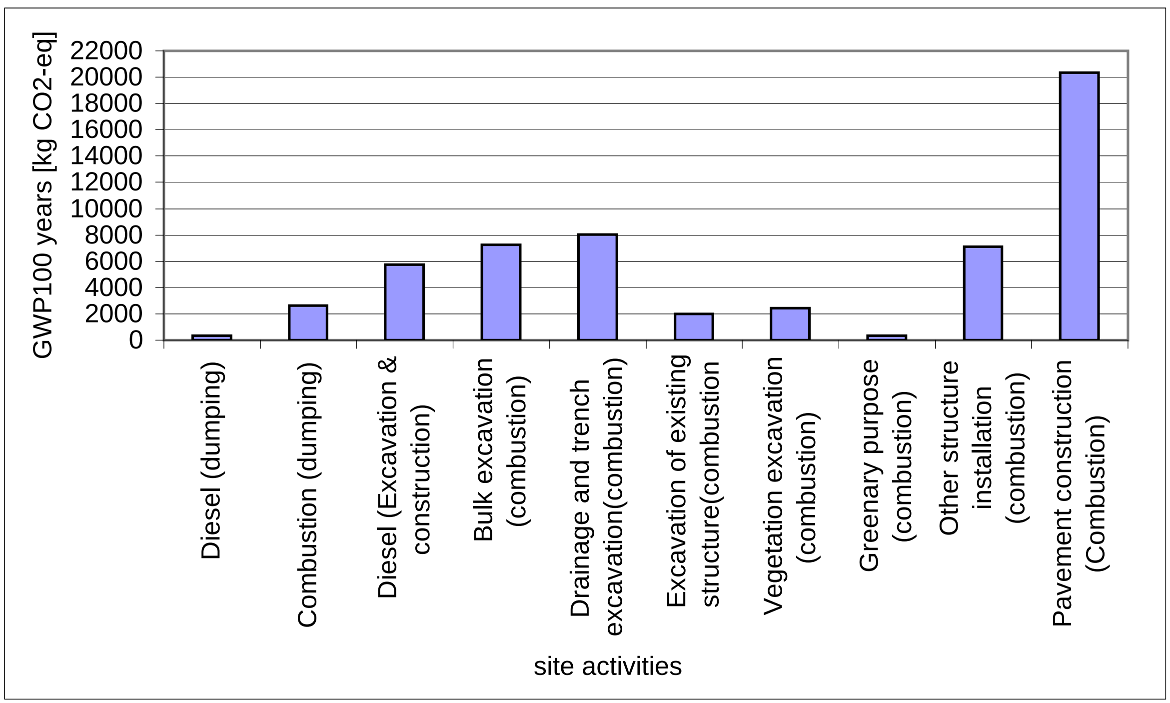


Table B3-1 and B3-2 show carbon footprint from different activities at site. Figure B3-2 shows carbon footprint for pavement construction is the most significant. This result is logical because pavement construction is the main structure for road construction and many machine works needed. Second largest contributor is excavation for drainage and trench. The third contributor for the case is bulk excavation due to large amount of soil bulk is going to be removed before extending the road.

Fiure B3-2: Carbon footprint on site

Table B3-3: summary table of carbon footprint of the case (ton CO2-equivalent)

Pavement material	Pavement material transportation	Pavement site emission	Other material transportation	Other structure installation	Excavation and site preparation	Dumping excavated material and filling	**Total ton CO2 - Equivalent**
148.7	7.62	22.8	2.32	7.9	22	3.32	**214.66**
69.27%	3.55%	10.62%	1.08%	3.68%	10.25%	1.55%	**100.00%**

Table B3-3 is the summary table that illustrates different activities of the case road and their contribution in carbon footprint. Most singinificant impact is from pavement material process, which is 149 ton CO2-equivalent. Second main contributor is site activities, which is altogether 56 ton CO2-eq. Material transportation has also contributed about 10 ton CO2-eq. This value covers only transportation from local distributor of product to site. If transportation is considered from the origin of production site to construction site the CO2- eq is believed to be more.Therefore, transportation should not neglect to include in system boundary.

Appendix C : Material inventory and $kgCO_2$-eq emission

Table C1:Material inventory table for road construction

		Different structures of road construction																				
Input Material	Unit	demolisition of existing system	site preparation	Embankment	Sub base course	Base course	Wearing course	Geotextile	Drainage system	Electrical cable	Railing	Fencing	sing pole	sign board	Road marking	Stone Edge	concrete Slab	electric Pole	Light Bulb	Luminaire	road lighting box	**Total quantity**
Fuel (diesel)	ton	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Electricity (Heavy fuel oil)	100Mj																					
Electricirty (Hydropower)	100Mj																					
Transportation truck (35 - 40 ton)	ton/km																					
Transportation truck (12 - 14 ton)	ton/km	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	
transportation air	ton/km																					
Transportation ship	ton/km																					
Transportation rail	ton/km																					
Blasted rock	ton				x																	
crushed rock	ton					x																
Concrete	ton								x				x				x	x				
Bitumen	ton							x														
Steel	ton										x	x	x	x				x		x	x	
copper	ton									x												
wood	m3											x										
PVC pipe	ton								x	x												
Stone	ton															x						
Plastic	ton							x		x												

Table C2: kg CO2- eq per unit material production process

Material	Fuel (diesel)	Electricity (Heavy fuel oil)	Electricirty (Hydropower)	Transportation truck (35 - 40 ton loading)	Transportation truck (12 - 14 ton loading)	transportation air, Cargo	Transportation ship (Ro Ro)	Transportation rail (diesel)	Blasted rock	crushed rock	Pre cast concrete	Bitumen (from crude oil)	Steel sheet (0.75mm zink coated)	copper wire	wood (with bark)	Stone	Plastic (polypropyline fober)	PVC pipe
Unit	Ton	100 Mj	100 Mj	Ton / km	ton / km	1000k gkm	Ton / km	ton / km	Ton	Ton	Ton	Ton	Ton	Ton	M3	Ton	kg	Ton
GaBi process	EU 15	Norway	Norway	Global	Global	Us	Global ,5000 dwt, light fuel pil	global	Us (lime stone blast)	DE	RER, ELCD	EU 15	DE	EU 15	US		EU27	RER
kg CO2- equivalent per unit material	388.1	20.775	0.497	0.049	0.079	0.062	0.021	0.013	5.77	14	120.9	287	2384	787	22.88	NA	2334	3271

Table C2 illustrates specification of different product in first row. These materials are needed for the construction of road (pavement and other supporting structures) and are also mentioned in appendix C1. Third row of the table is selected process data base, which is available in GaBi. The result of kg CO2-eq from each material process are obtained from selected GaBi process.

Table C3: Selected material and kg CO2-eq per unit

Material (in ton)	Blasted rock	crushed rock	Pre cast concrete	Bitumen (from crude oil)	Steel sheet (0.75mm zink coated)	copper wire	wood (with bark)	Plastic (polypropyline fober)	PVC pipe	Fuel (diesel)
kg CO2-eq	5.77	13.96	120.89	287.33	2384	787.2	22.876	2333.6	3271	388

Table C2 and Figure C1 illustrate kg CO2-eq emission per unit material production, which is used during road construction work. These materials are needed for pavement as well as other supporting structures.

Figure C1 shows one ton PVC pipe production emit more than 3 ton CO2-eq. PVC pipe is used for the purpose of drainage system and electricity system installation to protect electrical wires. Concrete pipe can be used for drainage system. One ton precast concrte emit 120kg CO2- eq. Therefore, selection of material makes difference in carbon footprint. But life period of the product should be considered instead of considering one time use of product.

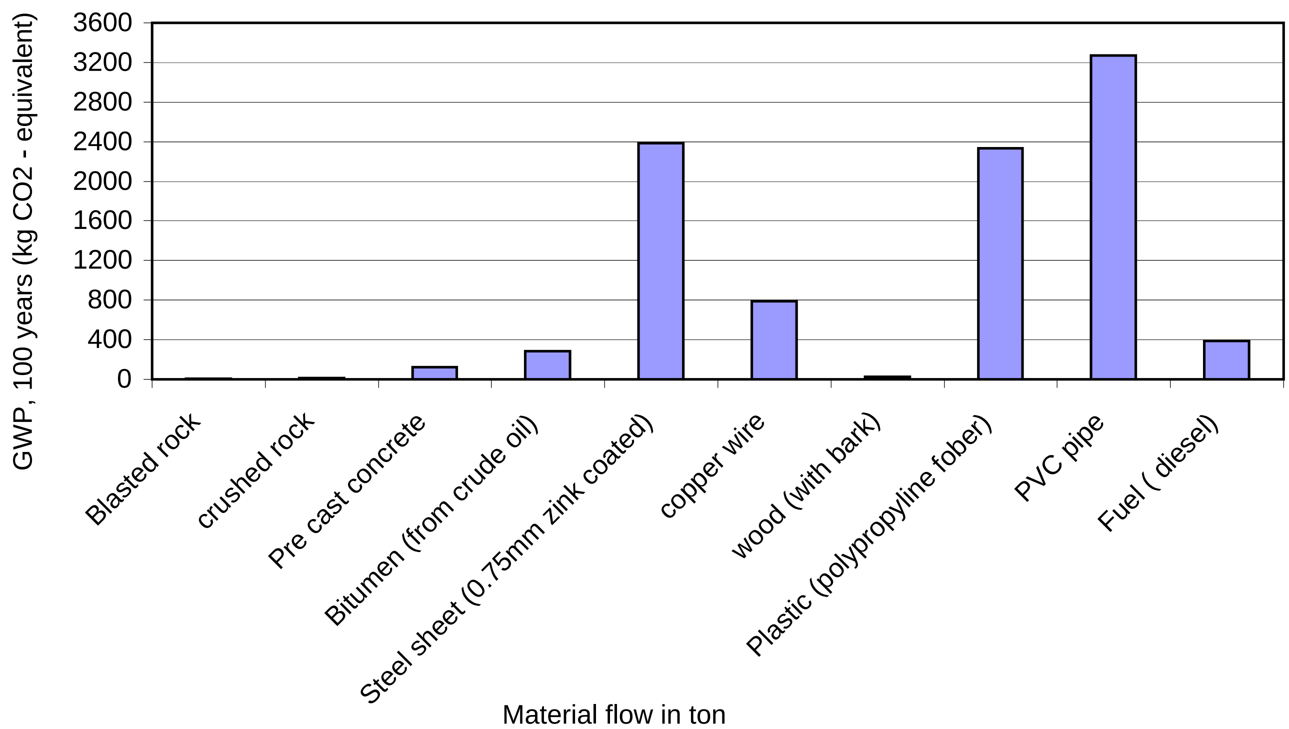
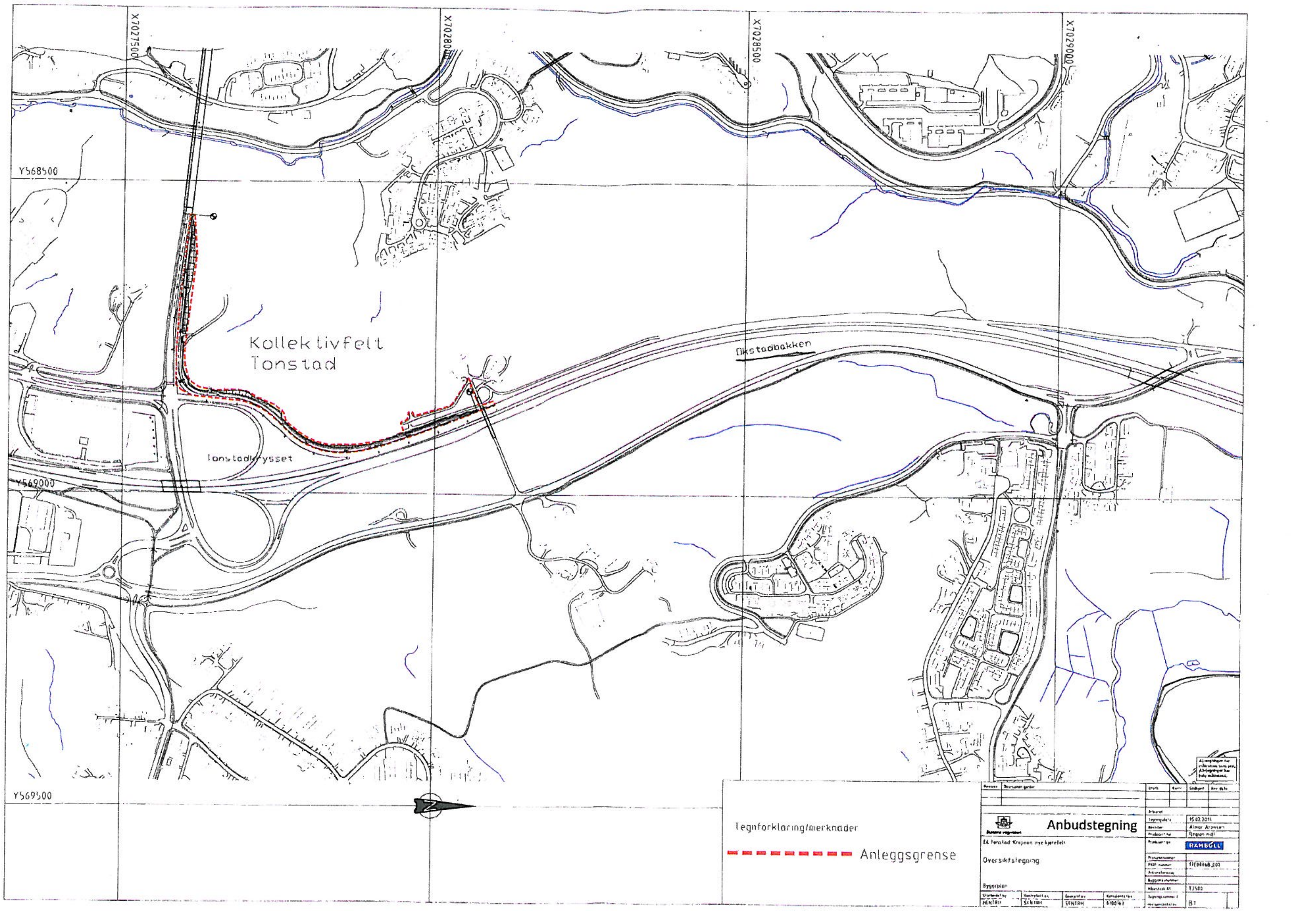
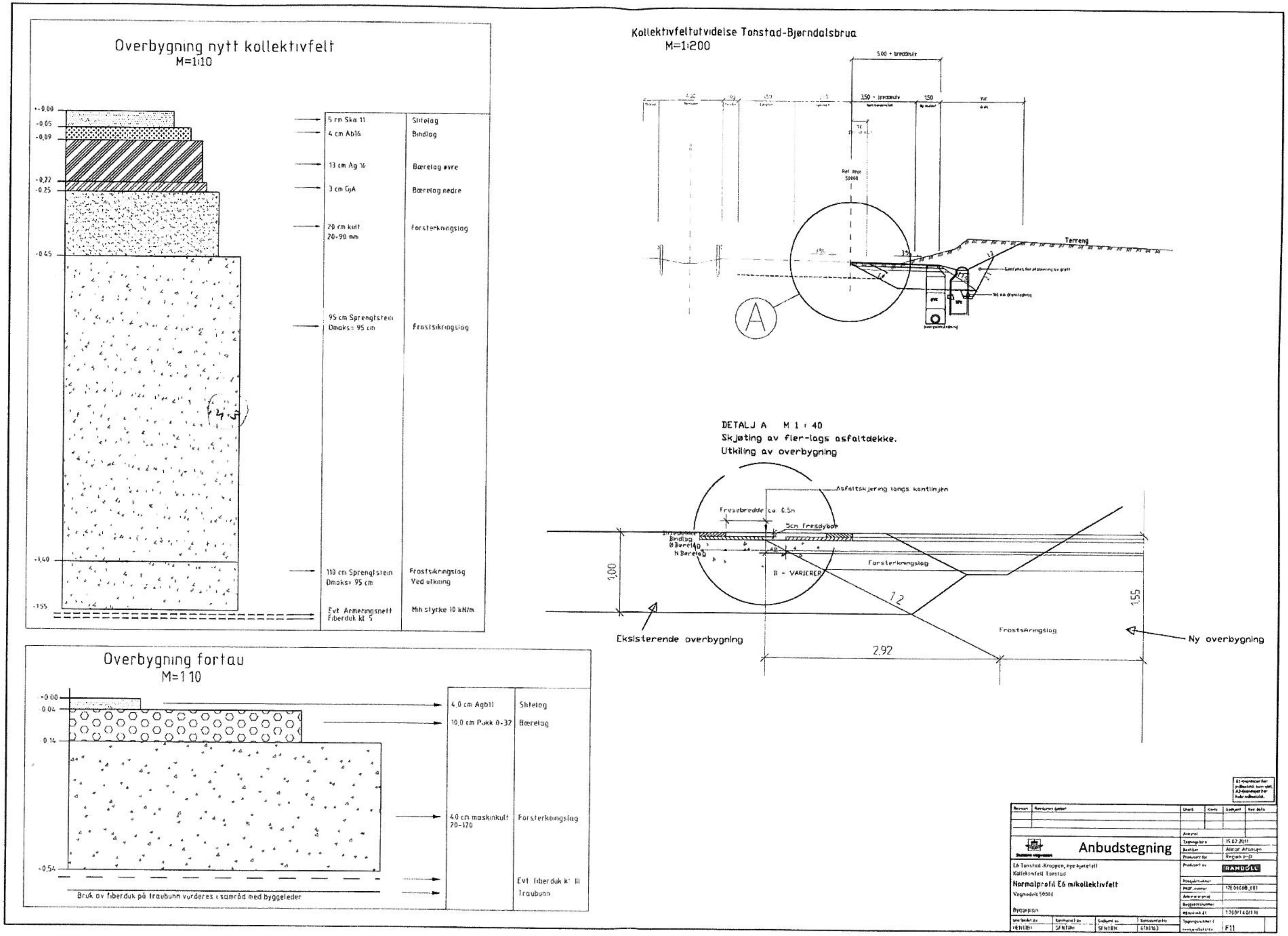


Figure C1: kg CO2-equivalent per unit material production

Appendix D: Location map and drawing of the case road


X7027500
X7028000
X7028500
X7029000
Y568500
Y569000
Y569500
Kollektivfelt
Tonstad
Tonstadkrysset
Okstadbakken
Tegnforklaring/merknader
Anleggsgrense
Anbudstegning
Oversiktstegning
Byggeplan
15.02.2011
Almar Arnesen
Region midt
RAMBØLL
1:2500
B1



Overbygning nytt kollektivfelt
M=1:10
+0,00
-0,05
-0,09
-0,22
-0,25
-0,45
-1,40
-1,55
5 cm Ska 11
4 cm Ab16
13 cm Ag 16
3 cm GjA
20 cm kult
20-90 mm
95 cm Sprengstein
Dmaks= 95 cm
110 cm Sprengstein
Dmaks= 95 cm
Evt. Armeringsnett
Fiberduk kl 5
Slitelag
Bindlag
Bærelag øvre
Bærelag nedre
Forsterkningslag
Frostsikringslag
Frostsikringslag
Ved utkiling
Min styrke 10 kN/m
Overbygning fortau
M=1:10
+0,00
0,04
0,14
-0,54
4,0 cm Agb11
10,0 cm Pukk 0-32
40 cm maskinkult
20-120
Evt. fiberduk kl. III
Slitelag
Bærelag
Forsterkningslag
Traubunn
Bruk av fiberduk på traubunn vurderes i samråd med byggeleder
Kollektivfeltutvidelse Tonstad-Bjørndalsbrua
M=1:200
5,00 + breddeutv
3,50 + breddeutv
1,50
Terreng
A
DETALJ A M 1 : 40
Skjøting av fler-lags asfaltdekke.
Utkiling av overbygning
Asfaltskjæring langs kantlinjen
Fresebredde ca. 0,5m
5cm fresdybde
Bindlag
Ø Bærelag
N Bærelag
B = VARIERER
Forsterkningslag
Frostsikringslag
1:2
1,00
1,55
2,92
Eksisterende overbygning
Ny overbygning
Anbudstegning
Statens vegvesen
E6 Tonstad-Kroppen, nye kjørefelt
Kollektivfelt Tonstad
Normalprofil E6 m/kollektivfelt
Vegmodell 50000
Byggeplan
15.02.2011
Alexer Aronsen
Region midt
RAMBØLL
170 04668_001
F11

Appendix E: Case information received from Statens Vegvesen in March 2011.

E6 KROPPAN – TONSTAD, Nytt kollektivfelt

E6 Tonstad – Kroppan skal utvides med eget kollektivfelt i sørgående retning fra Formo bru fram til Bjørndalsbrua, ca 7-8 km sør for Trondheim Sentrum. Formålet med prosjektet er å bedre framkommeligheten for kollektivtrafikk mot områdene Kolstad, Flatåsen og Saupstad. Det er i dag dårlig framkommelighet på denne strekningen da kollektivtrafikken står i kø med andre bilister.

Området består av dyrket mark, beite og litt skog.

Eksisterende veg utvides i en strekning på 815, med ca 5 meter. Dette arbeidet omfatter blant annet nytt drens og overvannsystem, trekkerør og kabelarbeider, flytting av lysmaster, rekkverksoppsetting, fjerning av masser og tilkjøring av masser.

<u>Framdrift:</u>

7. mars:	Sendes grunnlaget ut til entreprenørene
29. mars:	Innlevering av pristilbud
19.april:	Antatt tidspunkt for valg av entreprenør
18. mai:	Antatt oppstart
30.august:	Ferdigstillelse

Mengdeoppsett følger på neste side.

TableE-1: **Material information table received from Statens Vegvessen**

ARBEIDS-OPERASJONER	**OMFATTER**	**PLASSERING/ LEVERANDØR**	**MENGDER**	**Where/from who**	**Distance (km)**	**Vehicle**	**Working amount excavator**	**Number of trucks**
Riving av eksisterende veg	Fjerning av - rekkverk - master og stolper - asfalt fresing - asfalt riving - fjerning av gamle kabler - gjerder - kummer og rørledninger	Entreprenør velger deponeringssted. Eventuelt eget depot eller annen deponering	- ca 130 m rekkverk - ca 3 skiltstolper, 1 skiltportal, 16 lysmaster - ca 360 m2 fresing av asfalt. Antatt 120 kg/m2 - ca 800 m2 riving og fjerning av asfalt. Antatt 120 kg/m2 - ca 750 meter med fjerning av gamle kabler (200 kg/100m) - ca 245 m sauegjerde - 4 stk kummer.	Heggstadmyra Heggstadmyra Sjøla Sjøla Heggstadmyra Heggstadmyra Heggstadmyra	6 6 6 6 6 6 6	Cat 323D/FH16	50 hours for this box	1 1 3 6 1 1 1
Rydding og fjerning av buskas og hogst avfall	Ved tilfaller grunneier. Buskas må fjernes fra området	Entreprenør velger deponeringsted	- 3600 m2 areal som skal ryddes for skog og buskas – 1080 m3	Tipp	3	Cat 323D/FH16	60hours	75
Masseflytting	Jordmasse til deponi	Entreprenør velger deponeringsted	- 7200 m3, inkludert deponiavgift, antatt 1,5 tonn/m3.	Tipp	3	Cat323D/FH16	180 hours	500
	Jordmasser, disponeres i anlegget	Vegetasjonsdekke Planering i fylling Tetningslag i grøft	- 2100 m3, antatt 1,5 tonn/m3 - 150 m3, antatt 1,5 tonn/m3 - 1400 m3, antatt 1,5 tonn/m3		0,5	Cat323D/FH16	160 hours	250
Ledningsgrøft	- Grøft for overvann og drensledninger - Kabelgrøft	Ledningsgrøft langs kollektivfelt	- 1730 m3 grøft for overvannledninger og drensledning - 900 m3 kabelgrøft			Cat323D	200 hours	
Ledninger	- Overvannsledning - Drensledning	Lagt i rørgrøft, Leverandør velges av entreprenør	- 680 meter overvannledning - 800 meter drensledning	Heggstadmoen	6 6	Leveres av produsent		4 4
Kabler	- Belysningskabel inkl jordledning - Lyttebånd - Markeringsbånd - Fiberkabel	Leverandør velges av entreprenør	- 1325 meter belysningskabel inkl jordledning - 900 meter lyttebånd - 900 meter	Nexans Namsos (example)	200 incl incl incl	Leveres av produsent		1 incl incl incl

			markerkingsbånd - 900 meter fiberkabel					
Trekkerør		Leverandør velges av entreprenør	- 5450 meter trekkerør	Heggstadmoen	6	Leveres av prosusent		8
Trekkekummer		Leverandør velges av entreprenør	- 4 stk trekkekummer	Heggstadmoen	6	Leveres av prosdusen		1
Vegoverbygning	- Avretting traubunn - Fiberduk - Sprengt stein - Forsterkningslag	Hele strekningen, leverandør velges av entreprenør	- 5860 m2 - 5860 m2 - 4200 m3, antatt 1,8 tonn/m3 - 980 m3, antatt 1,8 tonn/m3		 6 6	Cat 323D Leveres av prod Cat323D/FH16 +h Cat323D/FH16 +h	20 hours 60 hours 60 hours	 1 180 45
Asfalt	Bærelag og asfalt		- 2668 tonn		10	Special vehicles, truck, asphalt paver, compactor	80 hours pr vehicle	Ca 150 trucks with asphalt
Grøntareal og skråninger	Utlegging og bearbeiding av jord inkludert såing	Leverandør velges av entreprenør	- 600 m3, antatt 1,5 tonn/m3	Ekstern tipp	6	Volvo FH16		40
Rekkverk		Leverandør velges av entreprenør	- 300 meter rekkverk - oppsetting av rekkverk	Ørsta	330	Leveres av prod Railing car	 90 hours	1
Stein	- Kantstein - Betongheller	Leverandør velges av entreprenør	- 75 meter - 3 m2	Heggstadmoen	6	Leveres av prod		1
Viltgjerde	Gjerde - impregnerte stokker - 10 cm netting	Leverandør velges av entreprenør	- 265 meter - oppsetting	Local engro	10	Volvo FH16 Cat 323D		1
Skilt	- skiltstolper - skilt - skiltportal	Leverandør velges av entreprenør	- 6 skiltstolper - 7 skilt - 1 skiltportal - oppsetting skilt	Heggstadmyra	6	Volvo FH16 Lift + bufferbil Cat 323D	 8 hours 13 hours	1
Vegmerking	- striper - sperrefelt/gangfelt	Leverandør velges av entreprenør	- 2100 meter vanlig vegmerking - 60 m2			Special vehicle	16 hours	
Belysning	- Armatur - Fundament og mast - Armatur over belyste skilt, LED - Veglysskap	Leverandør velges av entreprenør	- 20 stk armaturer - 20 stk fundament og master - 8 stk - 2 stk - oppsetting av komplett veglys	Unknown Ørsta Local engro Unknown	xx 330 incl xx	Leveres av prod Leveres av prod Incl Cat 323D	 16 hours	1 1 incl

Appendix F: EPD Asphalt as an example

AGB 11 asfalt (bransjegjennomsnitt)

FAV
FORENINGEN ASFALT OG VEISERVICE

NEPD nr: 216

Godkjent i tråd med ISO14025, $8.1.4 : 03.05.2011

Gyldig til: 03.05.2016

Sune Fossdal

Figur 1

Miljøindikatorer Fra råvareutvinning til legging av asfalt	Vugge til port	Legging	
Global oppvarming:	1062	8	kg CO_2/FE
Energiforbruk:	18 101	516	MJ/FE
Andel fornybare materialer:	10		%
Produksjonstemperatur:	150		°C

Verifikasjon av data:
Uavhengig verifikasjon av data og annen miljøinformasjon er foretatt av seniorforsker Anne Rønning med ISO14025, $8.1.3.

Deklarasjonen er utarbeidet av:
Camilla Skjerve-Nielssen og
Kari-Anne Lyng, Østfoldforskning AS

Anne Rønning

Østfoldforskning

PCR:
NPCR 18 Asphalt and crushed stone

Om EPD:
EPDer fra andre programoperatører enn Næringslivets Stiftelse for Miljødeklarasjoner er nødvendigvis ikke sammenlignbare.

Informasjon om produsent:

FAV (Foreningen Asfalt og Veiservice)
Postboks 5485 Majorstua, 0305 Oslo
Org.nr.: No 981 916 751
NS-ENISO 14001-sertifisert: -/-

I AGB11-produksjon brukes aminet Tall oil fatty acids, polyethylenepolyamine condensatem med CAS nr 68910-93-0. Kjemikaliet står ikke på Obs-listen.

Informasjon om produktet:

Funksjonell enhet:	1 tonn asfalt fra vugge til port (obligatorisk) og legging av asfalt (frivillig)
Produktets levetid:	Se under "Tilleggsinformasjon".
Analyseomfang:	Denne miljødeklarasjonen omfatter kun vugge til port, i tillegg til legging av asfalten
Årstall for studien:	2011
Årstall for data:	Gjennomsnittlig produksjons- og utslippsdata fra FAV
Antatt markedsområde:	Norge
Kontaktperson:	Arne Aaberg, Telefon: 23 08 77 67, arne.aaberg@fav.net

Produktspesifikasjon

Tabell 1

	Masse	*Andel*	*Datakvalitet*				*Andel resirkulerte materialer*
			Deklarerte data			*Scenario*	
	kg/FE	*%*	*Produksjon av råvarer*	*Transport av råvarer*	*Produksjonsfase for produktet*	*Legging*	
Bitumen	51	5 %	Spesifikke databasedata	Spesifikke data			
Pukk	831	83 %	Spesifikke data	Spesifikke data			
Asfalt (gjenbruk)	98	10 %	Allokert til forrige livsløp	Allokert til forrige livsløp	Spesifikke data	Scenario	*100 %*
Kalksteinsfiller	20	2 %	Spesifikke databasedata	Spesifikke data			
Amin	0,2	0 %	Spesifikke databasedata	Spesifikke data			

Ressursforbruk

Materialressurser

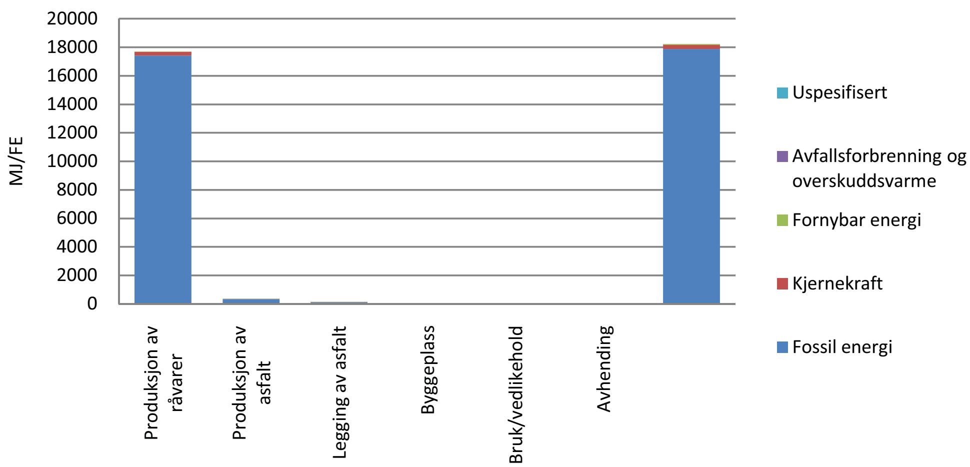
Tabell 2

Materialressurser		Enhet	Produksjon av råvarer	Produksjon av asfalt	Legging av asfalt	Kommentarer
Resirkulerte, fornybare ressurser			-	-	-	
			-	-	-	
Nye, fornybare ressurser	Vann	kg/FE	4 417	132	50	Turbinvann ikke inkludert
Resirkulerte, ikke fornybare ressurser			-	98	-	
Nye, ikke fornybare ressurser	Sand, stein og andre mineraler	kg/FE	849	1	6	
	Kalsium/kalkstein	kg/FE	22	0	0	
	Olje som råvare	kg/FE	-	-	-	
Sum		**kg/FE**	**5 289**	230	56	Alle ressurser bortsett fra luft og turbinvann

Land areal og vannressurser

Landareal er ikke kartlagt. Oversikt over vannforbruk finnes i Tabell 2.

Energiressurser



Figur 2. Energiforbruk totalt og fordelt på energibærer og livsløpsfaser.

Tabell 3. Energiforbruk fordelt på energibærer og livsløpsfaser.

Energiressurser		Enhet	Produksjon av råvarer	Produksjon av asfalt	Legging av asfalt	Totalt	Kommentarer
Fossil energi	Kull	MJ/FE	275	12	5	292	
	Olje	MJ/FE	16 418	303	111	16 833	
	Fossilgass	MJ/FE	721	19	8	748	
Kjernekraft		MJ/FE	260	29	5	293	Forbruk av kjernekraft import av el i norsk miks og råvareproduksjon i utlandet
Fornybar energi	Biomasse	MJ/FE	<0,5	<0,5	<0,5	<0,5	Inkluderer kraft fra vind, sol og bølge, samt geotermisk energi.
	Vannkraft	MJ/FE	36	22	1	60	
	Vindkraft	MJ/FE	5	1	<0,5	6	
Diverse	Avfallsforbrenning og overskuddsvarme	MJ/FE	<0,5	<0,5	<0,5	<0,5	
Uspesifisert		MJ/FE	<0,5	<0,5	<0,5	<0,5	
Totalt		**MJ/FE**	**17715**	**386**	**130**	**18231**	

Fremstilling av energiressurser følger EPD-Norges mal og kan derfor avvike fra prEN 15804.
Forbruket er beregnet ut fra Nordisk Produksjonsmix for el (unntatt hvis virksomhetene kjøper sertifisert fornybar elektrisitet).

Utslipp og miljøpåvirkninger

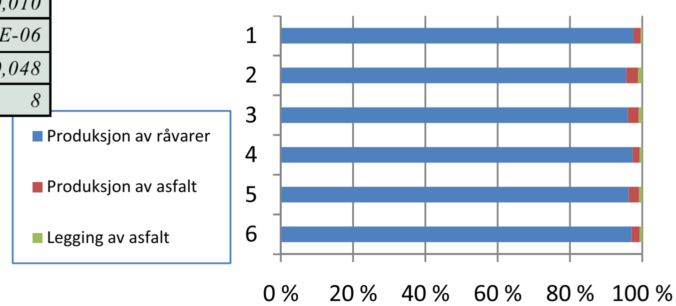
Miljøpåvirkninger

Tabell 4

		Enhet	Krybbe til por	Legging
1	Avfall	kg avfall/FE	2 744	15
2	Overgjødsling	kg PO43--ekv/FE	0,99	0,012
3	Fotokjemisk oksidasjon	kg C2H2-ekv/FE	0,94	0,010
4	Nedbryting av ozon	kg CFC-11-ekv/FE	1,52E-04	1,18E-06
5	Forsuring	kg SO2-ekv/FE	5,158	0,048
6	Drivhuseffekt	kg CO2-ekv/FE	1 062	8

Prosentvis fordeling per livsløpsfase av miljøpåvirkning

Figur 3



Emisjoner til innemiljø er ikke relevant for dette produktet.

Avfall og største utslipp på vektbasis

Tabell 5

Utslipp		Enhet	Produksjon av råvarer	Produksjon av asfalt	Legging av asfalt	Totalt	Kommentarer
Utslipp til luft	CO2 (fossil)*	kg/FE	1019,58	22,80	8	1050	
	CH4	kg/FE	6,4E-01	1,6E-02	0,01	0,67	
	N2O	kg/FE	0,64	0,02	0,01	0,66819	
	NOx	kg/FE	0,01	<0,005	0,00	0,01	
	SOx	kg/FE	5,61	0,21	0,07	5,895	
	CO	kg/FE	0,92	0,03	0,01	1	
	VOC	kg/FE	2,33014	0,09024	0,02642	2,44680	
	Dioksin	kg/FE	0,00000	0,00000	0,00000	0,00000	
	PAH	kg/FE	0,00009	0,00000	0,00000	0,00009	
	Cr, Cd, Hg og Pb	kg/FE	<0,005	<0,005	<0,005		
Utslipp til vann	KOF	kg/FE	5,03E+00	9,43E-02	2,77E-02	5,1E+00	
	Tot-N	kg/FE	0,01	0,00	1,09E-04	1,1E-02	
	Tot-P	kg/FE	0,03	0,00	5,35E-04	3,5E-02	
	Fosfat	kg/FE	-	-	-	-	
	Nitrat	kg/FE	0,00	2,5E-06	<0,00005	1,4E-04	
	VOC	kg/FE	0,01	1,5E-04	<0,00005	8,2E-03	
	Dioksin	kg/FE	0,00	0,00	<0,00005	1,2E-03	
	PAH	kg/FE	-	-	-	-	
	Cr, Cd, Hg og Pb	kg/FE	-	-	-	-	
Avfall	Avfall til materialgjenvinning	kg/FE		-	<0,5	-	
	Avfall til energigjenvinning	kg/FE	-	-	-	-	
	Avfall til forbrenning (ingen gj.v)	kg/FE	-	-			
	Avfall til deponi	kg/FE	2 692,7	51,1	14,7	2 758,6	
	Farlig avfall	kg/FE	6,2E-03	1,6E-04	9,8E-05	6,5E-03	radioaktivt
	Annet avfall	kg/FE	3,0E-02	1,2E-02	2,0E-03	4,4E-02	

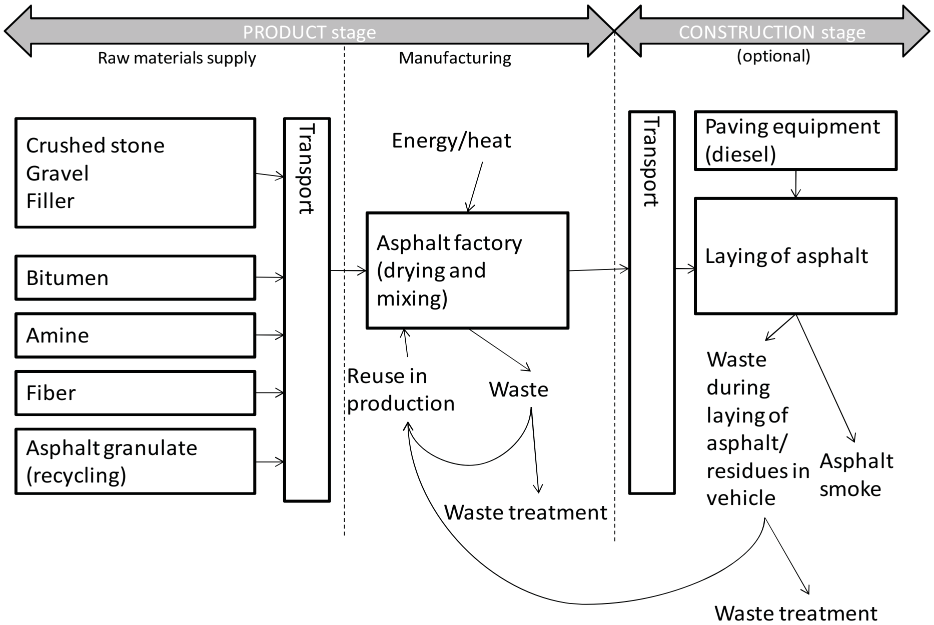
* Ikke-fossil (biologisk) CO_2 er ikke inkludert.

Tilleggsinformasjon/Avfallsbehandling for sluttprodukt

Produktet AGB11 er 100% gjenbrukbart.

Levetiden til AGB11 på trafikkert vei er ca. 15 år. Levetiden på plasser og gangareal ca. 25 år.
Det er 3 forhold som påvirker levetiden: 1) trafikkslitasje 2) klimatiske forhold og 3) setninger i grunnen under asfalten.
Hvis asfaltdekket ikke utsettes for slitasje vil oppherding av bitumen, på grunn av sollys og tilgang på oksygen, føre til at asfalten blir så hard at den krakelerer (sprekker opp i småstykker). Det kan ta 40 år.

Metodiske beslutninger



Figur 4. Systemgrenser og livsløpsfaser for asfalt

Råvareuttak:
- Råvareuttak inkluderer transport
- Spesifikke gjennomsnittsdata for pukkverk i Norge er benyttet
- Gjenvunnet asfalt erstatter 10 % pukk og bitumen

Produksjon av asfalt:
- Det er benyttet spesifikke data for produksjon av pukk

Legging:
- Det antas 4 cm tykkelse på asfalten og at et tonn med asfalt dekker 10 m^2
- Utslipp til jord og vann ved utlegging er ikke medregnet, fordi de regnes som minimale.

Allokeringsregler:
I de situasjoner der flere produktsystem er involvert, er følgende prinsipper for allokering gjort:

- For gjenbrukt asfalt inn i produksjonen (10 % av råmaterialene) er avskraping av brukt asfalt og transport til produksjonsstedet allokert til avfallshåndtering i det forige livsløpet og ikke inkludert i denne EPDen.
- For alle avfallsstrømmer som går til materialgjenvinning allokeres gjenvinningsprosessen til det systemet som benytter materialet som råstoff inn i sin prosess.

Referanser

EPD Norge (2010): PCR for asphalt and crushed stone, NPCR 18, 2010.

ISO 14025:2006, Miljømerker og deklarasjoner - Miljødeklarasjoner type III - Prinsipper og prosedyrer.

ISO 21930 Sustainability in building construction - environmental declaration of building products.

Skjerve-Nielssen og Lyng (2011): Livsløpsdata for AGB 11 asfalt, bakgrunnsdata for miljødeklarasjon (EPD), Østfoldforskning 2011. OR 08.11 Lukket rapport.

prEN 15804 – Sustainability of construction works – Environmental Product Declarations – core rules for the product category og construction products (Draft 2010-10-12).