Resource use efficiency of timber

A feasibility research

Universiteit Utrecht

Planbureau voor de Leefomgeving

Name	: Marc Leijtens
Student#	: 0438030
Email	: Leijtensmm@gmail.com
Track	: EPM
1st Supervisor UU	: Dr. Walter Vermeulen
2nd supervisor UU	: Dr. C. Dieperink
Supervisor PBL	: Dr. Mark van Oorschot
ECTS	: 45
Period	: June 2011 – may 2012

Acknowledgments

Hereby I would like to thank all the people I interviewed during my research. Your involvement has been of great value to my work, and I would not have achieved this without your commitment and interest. By sharing your work experiences and opinions with me, I gained new insights I would not have obtained otherwise.

Furthermore, I would like to thank my advisor at Utrecht University, Walter Vermeulen, Ernst Worell, Carel Dieperink and my supervisor Mark van Oorschot at the Environmental Assessment Agency. Your support and feedback were very helpful to me and gave me the guidance and motivation to complete my work.

Last but certainly not least, I want to thank Jenny, Willem, my family and others for their support and advice. Thanks to you, I had the motivation to move on and finish my work with success.

Abstract

As the world's population and welfare are on the rise, the pressure on natural resources such as timber is increasing rapidly. Therefore, it is becoming ever more important that the consumption of these materials becomes more efficient by enhancing the recycling- and reuse economy. This research scopes down to one product in particular: timber. This research is aimed at 1) identifying technical options that can be used to improve timber use efficiency in the construction industry, and 2) exploring the factors that determine the feasibility of implementing these technical options. Industrial ecology literature is used to identify, five options and their technical potential to reduce the amount of timber waste: prefabrication, Industrial Flexible Demountable (IFD) construction, timber skeleton construction, glued timber construction and selective removal of timber for reuse and recycling. Additionally, governance literature is examined to understand the social dimension of implementation. To be able to obtain insight on the feasibility of implementing these options in the construction sector, interviews are conducted with public actors, private actors and the scientific community. Representatives from licensing authorities, commissioning authorities, designers, contractors, branch organizations and knowledge brokers were included. The results generated by these interviews indicate that the progress towards implementing technical options to improve timber use efficiency is slow. The factors that influence the feasibility of implementation process relate to actor characteristics, institutional context within which the construction industry functions, and the policy content that regulates this industry. As for the actor-based features, results indicate that the feasibility of creating a coalition between the above mentioned actor groups is compromised due to competing interests and priorities between them. With regard to institutional features, project-based cooperation and changing constellations of actors result in a lack of knowledge institutionalization and shared responsibility, which limit the opportunities for improving timber use efficiency. The influence of the policy content on timber use efficiency is weak; licensing authorities devote little attention to timber use efficiency. The main focus appears to be on regulating energy consumption during the use phase of buildings. This research provides the reader with an in-depth understanding of how these factors influence the implementation of options that improve timber use efficiency.

Keywords: Construction, efficiency, innovation, institutions, timber use, policy content

Table of contents

1. INTRODUCTION 9

1.1 RELEVANCE OF STUDYING TIMBER USE EFFICIENCY 9
1.2 SCOPE OF RESEARCH 10
1.3 THESIS OUTLINE 12

2. THEORIES AND CONCEPTS 15

2.1 INTRODUCTION 15
2.2 INDUSTRIAL ECOLOGY LITERATURE 15
2.3 GOVERNANCE LITERATURE 18
2.4 RESEARCH IMPLICATIONS 20
2.5 ADDRESSING FEASIBILITY: A CONCEPTUAL FRAMEWORK 21
2.6 CONCLUSION 27

3. METHODOLOGY 29

3.1 INTRODUCTION 29
3.2 SELECTION OF TECHNICAL OPTIONS 29
3.3 CASE STUDY DESIGN 29

4. MATERIAL FLOW ANALYSIS AND IDENTIFICATION OF OPTIONS FOR EFFICIENCY GAINS 36

4.1 INTRODUCTION 36
4.2 GENERAL DESCRIPTION OF FOREST RESOURCES 36
4.3 TIMBER PRODUCTION AND TRADE 36
4.4 TIMBER PROCESSING AND USE IN THE EU-27 39
4.5 IMPORT 40
4.6 PRIMARY PROCESSING 41
4.7 SECONDARY PROCESSING 41
4.8 APPLICATION OF TIMBER: THREE INDUSTRIES 41
4.9 WASTE TREATMENT: CHARACTERISTICS OF THE WASTE FLOW 45
4.10 TECHNICAL OPTIONS AND THEIR POTENTIAL 47
4.11 CONCLUDING REMARKS 55

5. RESULTS I: ANALYSIS OF SCORECARD 57

5.1 INTRODUCTION 57
5.2 PREFABRICATED CONSTRUCTION 60
5.3 INDUSTRIAL, FLEXIBLE AND DEMOUNTABLE (IFD) CONSTRUCTION 61
5.4 TIMBER SKELETON CONSTRUCTION 62
5.5 GLUED TIMBER CONSTRUCTION 63
5.6 SELECTIVE REMOVAL OF TIMBER PRODUCTS AND MATERIALS 64
5.7 SYNTHESIS OF RESULTS 65

6. RESULTS II: OPPORTUNITIES AND BARRIERS 68

6.1 INTRODUCTION 68

6.2 Actor-based features 68
6.3 Synthesis of actor-based features 75
6.4 Institutional features 78
6.5 Synthesis of institutional features 82
6.6 Policy content features 83
6.7 Synthesis of policy content features 86

7. CONCLUSIONS AND DISCUSSION 89

8. REFERENCES 93

Literature 93
List of interviews 100
List of tables and figures 101

9. APPENDICES 104

Appendix 1: Scorecard for assessing the relevance and difficulty of implementing technical options related to the construction sector 93
Appendix 2: Interview guide for actors involved in the construction industry 99
Appendix 3: Function and designation in the EU, 2010 101
Appendix 4: Economic value of non-timber products in EU, 2005 102
Appendix 5: Standardized default factors to convert cubic metres of solid timber to oven-dry tonnes of timber material 102
Appendix 6: Effect of technical reduction measures on paper demand for newsprint and other graphical papers 103

1 Introduction

This research aims to assess to what extent it can be expected that certain technical options for a more efficient use of timber are agreed on and implemented by actors involved in the consumption of timber. Investigating and explaining why certain technical options are implemented to a certain extend is the starting point for this thesis. The technical options have a certain potential to reduce timber use, without compromising the quality of goods and services supplied by this natural resource.

Communication of the EU Thematic Strategy on Resources
"It is necessary to develop means to identify the negative environmental impacts of the use of materials and energy throughout the life cycles (often referred to as the cradle to Grave approach and to determine their respective significance). This understanding of global and cumulative impacts along a causal chain is needed in order to target policy measures so that they can be most effective for the environment and more cost-efficient for public authorities and economic operators" (JRC, 2011, p. 6).

1.1 Relevance of studying timber use efficiency

During the past three decades, increasingly advanced technologies provide us with the opportunity to use natural resource commodities such as timber far more efficiently. According to studies on resource use efficiency, it appears that 15 to 25% of virgin timber material is used in the final product (Jonkers, 2011, p. 3-4). On the European level, much research has been done in the development and innovation of reduction-, reuse- and recycling strategies of timber through the EU Thematic Strategy on Resources (JRC, 2011). Despite the abundant availability of studies on opportunities to increase timber use efficiency, it is yet unknown why implementation of these options appears to be difficult. On the international level, public and non-state actors involved in timber working industries often express strong support for pilot studies with waste-reducing strategies, but mainstreaming them appears to be difficult (Vermeulen, 2006, p. 575). International implementation of technical options to increase the efficiency of timber use requires actors to alter their practices. According to Spoerri et al (2009), "the anticipated changes to achieve a higher efficiency in material use are associated with considerable uncertainties. In addition, it remains unclear what factors and constellations among them will be most decisive for the feasibility of the implementation of technical options" (p. 593). To fill in the knowledge gap mentioned earlier, this research combines the knowledge contained in industrial ecology- and governance literature. Industrial ecology literature is needed to quantify the efficiency problem at hand. In addition, governance literature is needed in addressing the social dimension of the implementation of technical options. The roles of natural and social sciences are explicated in chapter 2.

There are five key drivers which explain why improving timber use efficiency is an important issue, including:

1. Environmental drivers; including reduced resource extraction, processing and CO2-emissions from concomitant activities such as transport and manufacture. Moreover, the CO2-storage capacity of these forests is becoming ever more limited, with consequential negative impacts on climate change.

2. Financial drivers; predominantly the savings that can be derived from more timber use efficiency and avoided waste management and disposal costs and fees.
3. Waste management is becoming more difficult, with over 70 million tonnes of timber waste being produced every year and landfills becoming either banned or restricted.
4. Corporate Social Responsibility (CSR) drivers, referring to firms that want to demonstrate their involvement with sustainability.
5. Project specific drivers, in relation to the implementation of waste reduction and management practices needed to achieve policy objectives and improved timber use performances.
   (WRAP, 2010).

This thesis provides a brief overview of the three major timber working industries, including paper and pulp, packaging, and construction sector. Thereafter, a more in-depth feasibility study will be conducted on timber use efficiency in the construction industry, as this appears to be most relevant with regards to its low level of efficiency compared to the other industries. A report published by De Bruijn and Maas (2005) concluded that the construction industry demonstrates little innovation with regard to material use. The report supports this claim by arguing that 35 per cent of all people employed in this sector works at technical innovative facilities, as opposed to the average of 50 per cent for total private commercial activities conducted within all sectors. However, only 0,22 per cent of total turnover in construction is invested in research and development activities, a share that is significantly lower than the percentage in capital-intensive (3,6 per cent) and labor-intensive (1,7 per cent) sector. Moreover, the construction sector scores low with regard to the share of academic and research and development employees in total workforce. Innovation in construction tends to focus on ad hoc solutions to problems that occur on construction sites, instead of methods and techniques that can be used to avoid these errors (p. 5). The report implies that if we want to improve timber use efficiency, one needs to focus on the construction sector.

1.2 Scope of research

The focus of this research is on the technical potential of options to increase timber use efficiency, and the factors that determine the political feasibility of their implementation. To investigate the political feasibility of these options, it is important to define the term ‘governance’. This concept is traditionally used as a synonym for ‘government’. For the purpose of this dissertation, we adopt the interpretation of the concept by Rhodes (1996) as “a change in the meaning of government, referring to a new process of governing; or a change in condition of ordered rule; or the new method by which a society is governed” (pp. 652-3). This definition adapts to the focus of this research, because it aims to describe ’a change in condition of ordered rule’, i.e. the changes needed in the governance system to improve efficiency in timber consumption.

The European Commission (EC) integrates timber use efficiency in timber use as part of its policy programme on biodiversity conservation and sustainable development[1]. This study is in line with the request of the EC to obtain insights on the opportunities to increase

[1] The concept of sustainable development was introduced in the report published by the Brundtland Commission in 1987, which used the most widely accepted definition: “Development which meets the needs of current generations without compromising the ability of future generations to meet their own needs".

use efficiency across timber-consuming industries. Much research has been done in the field of timber production efficiency, regarding the extensive list of scientific journals on forestry and ecology. However, the performance of manufacturing and recycling processes receive little attention by scientists. This research serves as a useful contribution to natural resource use, because it seeks to extend the body of knowledge on the post-harvest segments of the timber chain.

1.2.1 Research objective

This research is practice-oriented; it is the aim to identify the bottlenecks and opportunities in situations of transition that limit the feasibility of implementing technical options to improve timber use efficiency in the construction sector. The project context consists of the way in which these bottlenecks and opportunities are viewed by stakeholders involved in the construction sector. The knowledge gap described in the introduction is directly linked to the research objective of this thesis, which is devised as follows:

Identifying and explaining the factors related to actors, institutions and policy content, which may limit or promote the efficiency of timber use in the Dutch construction industry

1.2.2 Research question

The aim of this project to identify and explain the factors that promote the implementation of various technical options to improve efficiency of timber consumption in the EU-27. Therefore, the following research question has been devised:

> "Which technical options, drawn from industrial ecology- and governance literature, are available to increase timber use efficiency in construction, and what factors, related to actor characteristics, institutions and policy content, determine the feasibility of the implementation of these technical options?"

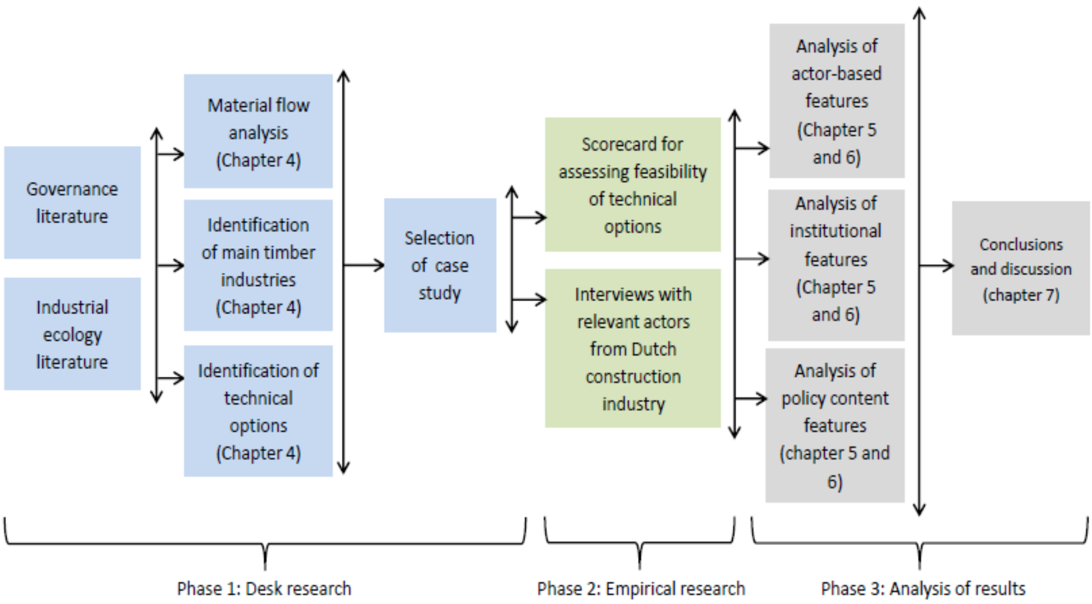
This question has the underlying assumption that there are conditions or rules related to actor-based characteristics, institutional settings and policy context, which can impose opportunities or barriers on the implementation of technical options which improve timber use efficiency during the design and demolition stage. This research question is divided into four sub-questions. First, we have to reconstruct the physical flows of timber, including its sources and distribution patterns across major timber-using industries in Europe. After selecting the main sectors of timber use, the main areas of waste reduction, i.e. the activities and processes are identified in which large efficiency gains can be achieved. Third, an overview of the most feasible technical measures and their potential to improve timber use efficiency is given. Fourth, we scope down on the factors that influence the implementation of such technical options, by examining the actor-based characteristics, institutions that regulate actor networks, and the policy content.

1.2.3 Sub-questions

The research question has been broken down into the following sub-questions:

1. What are the main sources, distribution patterns and applications of timber use in Europe?
2. What are the main activities and processes in which timber use efficiency can be increased?
3. Which technical options are available to reduce the loss of timber material, and what is their potential impact on timber use efficiency?
4. What factors, related to actors, institutions and policy content, may limit or promote the implementation of these technical options?

Figure 1: Research framework



Source: based on Course manual governance for Sustainable Development 2010-11

1.3 Thesis outline

This paper is structured as follows: the first phase of this research commences with outlining the theories and concepts that will be used to explain how implementation processes can develop, by identifying them from industrial ecology and governance literature. Additionally, the conceptual framework and method used to investigate timber use efficiency will be outlined. A material flow analysis is conducted to identify the main wood streams in the EU-27. Furthermore, the three main timber working industries are identified with regard to their use volumes and efficiency performance to determine where the largest efficiency gains can be achieved. Following the results of his material flow analysis, the construction industry is selected for closer analysis. The second phase consists of obtaining empirical data through conducting interviews with relevant actors in the Dutch construction sector, including licensing authorities, commissioning authorities, designers, contractors, branch organizations and research institutes. In the third and final phase, the results of these interviews will be analyzed and translated into recommendations for tangible actions that can be taken to address the efficiency problem. The analytical section is finalized with the main conclusions and points of discussion.

2 Theories and concepts

2.1 Introduction

This chapter outlines the theories and concepts on which this research is based. From a theoretical perspective, we can explain how timber use efficiency can best be studied, and what, according to these theories and concepts can be done to improve timber use efficiency to its optimum. The first step in studying timber use efficiency is to assess environmental literature for relevant theories and concepts that explain how timber use efficiency can be improved. The literature assessment involves two bodies of knowledge; industrial ecology and governance. Using both bodies of knowledge allows us to 1) obtain insights on the technical options available in the construction industry and their potential impact on timber use efficiency, 2) the actors involved in the construction sector, 3) the extent to which the technical options are implemented by these actors, and 4) the factors that determine the social feasibility of these technical options. In using environmental literature, we can obtain a view on the theoretical contribution each technical option can deliver to improving timber use efficiency.

2.2 Industrial ecology literature

For decades, it has been acknowledged that industrial ecology knowledge has played a central role in studying societal phenomena. Vermeulen (2006) argues that: “Natural scientists have played a dominant role, which is quite understandable, industrial ecology having its origins in ecology, engineering and even partly the business community” (p. 575).
Industrial ecology describes and explains the idea that the production and consumption of these goods and services has concomitant environmental impacts on the ecological system. This notion has itself become a growing focus of study in the industrial ecology literature. Research executed by ecological scientists, governments and private companies are digging up issues related to waste treatment, pollution control and environmental protection. It has been acknowledged by various authors that better natural resource management cannot be attained without integrating the concept of industrial ecology into the production and consumption of industrial goods and services (e.g. Ehrenfeld, 2004; Erkman, 2002; Allenby and Cooper, 1994; Korhonen, 2004; Graedel and Allenby, 1995). The concept of industrial ecology is useful in helping industrial systems to be operated more or less like a natural ecosystem, thereby causing as less damage as possible to the natural and social environment.

In the context of this research, the knowledge obtained from industrial ecology literature is used for addressing sub questions one, two, and three. The first sub question concerns mapping the material flows of timber throughout major industries. Industrial ecology is useful for studying material and physical flows (like timber), especially in the light of industrial production and consumption. The second question seeks to identify the main processes and activities contributing to reduced timber use efficiency. Industrial ecology is about the practices of companies, ranging from resource use to waste disposal. This knowledge can be used for the development of business strategies, which accounts for balanced and sustainable production and consumption: the triple bottomed line ‘People, Planet, Profit (Elkington, 1994, pp. 90). The same applies for the third sub question, concerning the identification of technical options to increase the efficiency of timber use. Prevention, reuse and recycling are means of using timber in a more efficient way, whereas incineration can contribute to regaining a share of the energy contained in the materials.

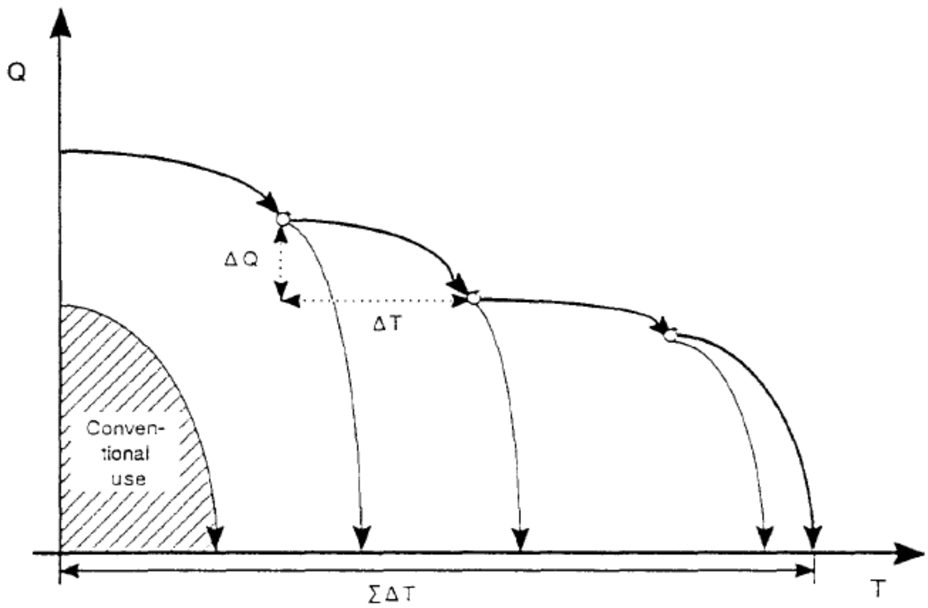
These options are certainly not new and unique, as various researchers have conducted studies concerning options for timber use efficiency. Pivotal in these studies is the waste hierarchy, also named the "Ladder van Lansink", which prioritizes high-value use of materials over low-value applications.

Waste hierarchy "Ladder van Lansink" (LAP, 2007)

- Quantitative prevention: the production of waste materials or products is prevented or limited
- Qualitative prevention: During production, only materials and products are used that cause limited or no environmental impacts after their consumption.
- Product reuse: Products are reused in their original form.
- Material reuse: materials of which a product is manufactured are reused
- Incineration with energy recovery: waste materials are used as biomass for energy generation.
- Land filling: waste materials are land filled

The approach taken in industrial ecology literature is to reduce waste, while recognizing that some solutions in construction projects are most likely to be effective in waste reduction, together with benefits such as cost savings. An important concept embedded in the waste hierarchy is the 'cascading principle' by Lafleur and Fraanje (1997), which is depicted in figure 2. Cascading is defined as "the sequential exploitation of the full potential of a resource during its use" (p. 22). The first step of this ladder is to prevent waste, by using alternative materials or to extend the lifespan of the timber product. The other five steps include the reuse, recycling, composting, incineration with energy recovery, and dumping. These steps indicate the ranking of preferred application of used timber. According to this principle, a recycle product or material passes through consecutive stages of use, of which each stage represents an application of the product or material with minimal loss of quality. At every node in the graph, a choice is made of how to re-apply the product or material derived from the previous stage. Choosing to dispose the product may block alternative applications in the future. When applied in timber consumption, we find that the cascading chain depicted below is about timber material with a high fibre quality Q, a certain lifespan per application ΔT, and seeking to extend the overall lifespan of the timber material $\sum \Delta T$, while minimizing ΔQ (Ibid.: p. 22).

Figure 2: Cascading of timber



Source: LaFleur and Fraanje, 1997, p. 23

Incineration with energy recovery is becoming more popular due to government energy policies. With this strategy, a large share of the potential recovery is lost, because the used timber is not used for high-end cycles such as reuse or cascading. When determining the alternative with optimal use of the fiber quality, trade-offs have to be made with regard to CO2-emissions and other environmental effects arising from transport and processing. Additionally, economic and social trade-offs play a role in this decision. In this context the discussion of 'decoupling' is relevant, in which economic value and environmental effects are decoupled; a decreasing fiber quality does not necessarily imply a decrease of its economic value. Examples are the use of timber construction beams as floor panels or furniture. With regard to the timber using industries that will be analyzed in this research, industrial ecology literature also refers to 'principles of designing out waste' (WRAP, 2010, p. 14). These principles are based on numerous studies on timber use efficiency carried out by scientists in cooperation with actors involved in timber use. These principles provide the theoretical foundation for identifying areas of improving timber efficiency, i.e. where the 'quick wins' can be achieved (Ibid.: p. 16). To be able to measure the feasibility of implementation of these principles, industrial ecology distinguishes between various technical options; the construction methods that are used to improve timber use efficiency. The options that are identified for waste reduction and material optimization throughout the construction process are based on these key principles, in which each option represents one of the principles The guidance contained in these principles is intended to provide a solid basis for improving timber use efficiency throughout the construction process (Ibid, p. 14).

1. **Design for reuse and recovery**
2. **Design for off-site construction**
3. **Design for deconstruction and flexibility**
4. **Design for waste efficient procurement**
5. **Design for materials optimization**

For the first principle, the literature has identified that the reuse of timber products and materials has a significant potential to reduce environmental impacts such as embodied energy, timber waste and CO2 emission. With reuse, the life of these products and materials is extended, thereby spreading the annual waste burden over a greater period. Regarding the waste hierarchy depicted above, reuse is prioritised over recycling, which involves additional processes to reintroduce timber products and materials in the consumption chain, of which some have their own environmental impacts. The second principle refers to the benefits of off-site production in timber using industries, such as the potential to significantly reduce timber waste particularly when waste materials are better reused and recycled on a large scale. Off-site manufacturing is one approach to improving timber use efficiency, also called 'Modern Methods of manufacturing'. These methods, such as prefabricated and modular or volumetric construction, will be discussed in greater detail in chapter four (WRAP, 2010, p. 20). The third principle refers to various 'good practices' that manufacturers and users can consider during the production and consumption of industrial timber goods. 'Good practices' refers to a design process, in which resource use efficiency plays a pivotal role, without compromising the quality of the manufactured product (Ibid.: p. 23). The fourth principle draws on how producers affect the generation of timber waste during production and consumption. The fifth principle refers to the need for producers to consider opportunities for the recovery of timber products and materials after consumption, when they are discarded. The literature recognizes that the time frame, which extends far beyond that of the professional and financial commitment of producers and users, induces an important difficulty in applying this principle. On the contrary, it is argued by supporters of this principle that not considering "design for deconstruction and flexibility" can substantially limit future progress of design for reuse (Ibid.: p. 27). When carrying out this research, the relevance of these principles will be examined by applying them to the timber using industries included in this research.

2.3 Governance literature

Governance literature plays a crucial role in explaining the progress of implementing measures of any kind in solving or mitigating sustainability problems. According to Driessen et al. (2011), environmental governance literature is regarded as "(…) the answer to the growing concern about degrading environmental quality, depletion of resources, biodiversity loss and climate change" (p. 2). Furthermore, they emphasize that "The concept of governance relates to the means by which society decides and acts upon the objectives related to management of the natural environment" (Ibid. p. 2). These means include rules, processes and policy instruments that eventually result in decisions and implementation. Environmental governance emerged as a concept which acknowledges that public authorities are not the only actors in control when it comes to solving societal problems. In contrast, governance literature gives more attention to interactions between actors pertaining to the state, market and civil society (Ibid. p. 2). Classic rational-analytical policies are designed to address ecological problems related to production and consumption, and it has become clear that one-way decision-making must be replaced by a 'governance approach'. This approach suggests that "governing from a governance perspective always involves an interactive process because no single actor, public or private, has the knowledge and resource capacity to tackle problems unilaterally" (Stoker, 1998, p. 17). Lemos and Agrawal (2006) reinforce this argument by stating that "…it has become clear that seemingly purely market-, state-, or civil-society-based governance strategies depend for their efficacy on support from other domains of social interaction" (p. 298). This signifies the idea that both the natural and social domain is needed in addressing resource use problems. Scharpf (1978) supports this argument by emphasizing that "it is unlikely (…) that public policy of any significance could result from the choice process of any single unified actor" (p. 347). Other authors (e.g. O' Toole and Montjoy, 1984; Kickert et al., 1997) support this claim by arguing that: "Environmental policy is formulated and implemented in situations where multiple actors interact at multiple levels. At any given time, we can observe certain actor configurations in which issues are framed according to certain principles, following certain routines". These interactions between actors refer to a set of institutional features (North, 1990). Policy arrangements are recognizable in terms of policy content, which means that it has defined goals and policy instruments to achieve them (Glasbergen, 1992). Hence, if we want to improve our understanding of the factors that influence the progress of implementation, all three clusters of factors must be studied. Governance systems of any kind include actors from three domains, each with their own specializations and responsibilities:

- Government; where power is exercised and interests are negotiated (Fearon, 1998) guided by political, legal, macroeconomic and communicative rationalities
- The domain of production of goods for meeting the material needs of society, using economic rationality within an institutionalized market
- The domain of science, producing new knowledge, using logic and a positivist rationality, but structured by many disciplines and with various competing paradigms (Vermeulen et al., 2006, p. 586)

The reason why all three domains are included in this research refers to the governance perspective, which holds the premise that: "the classical view of state-induced decision-making processes is replaced by policy theories emphasizing the interdependencies between governments and actors pertaining to the market and scientific community, thereby requiring the governance perspective". Governing from a governance perspective always involves an interactive process because no single actor, public or private, has the knowledge and resource capacity to tackle problems unilaterally" (Stoker, 1998). In addition, Jessop (1998) states that "building effective governance mechanisms, amongst other things, requires methods for coordinating actions across different social forces with different identities, interests and meaning systems". By using this body of knowledge, we can explain why the actors involved in construction adopt the technical options to a certain extent, and the factors they perceive to be beneficial or detrimental to the feasibility of the implementation of technical options in timber use. Each of these actor groups must be considered in this research. We will analyze the perception on the technical options defined in the industrial ecology literature, and why they do or do not perceive the specified options to be feasible. By using governance literature, we can identify the factors that explain the differences between these groups with regard to the implementation of the technical options.

Industrial ecology and governance literature is summarized as innovation literature. Goverse et al. (2001) stresses the essence of the relationship between innovation and implementation practices, by arguing that: "Innovations do not take place in a vacuum, but are shaped and framed by the broader implementation environment" (Goverse et al., 2001, p. 55). Whether innovation is successful depends on factors within this implementation environment. Examples of such factors are knowledge resources, attitude towards implementation, and cooperation between actors. By investigating the innovative characteristics of technical options, we can obtain insight in the factors that act as barriers that may obstruct implementation of these options.

2.4 Research implications

The use of industrial ecology and governance literature to study timber use efficiency has certain implications for the steps taken to conduct this research. The first implication is that of companies changing their practices geared towards profits on the short term, to capturing the opportunities of improving timber use efficiency. For this research, we include actors pertaining to the public domain, market parties and scientific communities. To obtain a good view on their behavior, we need to understand processes of changing practices and routines of actors from all three domains, how they are constructed as a means of addressing demands, problems and challenges form the societal context in which they operate. In order to make these changes, we need a process of reflexive adaptation of proposed technical innovations and additionally need to address organization issues, requirements, and demands (Vermeulen et al., 2006, p. 587). By studying how governments, businesses, civil society organizations and scientific communities cope with these demands and challenges can provide us with a view on what can be expected from technical innovations in timber use.

The second implication is that the implementation of technical options mainly refers to processes of adaptation and innovation. Various authors from innovation literature are optimistic about the implementation of innovations. However, various case studies on innovation processes do not support this claim. If we want to explain the factors that determine the progress of implementation of technical options in timber use, we must analyze the interests and capacities of actors operating in the public domain, market and scientific community. Adoption of technical options is viewed as the decision made by firms or organizations, each with their own characteristics. The analysis of the progress of innovation takes place on the system level, i.e. the 'innovations system or network' (Foray and Grübler, 1996; Freeman, 1996).

The third implication is that the implementation of technical options derived from industrial ecology literature should not be analyzed as single-actor activities, but as a cooperative process between multiple actors. Needless to say, cooperation between actors from different domains is not unique. However, It must be explained how cooperation between actors emerges. In general, new forms of cooperation complement or replace old forms of practices and routines. The old forms have proven to be reliable, whereas the success about new forms is still uncertain and need additional investments in time and energy to develop.

The fourth implication refers to the implementation of various policy processes in construction industry. Taking the perspective of firms and organizations (i.e. licensing authorities, commissioning authorities, designers, contractors and knowledge brokers), they are confronted with multiple policy agendas from public authorities on different levels. As different government agencies implement different parts of policy agendas, this often results in conflicting and overlapping claims. Thus, companies and organizations will set their priorities and develop solutions that are efficient and suitable to respond to external influences, thereby taking into account budget and time limitations (Vermeulen, 2006, p. 579). Industrial ecology reflects on the development of technical options in timber use, but does not take into account the social dimension of these options, i.e. the feasibility of their implementation by firms and organizations. Governance literature considers this social element and plays, in addition to industrial ecology, an important role in this research.

These research implications will be reflected on in the concluding chapter, to examine whether they have impact on this research.

2.5 Addressing feasibility: a conceptual framework

Environmental governance literature provides a clear framework for studying sustainability problems, which gives us an understanding of how and why all kinds of measures are implemented to solve or mitigate sustainability problems. As explained earlier in paragraph 2.2.2, three different clusters of features are relevant to obtain an understanding of the factors that determine the feasibility of implementing technical options in the construction industry. These are:

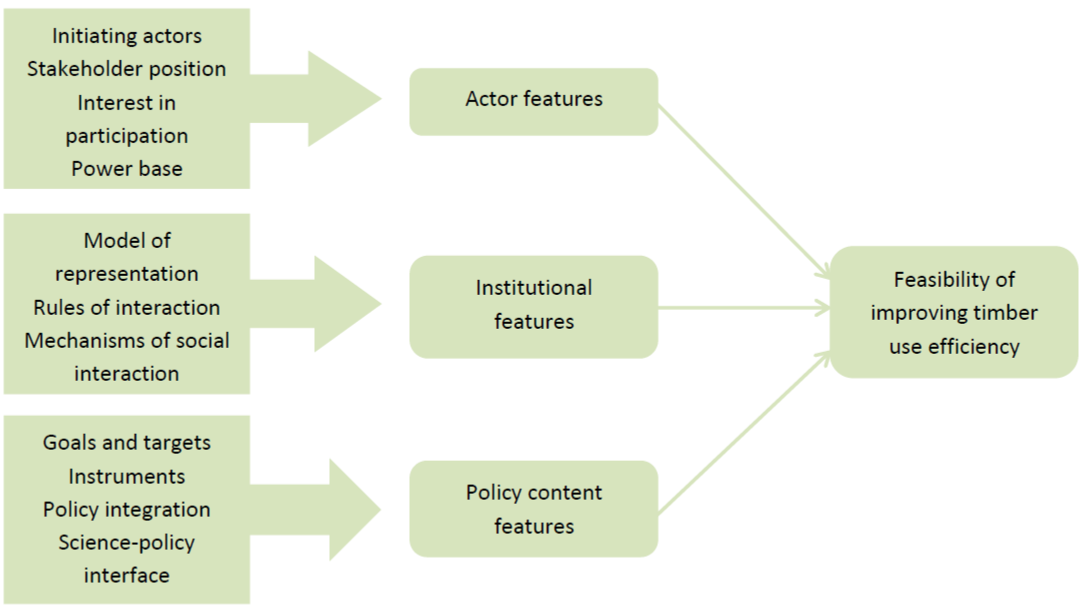
1. Actor features; initiating actors, stakeholder position, interests in participation, power base

2. Institutional features; model of representation, rules of interaction, mechanisms of social interaction

3. Policy content features; goals and targets, instruments, policy integration, science-policy interface

This conceptual framework can lead to detailed explanations for the implementation of technical options in the construction industry. The actor-based features include: key initiating actors, position of the other stakeholders, the policy level at which actors operate, and the formal or informal basis of power of the actors. Institutional features include: Model of representation, formal and informal rules of exchange and interaction, and mechanisms of social interaction. Policy content features include: the types of goals that are pursued, policy instruments that are used for policy implementation, the types of knowledge that are used for policy preparation, decision-making and policy implementation, and the extent to which policy sectors- and levels are integrated, (p. 5). Figure 3 represents the conceptual framework, including the three groups of features that will be used to illustrate the main factors that influence the feasibility of improving timber use efficiency in the construction industry.

Figure 3: Governance framework



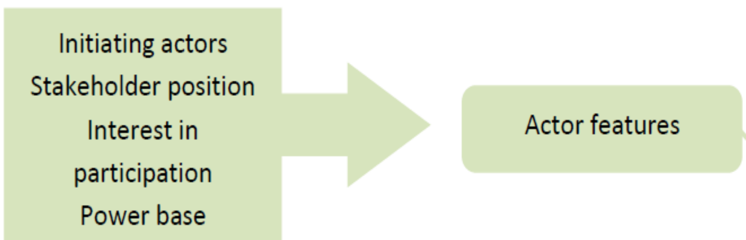
Source: Adopted from Driessen et al. (2011, p.21)

Actor-based features discuss the key public actors that initiate action and define environmental interests in addressing the issue of timber use efficiency. Stakeholder positions specify the relative distance between actors in the stakeholder arena according to their interests, capacities and interaction with other stakeholders. The policy level refers to whether actors operate on a local, regional, national or supra-national level. The power base specifies the resources of actors, and their ability to mobilize these resources.

Institutional features provide an understanding of the relationships between actors from the different domains. Among these features is the model of representation, which describes how environmental governance is represented and by who. Rules of interaction refer to the formal and informal rules created by actors to organize procedures, participation and implementation. According to Scott (2004), it focuses on "…the deeper and more resilient aspects of social structure. It considers the processes by which structures, including schemes, rules, norms, and routines, become established as authoritative guidelines for social behavior" (p. 408). Mechanisms of social interaction specify how these formal and informal rules are shaped and implemented; this can be either top-down, negotiated between public and private actors or exclusively by actors operating in the private domain or civil society.

Policy content features focus on the involvement of public authorities in the construction industry through the setting of goals and targets, implementation of policy instruments, policy integration, and the science-policy interface. The policy perspective is used to assess the contribution of sustainability strategies on the construction sector. The role of the state is to establish and maintain regulations which create an appropriate environment for innovations to occur (Lundvall, 1992, p. 24). Originally, innovation is associated with technical improvements, where private firms engage in research and development processes to create new products and materials. This perspective of innovation was popular during the first half of the 20th century. Interestingly, the way of thinking and theorizing on the policy of innovation has changed drastically, and it is recognized that policy makers should also innovate policies to control and manage societal developments and address desired or undesired effects (Arts and Van Tatenhove, 2004, p. 342). With regard to recent developments of innovation, the policy perspective has shifted from a product-based emphasis towards the view that innovation is a systemic process (Edquist, 2004, p. 34; Galli and Teubal, 1997, p. 26). The three groups of features operate within the context of macro-social and -economic developments. However, it is yet unknown to what extent they play a role in determining the feasibility of these options. Economic factors such as investment costs, payback-period, cost-efficiency and economic prospects of a firm may determine implementation, as well as environmental awareness in society, and energy pricing. These factors will be briefly mentioned, but are not within the scope of this study and will therefore not be explored.

2.5.1 Actor-based features



Initiating actors: The reason why an actor initiates, or is involved in the construction industry is of primary interest to this research. The initiating potential of an actor can be identified by its adoption of technical options while little is known about its impact on timber use efficiency or cost-efficiency. Initiating actors can be characterized by their sustainability considerations, long term vision, active participation in experiments and pilot studies, and so on.

Stakeholder position: An actor's position relative to other actors in the field determines to what extent it can influence the implementation of technical options in timber using industries. Bryson (2004) presents a useful way of identifying the position of stakeholders in the construction sector, by focusing on four aspects: interest, power, resources and regular contact with other actors. Bryson's model provides a tool to illustrate which actors are important in taking the lead in addressing timber use efficiency, which actors must be targeted to address this problem. Based on this model, conclusions can be drawn about which stakeholder networks can be formed to create the circumstances under which innovations in timber use efficiency are most likely to occur. The four aspects below represent the features that are studies in order to determine the stakeholder position of actors pertaining to the government, market parties and scientific community.

Interest in participation: the extent to which an actor expresses its interest in influencing the construction sector. By identifying the interests, an actor can be positioned within a certain category in the grid.

Power base: the amount of power (e.g. an actor can exercise is determined by measuring the resources an actor has, and the capacity to mobilize these resources. The amount of power is also categorized as low, medium or high.

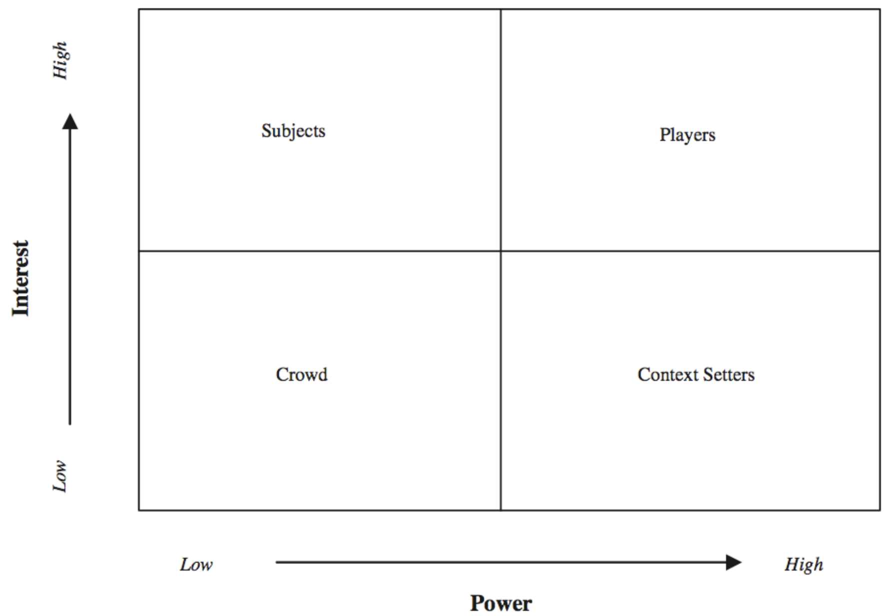
Resources: the assets an actor can use to promote or limit the implementation of technical options. Resources can be either technological, human, financial, and political in nature. Moreover, not only the possession of resources is interesting, but also the actor's ability to mobilize these resources. The number of resources of an actor, and the ability to mobilize these resources is categorized as low, medium or high.

Regular contact with other actors: It is relevant to analyze whether an actor has regular interaction with other actors in the field. Although the term 'regular' is not specified, it is supposed to indicate coalitions that may be formed within the actor network. Coalitions are created when two or more actors collaborate to meet a common objective. In the case of timber use efficiency, to oppose or support the implementation of technical options.

After assessing the four aspects of stakeholder position, each actor can be positioned as ''key players, ''context setters'', ''subjects'' and ''crowd'' in the power-versus-interest grid in figure 4(Eden and Ackermann, 1998; De Lopez, 2001). This categorisation is useful in specifying how actors may be involved, who must be actively engaged due to their high interests in and power over a certain phenomenon. Context setters are characterised by their significant influence over, but little interest in solving an issue. These actors must be closely monitored and controlled, because they may pose a risk to the implementation process. Subjects have a high interest but are little influential, and are thus lacking the capacity to impact the implementation process. However, they are, almost by definition, supportive and can gain influence by forming coalitions with other actors. These actors are often marginal, which must be empowered in order to increase long term viability of the implementation process. The crowd are actors with little interest and influence over the process and its outcomes. Moreover, there is little need to involve them in the process. Typically, interest and influence can change over time and the consequences of such changes can be considered. For example, actors can form coalitions to either promote or prevent a certain outcome. A categorisation can be used to locate where certain coalitions are most likely to be created. The categorisation approach can be further strengthened by adding additional attributes to the actors. Patterns in these attributes can be taken into consideration in terms of the categorisation factors interest, power, resources and contact with other stakeholders.

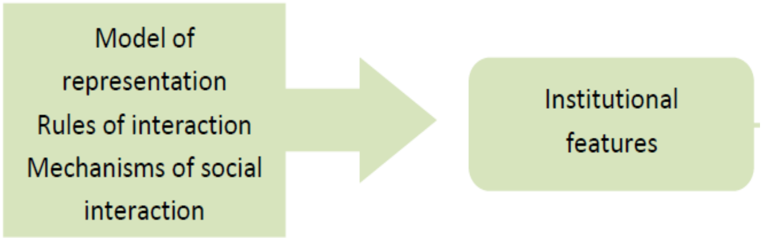
Interest and power typically change over time and the impact of such change can be considered. For example, stakeholders may form alliances to either promote or defeat a particular outcome and a stakeholder analysis can be used to identify where such alliances are likely to arise. The analytical power of this categorisation can be improved by adding further attributes to the stakeholders. Patterns in these attributes can then be considered in terms of the categorisation factors. For example, stakeholders located in an interest and influence matrix could also be labelled as ‘‘supportive’’ or ‘‘unsupportive’’. This could be visually represented to determine whether there are any clusters of supportive or unsupportive stakeholders and if so, the implications considered in the context of interest and influence Numerous actor attributes can be added in this way, the outcomes examined and the implications assessed (Reed et al., 2009, p. 1938).

Figure 4: Roles of actors in terms of power and interest



Source: Bryson (2004, p. 30)

2.5.2 Institutional features



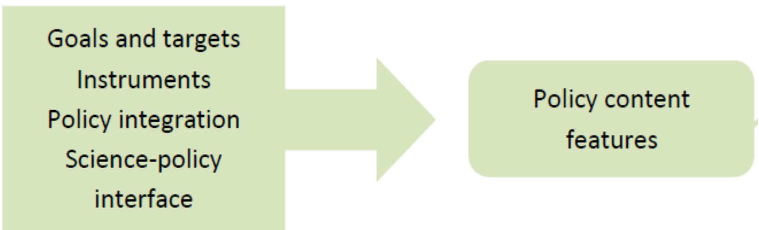
Variables associated with the institutions of the construction market describe the formal and informal rules of behavior, procedures and routines applied in the market of construction and demolition timber waste. These variables describe the actions taken by actors, and the conformity with the (in)formal rules of the construction and demolition sector. The codes of practice refer to sustainability and environmental awareness; the intention of timber working industries to use timber in such a manner that it can be reused or recycled.

Model of representation: The model of representation refers to how policy arrangements are created; are they imposed by the government itself, or do they evolve through the establishment of partnerships between public authorities and private actors? By studying the model of representation, attention is drawn to strategic choice, international cooperation, professional attitude, financial independence, openness in the working process, opportunities for other parties to participate after the initiating phase, and the commitment to share resources and risks (Glasbergen and Groenenberg, 2001, p. 13). These aspects will be analyzed in this research, in order to provide insight into the relationship between partnerships and government policy.

Rules of interaction: "the constitutive process is the process of ongoing interaction among multiple included actors" (Tatenhove et al., 2000, p. 9). In analyzing the rules of interaction, we can analyze whether and how specific patterns of interaction lead to more or less accepted informal and formal rules, shared problem definitions and coalitions acknowledged and legitimized in the context of policy arrangements (Ibid.: p. 20).

Mechanisms of social interaction: In analyzing the mechanisms of social interaction, it can be determined whether policy arrangements are imposed through a 'command-and-control' mechanism, by private actors autonomously within predefined top-down boundaries, or bottom- up through social learning, deliberations and negotiations among private actors (Driessen et al., 2011, p. 21).

2.5.3 Policy content features



Goals and targets: This aspect illustrates the ambitions of public authorities on timber use efficiency in concrete figures. Parris and Kates, (2003) note that: “Goals and targets can be specified in both quantitative and qualitative terms, and associated indicators that further characterize a sustainability transition by drawing on the consensus embodied in internationally negotiated agreements and action plans” (p. 8068). Furthermore, Parris and Kates (2003) find that such analysis can often reveal “levers of change,” forces that both control the rate of positive change and are subject to policy intervention (p. 8068).

Policy instruments: Policy instruments refer to the methods used by public authorities to achieve the desired effect. The two types of policy instruments are regulatory and economic in nature. Regulatory instruments, such as laws and regulations, are the most frequently used policy instruments to attain the goals and targets in sustainable development. Economic instruments , including subsidies for certain products or services and tax credits for investments that induce a positive change towards sustainability, are also used as a means of influencing the practices of individuals and firms. Other instruments are voluntary in nature, such as bi- or multilateral agreements negotiated between public authorities, private companies and NGOs, commitments made by private firms independent of government pressure, and public purchasing programs (OECD, 2010). With regard to timber use efficiency, all three instruments play crucial roles. Usually, multiple instruments are combined to address a specific sustainability problem. Since these issues contain many different aspects, various policy instruments are needed to address them. Additionally, mixes of instruments allow more flexibility for firms to comply with government policies, and reducing uncertainties of the compliance costs. On the contrary, instrument mixes should be formulated in detail to avoid conflict and overlap between them, resulting in a cost-ineffective compliance framework and unnecessary administrative costs (OECD, 2010)

Policy integration: Policy integration addresses the issue of unexpected effects of policies (externalities) and addresses the insufficient problem solving capacity of society, expressed in terms of complex problems. Policy integration concerns coherence among various policy fields, to reduce overlap, policy gaps and contradictions between them. Integration of policies can take two different routes: by including issues of one policy field into another, or by coordinating and mixing multiple policies into a unified policy field. Additionally, policy integration focuses on the interdependencies between various dimensions (economic, social, ecological, intergenerational, and geographic. This focus requires an integrated approach including all these dimensions, as well as the involvement of relevant social actors and government levels (Rossy et al., 2010, p. 25).

Science-policy interface: Science and policy making are very different from one another, but can and should be complementary (National Research Council, 1995). On one hand, scientists have knowledge about theory, methodology and research techniques. On the other hand, policy makers have knowledge about governance processes, constituencies, and value orientations expressed in terms of legal mandates. Whereas science is concerned with descriptions, explanations and inquiries, policy making focuses on the governance of human actions. Moreover, science is supposed to be value-free, and policy making is normative, reflecting upon societal norms and values (Plasman, 2008, p. 811). Also, the time span of science covers years and sometimes even decades, whereas that of policy makers frequently reflects on the need for information on the short term, driven by political agendas. Scientists can identify problems, but have no political power to solve them through policy making. Acknowledging this issue is the first step in the development of effective cooperation between scientists and policy makers.

2.6 Conclusion

The added value of this detailed analytical framework is that it does not only focus on different types of environmental governance, but also on specific features of the actor base, the institutions, and policy content. The governance framework is primarily intended as a benchmark to measure transitions from one type of environmental governance to another. When transitions are mapped over time, it is essential to identify the main drivers that are responsible for these transitions. By analyzing variations between these features, one can arrive at an objective characterization of these changes by scoping down to the significance of these features. In table 7 to 11 depicted in chapter five, the features related to actor characteristics, institutions and policy content will be used to determine the perspectives of actors pertaining to the public sector, market parties and scientific domain towards technical options to increase timber use efficiency. In order to make these features operational for this research, they are translated into factors, which can be valued by the actors as opportunities or barriers[2].

[2] For an overview of these factors, see table 9 to 13 (p. 56 to 61)

3 Methodology

3.1 Introduction

This research consists of two major components: a literature assessment and a case study research. First, an assessment of Journal articles, policy documents, databases and monitoring reports related to the construction industry will be used, For answering these questions, data about the main timber working industries and technical options available in the Netherlands has to be obtained. The main sources for obtaining this technical data are electronic University databases containing scientific articles, such as Scopus (Scientific Journals) and Omega (articles, reports). Additionally, open-access databases such as the Food and Agriculture organization (FAO), Eurostat and Standard International trade classification (SITC) provide data about trade volumes and use. PBL provides access to annual monitoring reports and policy studies about timber use and recycling. Examples are monitoring reports by Probos, environmental assessments and national policy analyses on timber consumption among which various reports published by the EC (1999), Eurostat (2011) and Faostat (2011) to obtain insights on 1) the major destinations for timber use, 2) consumption volumes, 3) actors and activities related to the use of timber, and 4) technical options available to each timber working industry and their potential impact on improving timber use efficiency.

3.2 Selection of technical options

Before analyzing the feasibility of improving timber use efficiency in timber using industries, a number of options to achieve this will first be identified in chapter four. For each of these options, their potential to increase timber use efficiency will be determined based on the industrial ecology literature introduced in the previous chapter. During the empirical research, actors will be asked to demonstrate their perspective towards the importance of each option in improving timber use efficiency, as well as the implementation difficulty of each option. In doing so, an insight can be obtained about the feasibility of implementing the most relevant technical options, which barriers actors are confronted with in using each option, and which options may need additional research to improve their implementation.

3.3 Case study design

After having identified the main technical options for further analysis, the research scope is narrowed down to the timber using industry in which the largest potential efficiency gains can be achieved, which is selected as the case study. Case study research is a suitable method to generate both qualitative and quantitative data, and provides up-to-date information about developments in the field of research. As opposed to other research methods, case studies can generate in-depth information and data about a specific situation, using a large number of variables (see governance framework in figure 3). Verschuren and Doorewaard (1999) note that: “Through a detailed observation on location, by conducting interviews in combination with a study of all sorts of documents, a profound insight can be obtained into the way various processes take place, and the reason why they develop in one way instead of another” (p. 146). Hence, case study research is a relevant method with regard to the aim of this research, which is to obtain a detailed insight on the feasibility of implementing technical options to improve timber use efficiency and the practical opportunities and barriers that play a role. The following subsections will explain the selection criteria used for selecting the case study, stakeholder selection and interview guide.

3.3.1 Case study selection criteria

The case study used for further analysis of this research, is delineated based on the desk research and material flow analysis in the previous chapter. The data needed to conduct this analysis generated the following criteria about how to define the case study:

(i) Volume of timber consumption and level of efficiency
(ii) Potential efficiency gains
(iii) Data availability and practicality
(Based on Kamphorst and Oorschot, 2011, p. 16)

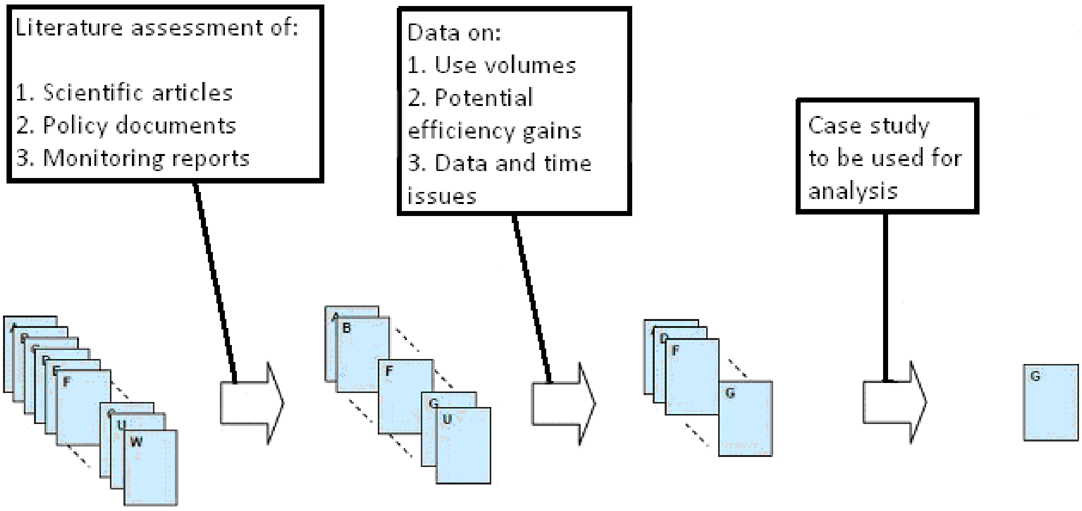
Volume of timber use and level of efficiency: in selecting a particular timber flow, it is essential to select one with high use volumes. The technical options discussed in the previous section will yield the largest impacts when implemented in timber flows with high volumes. However, the timber volume alone does not determine which timber flow is selected; the level of recycling in a particular flow indicates the potential efficiency gains that can be achieved.

Potential efficiency gains: the selection of a particular timber flow is also determined by the potential efficiency gains that can be achieved in that flow. In other words, the focus is on a timber flow in which 'quick' and large efficiency gains can relatively fast be achieved through better management of the timber flow.

Data availability and practicality: this research is also limited by data and practical issues. Essential to the coverage of the case study research is the availability of sufficient data. From the literature study conducted in the previous section, it can be concluded that there are large variations in data availability among timber flows. For example, data about quantities and volumes related to furniture production is poorly presented in the literature, which makes it difficult to assess this industry. Moreover, this research is based on a 'quick scan' of the main timber flows on the European level. Considering the limited time budget available for this scan, some timber flows with large potential efficiency gains are, despite of their relevance, excluded from this study[3]. The selection criteria in paragraph 3.3.1 narrows the research scope down to the most significant timber flow with regard to timber use efficiency: **design, construction and demolition of the Dutch construction industry**. The case study research is geared towards assessing the feasibility of improving timber use efficiency throughout the design-, construction- and demolition process of the construction sector. For each segment, the actors, institutions and policy content related to them will be analyzed. This will be further explained in the following section.

[3] The furniture industry represents such a flow, but imposed analysis difficulties and is therefore excluded from this research.

Figure 5: Process of case study selection



Source: Based on Villanueva et al. (2010)

3.3.2 Stakeholder selection

Governance literature recognizes that "a broad array of hybrid environmental governance strategies are being practices, and it has become clear that seemingly purely market-, state-, or civil society-based governance strategies depend for their efficacy on support from other domains of social interactions" (Lemos and Agrawal, 2006, p. 298). Adequate policy research therefore involves actors from all these domains. In addition to this, policy analysts seek to understand how actors, institutions and policy instruments form the policy agendas of actors operating in social networks. In any governance research, stakeholder selection has far-reaching consequences for the generation of results about the interests, behavior, policy agendas and influence on decision-making processes of the relevant actors (Brugha and Varvasovsky, 2000, p. 239). Stakeholder research plays an important role in the assessment of various technical options in timber use, as it is used to cooperate effectively with stakeholders, to understand the policy context, and to assess the feasibility of policy alternatives in implementing these technical options (Reed et al., 2009, p. 1933). For this reason, stakeholder research plays an important role in obtaining insights on the attitudes, interests and capacities of stakeholders on the available options to improve timber use efficiency discussed in natural science literature. Interviews are conducted on 22 respondents from the public, private and NGO domain, either face-to-face, or via phone and e-mail. Table 1 depicts all six subgroups of actors from the public, private or NGO sphere. In Actors related to the public sphere are the licensing authorities (municipalities). Actors related to the private sphere are the commissioning authorities, designers, construction engineers and contractors. The NGO sphere covers both branch organizations and knowledge brokers. These categories are based on the roles of the selected actors.

Public actors

Falkner et al. (2003) argue that: "Actors operating in the public sphere are important in creating the policy context that give rise to institutional arrangements that structure and direct actors' behavior in an issue-specific area" (Falkner, 2003, p. 72-73). Hence, public actors are expected to take responsibility for natural resource management. They seek to influence the implementation of technical options by creating rules and regulations, which discourage or stimulate certain behavior patterns of non-state actors.

Private actors

Actors that operate in the private domain all have their own perspectives on natural resource management problems. Each actor uses the same resources for different reasons, and values this use in different ways. In addressing the implementation of technical options to improve resource use efficiency, it is therefore crucial to understand these different perspectives and valuations.

NGO actors

The increasing involvement of civil society groups and scientific or knowledge institutes in policy processes signifies an interesting point in studying timber use efficiency. NGOs are empowered by their ability to influence public authorities and the policy agendas of private firms without having to rely on established channels of decision-making (Wapner, 1997, p. 66). The public actors included in the interview research are Zoetermeer, Delft, Utrecht and Amersfoort. Private actors include a number of large housing associations: Ymere, Eigen Haard, and Rochdale. Among the designers, these are: LAM Designers, Zecc Architecten, Maarten van der Breggen Architecten, and Greiner & Van Goor Huijten. With regard to the knowledge brokers, the following actors are selected: W/E Advisors, Probos, Stichting Hout Research, Nyenrode Business University and E/E Advisors. The selection of contractors includes Schijf Groep, and De Groot Vroomshoop.

Table 1: Actors related to the construction industry

PUBLIC ACTORS	PRIVATE ACTORS			NGO ACTORS	
Licensing authorities	**Commissioning authorities**	**Designers**	**Contractors**	**Branch Organizations**	**Knowledge brokers**
Municipality of Zoetermeer	Ymere	LAM Designers	Schijf Group	Association of demolition contractors (BRBS)	TNO Bouwen
Municipality of Delft	Eigen Haard	Zecc Designers	De Groot Vroomshoop	Association of Demolishers (Veras)	Probos
Municipality of Utrecht	Rochdale	Maarten van der Breggen Architecten		Centrum Hout	Stichting Hout Research
Municipality of Amersfoort		Greiner & Van Goor Huijten		Dutch Association of Timber manufacturers (NBvT)	Nyenrode Business University W/E Advisors

3.3.3 Interview guide for case study

Scorecard

The first part of the interview consists of a scorecard, which is used for expressing the feasibility of implementing technical options which can be used to improve timber use efficiency. With this scorecard, it is the aim to determine the feasibility of improving timber use efficiency based on two parameters: 'Importance', and the 'implementation difficulty' of each technical option. The scorecard is constructed as follows: in the first part, the respondent is asked to indicate his or her perception towards the importance of each technical option on a numerical scale, ranging from 1 ('not relevant') to 5 ('relevant'). In doing so, insights are obtained on the actors' perspective on the importance of each technical option in improving timber use efficiency. In the second part, the implementation difficulty of each technical option is assessed using eight factors, which are drawn from the governance framework. Each factor can be interpreted by the respondent as an 'opportunity' or a 'barrier', again using a numerical scale ranging from 1 (opportunity) to 5 (barrier)[4]. In applying this analytical scorecard, it is the aim to investigate which factors play an important role in creating opportunities for or imposing barriers on improving timber use efficiency. The factors that yield significant scores in terms of opportunities or barriers are used to explain the feasibility of improving timber use efficiency, and will be evaluated in the final chapter.

Governance questions

The second part of the interview guide consists of an in-depth interview, during which the respondents (i.e. representatives from municipalities, firms, or organizations) are confronted with a uniform list of questions[5], which cover the following aspects:

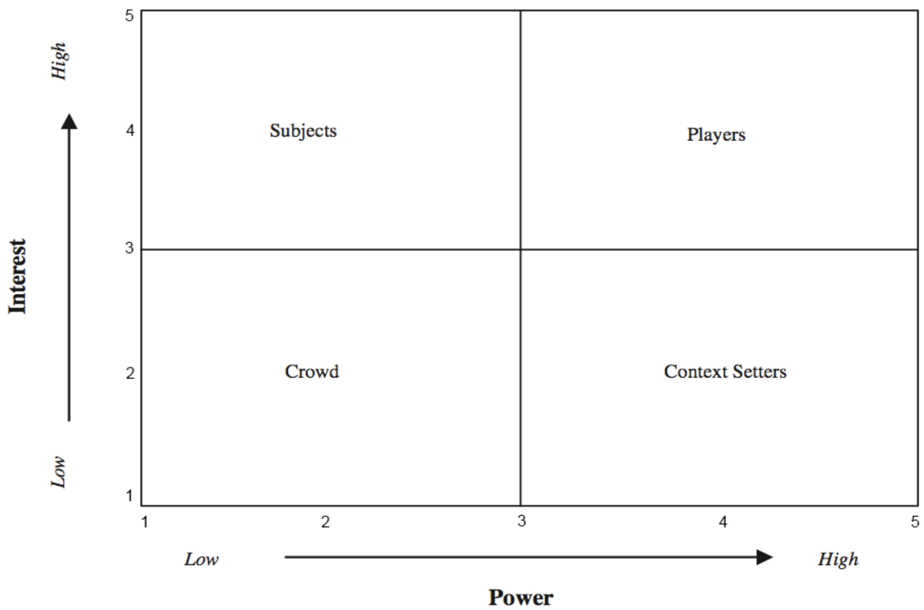
- Vision and attitude of the respondents respective institution, firm, or organization towards timber use efficiency in the construction sector
- Technical options used by the interviewees' respective institution, firm or organization, and its perception on the contribution of these technical options on improving timber use efficiency
- Main considerations for using or not using certain technical options, and which factors play a dominant role in making these considerations
- The interviewees' perception on which actor-based, institutional and policy conditions can lead to better implementation of the respective technical options,
- How the interviewees' institution, firm or organization can contribute to creating these circumstances

The information provided by the respondents is used to pinpoint the stakeholder position of each actor in the power-versus-interest grid. As explained in the theoretical section of this research, stakeholder position is determined according to: 1) Interest, 2) power, 3) resources and 4) regular contact with other stakeholders. For each of these four indicators, qualitative values can range from 'low', 'low-medium', 'medium', to 'medium-high' or 'high'. In order to place each actor in the grid, we need to translate these qualitative values to quantitative ones. For consistency reasons we use the same range of values, whereas a qualitative value of 'low' corresponds with 1 and 2, 'medium' with 3, and 4 and 5

[4] See Appendix 1 for scorecard
[5] See appendix 2 for the complete list of interview questions

with 'high'. By attaching quantitative values to the actors and placing them in the power-versus-interest grid depicted in figure 6, accurate conclusions can be drawn with regard to the feasibility to form strategic alliances among actors to address timber use efficiency in the construction industry.

Figure 6: Format of power-versus interest grid



Source: adapted from Bryson (2004)

4 Material flow analysis and identification of options for efficiency gains

4.1 Introduction

The first section provides a general description of timber resources- and their consumption in Europe. First, data about European timber production and trade will be described. Second, the main activities and actors related to the applications of timber are explored. In doing so, one can obtain an insight on the post-harvest segments of the chain which show poor performance in timber use efficiency. After investigating the performance in each application field, a variety of technical options will be described how to improve use efficiency for these applications.

4.2 General description of forest resources

42 % of Europe consists of forest area, which is equal to 178 million hectares of land surface (Eurostat, 2011). Timber is the most common product of forests, which, if regulated well, can be harvested without disturbing its protective or recreative functions. This implies that harvesting timber will not cause soil erosion, or influence ecological reproductive cycles. The circle diagram below depicts the variety of forest products and services. One must note that this diagram reflects both the products and services from 'forests', as well as those from 'Other Timbered Land'(FOWL), which is defined as any patch of vegetated area larger than 0,5 hectares with a tree cover of 5-10% (Eurostat, 2011, p. 17). In these parks trees are protected, and provide the habitat for animal and plant species. Other national parks have a protective function for ecosystems or landslide prevention. On average, 13% of forested areas in the EU are designated as protected[6]. The vast majority of forest stands (85-90%) has multiple functions, and may fulfill protective functions without being designated as such. In some EU countries, there is no clear distinction between protective and protected forests. However, forests also cover other economic benefits than commercial logging and social services. Forests also provide recreational or cultural services. Additionally, forests also provide other 'non-timber' products, such as mushrooms, truffles, fruits, vegetables, nuts, bush meat and honey. In an attempt to monetize these 'non-timber' products and services, it was estimated by Eurostat (2011) that European forests contributed EUR 34,9 billion on products and services to the GDP in 2008[7]. It must be noted that, especially in Mediterranean member states, non-timber products are harvested in an unofficial manner, which makes their quantification difficult. As part of the Global Forest Resources Analysis (FRA), the economic value of non-timber products and services are listed for the EU (eurostat, 2010).

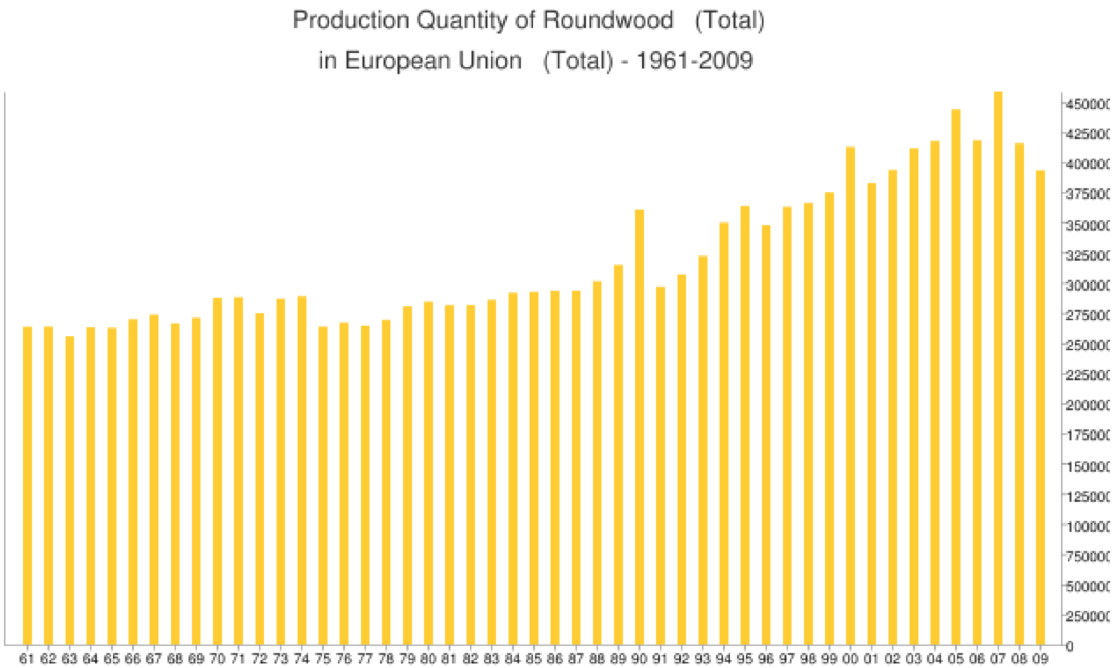
4.3 Timber production and trade

The production of timber in Europe consists for 76% of roundtimber, which is used for industries such as paper- and pulp, packaging, and construction. The remaining 24 % is fuel timber, used for renewable energy production. According to the 2011 forestry statistics of the European forestry statistics (Eurostat), EU roundtimber production experienced

[6] See appendix 3 for designation of forest functions in EU-27 member states
[7] See appendix 4 for economic valuation of non-timber products in EU-27 member states and EU-candidates.

production growth between 1961 and 1990 (360,6 million M³). Due to the consequences of the financial crisis of 1989, production levels decreased by 7,8% during the following year. After a period of steady growth until 2007 (458,3 M³), production levels dropped due to the second financial crisis in 2008. This resulted in a 14,3% decrease during the years 2008 and 2009 (392,9 M³), the lowest production level recorded since 1999.

Figure 7: industrial round timber production in the E-27 1961-2009 (in 1000 M³ roundtimber equivalence r.e [8])

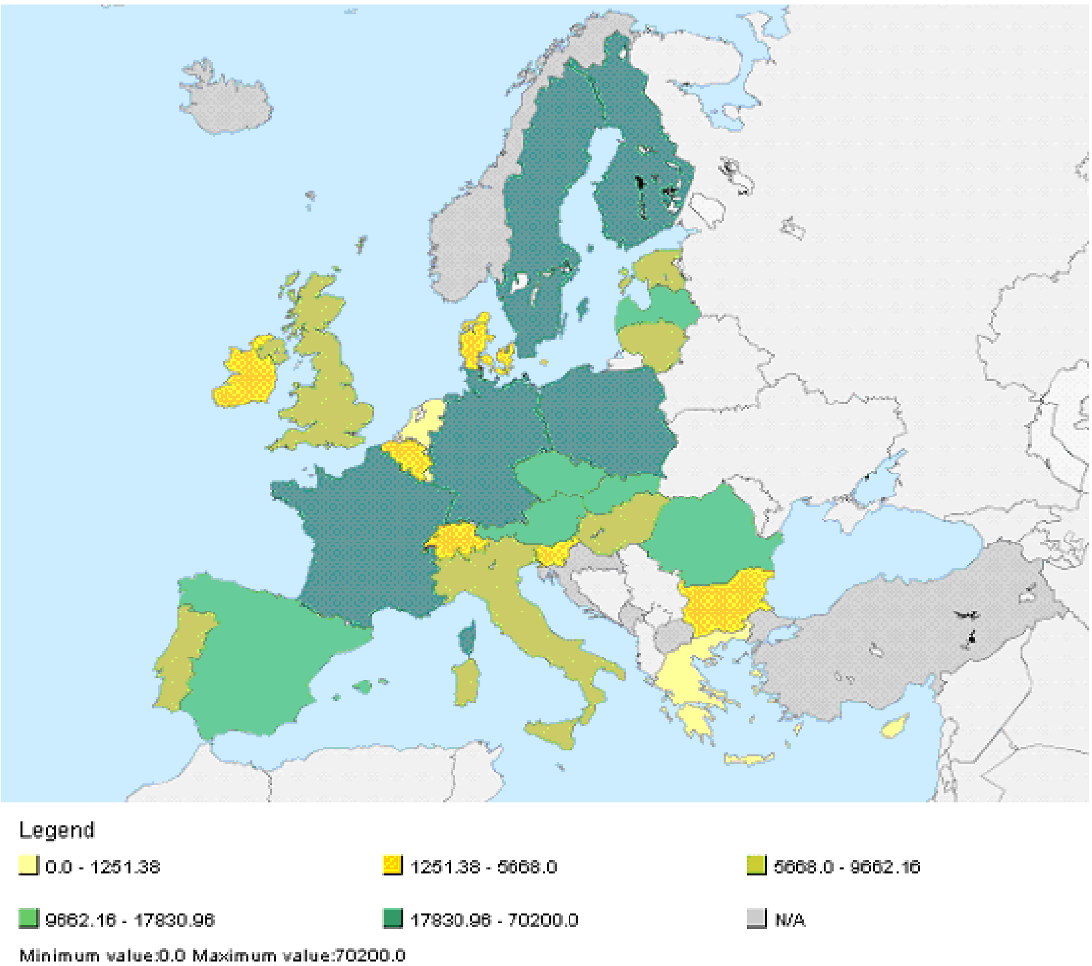


Source: Mongabay, 2011

The colored map in figure 7 indicates the production levels by country in 2010. The largest producer is Sweden (70200 M³ r.e.), followed by Finland (50951 M³ r.e.), Germany (54418 M³ r.e.), France (57362 M³ r.e.) and Poland (35378 M³ r.e.). Together, these countries contribute 63 % to the European timber market.

[8] The unit r.e. can be defined as the amount of roundtimber needed to produce a timber product.

Figure 8: Timber production in the EU-27 in 2010 (in 1000 M^3)



Source: Eurostat, 2011

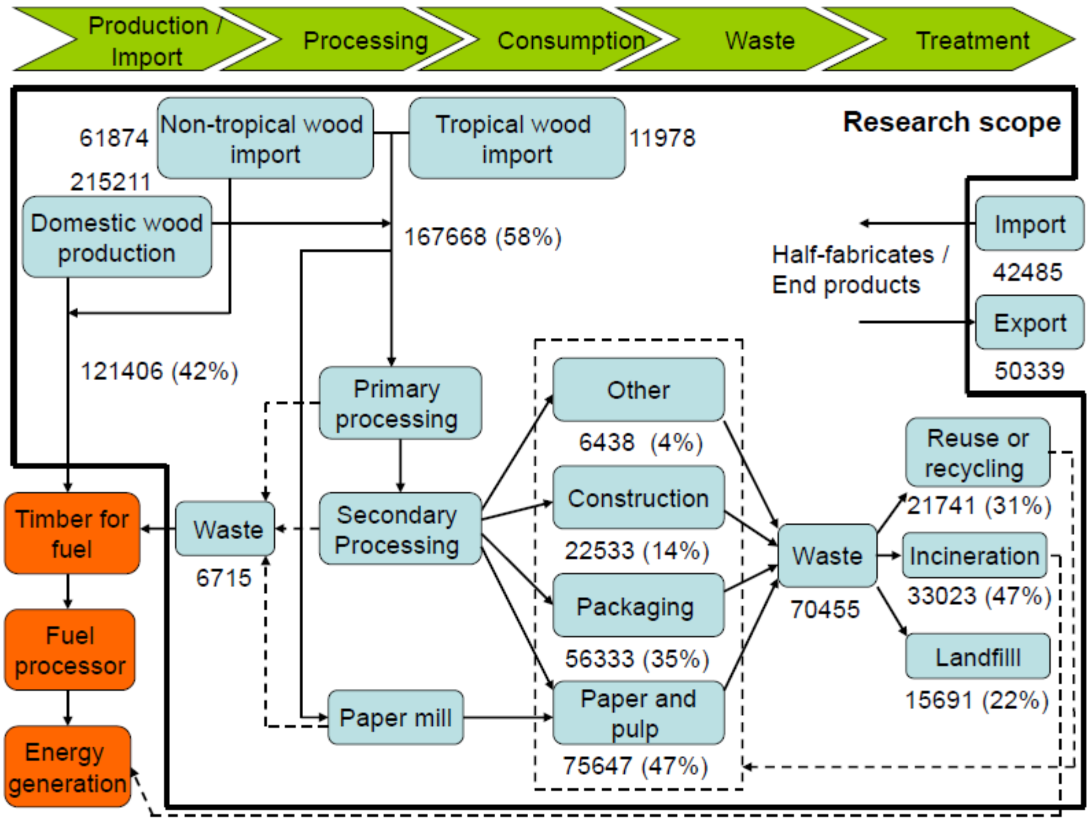
Figure 8 depicts an overview of the European timber producing countries. The largest exporters of roundtimber are France (4,5 million M^3 r.e.), Germany (4,3 million M^3 r.e.), and the Czech Republic (4,2 million M^3 r.e.). Together, these countries make up 60 % of all timber exports. The largest importing countries are Austria (86 million M^3 r.e.), Germany (74,7 million M^3 r.e.), Sweden (47,1 million M^3 r.e.) and Finland (46,5 million M^3 r.e.), which account for 63% of all imports. Databases such as Faostat (2011) and Eurostat (2011) do not provide the timber consumption data directly, and must therefore be calculated according to the following formula: *Domestic production + import – export = consumption.* According to Eurostat (2011), Germany is the largest consumer of timber (91,6 million M^3 r.e.), followed by France (62,4 million M^3 r.e.), Sweden (62 million M^3 r.e.), and Poland (45,2 million M^3 r.e.). Together, these countries contribute 52% to the EU's total timber consumption (Eurostat, 2011).

To obtain a more in-depth view on the processes of roundtimber harvesting and the production of timber products, a material flow analysis is conducted. Figure 9 depicts the main flows and processes of timber material in units of roundtimber equivalencies (r.e.). In doing so, it becomes clear in which activities in which the largest efficiency gains can be achieved. A difficulty of the material flow analysis is related to the units used for the data. While timber production quantities (input) are measured in cubic metres, timber waste flows and timber product quantities (output) are measured in kilotonnes of timber material.

As the use of multiple units may cause confusion, kilotonnes will be used as the default unit. When converting metric tonnes into kilotonnes of timber material, a few factors must be taken into consideration. First, total roundtimber production consists of various types of timber with different market shares and timber densities. In order to simplify the conversion, standardized density factors from the IPCC guidelines (2006) are used to convert cubic metres of solid timber into tonnes of oven-dry timber for both tropical and non-tropical timber. The standardized conversion factors cover all types of roundtimber, as well as fuel wood, chips and particles, and timber residues[9]. According to the most recent data, 42% of the timber production is directly used as fuel wood. The remaining 58% is applied in the three main industries discussed in this research: paper- and pulp manufacturing, packaging and the construction sector. The paper- and pulp industry has the highest share in timber use (47%), followed by the timber packaging industry (35%), construction (14%) and other applications (4%; mainly furniture). After harvesting and import, the timber material is subject to standard primary processes, such as sawing and cutting. During secondary processes, the timber material undergoes treatment geared towards their specific application, such as coating, gluing, painting and so forth. After its primary use, the timber products are subject to recycling for other purposes, or used as fuel timber for energy generation.

4.4 Timber processing and use in the EU-27

Figure 9: Timber flows in the EU-27



Source: Based on Eurostat (2011), CEPI (2011) and Villanueva et al. (2010)

[9] See appendix 5 for overview of conversion factors

According to the material flow system depicted in figure 9, 121406 kiloton (42%) of all virgin timber is directly used for energy generation. The share of processed timber that is used for the manufacturing of timber products is distributed over three main industries: Paper and pulp (47%), packaging (35%) and construction (14%). The remaining 4% is mainly used for furniture production. In some cases, the literature also presents information about furniture production which uses various materials, not exclusively timber, and is therefore not timber-based. Another reason is that statistics used in this section are based on the Standard International Trade Classification (SITC), which does not distinguish between furniture manufactured from timber and that made of other materials. To avoid the inclusion of non-timber materials in the presentation of data, furniture is not considered in this analysis (Eurostat, 2011, p. 57).

From the 70455 kiloton of used timber and paper products that remain after consumption, 21741 kiloton (31%) is reused or recycled as construction material, packaging or household products. 33023 kiloton (47%) is used for energy generation. This share is likely to increase up to 52% in 2020, thereby increasing the pressure on reuse and recycling rates (EC, 1999). The flow diagram in figure 10 provides a more detailed overview of waste treatment processes. General trends in the secondary processing industries are directed towards more 'prefab' elements and half fabricates. Due to improved technologies for timber modification, the number of actors involved in this branch of activities is growing. These technologies allow companies to integrate small pieces of timber into large products or elements. Moreover, firms can combine various types of timber for the same application, which increases the efficiency of timber use. However, some applications combine timber with non-timber materials, which decreases its opportunities for recycling and reuse. With regard to timber upgrading, companies increasingly use metal-free substances, thereby avoiding separate waste collection and treatment. A concomitant issue is the recognition of the various types of upgraded timber, and distinguishing the substances used. Increasingly (and as with primary processes), hardwood-producing countries conduct the secondary processes themselves and export half-fabricates and end products. This trend requires more transparency and traceability about the use efficiency in this segment of the chain. To allow for further development of timber as a highly efficient material for various purposes, environmental gains must be achieved in specific segments of the timber chain. A number of relevant processes or activities performed in the chain are:

- Production and import
- Primary processing
- Secondary processing
- Wholesaling and distribution
- Application processes
- Treatment or disposal

For every segment of the chain, the main characteristics and practices of the processes will be explained, as well as the actors involved. In describing the trends and developments, the focus is on the implementation of recycling measures and sustainability concepts (including cradle-to-cradle). With this data, the effects of the practices in each segment on the timber waste flow and timber use efficiency can be derived.

4.5 Import

According to current figures, Europe uses ca. 167668 kiloton r.e, of which 50339 kiloton r.e. is exported as half-fabricates or end products, mainly to Russia, the US and

Canada. 42485 kilotons of half-fabricates or end products are imported, mainly from China. Europe is to a large extent self-sufficient; 74,2% of total timber production originates from domestic forests. The additional 25,8% is imported from the Russian Federation and Canada. Only 4% of total imports consist of tropical hardwood, which is imported from Indonesia and South-America (Probos, 2010, p. 10).

4.6 Primary processing

The primary processes are the first post-harvest activities. These include the cutting, debarking and sawing of the raw timber material. The logs are processed into beams for transportation. Additionally, the timber may be subject to an anti mould treatment. This process is relevant for the timber flow downstream, because it determines how the timber will be applied, and whether it will be reused, or directly incinerated for energy generation. However, in many cases the timber is treated in a superficial manner, and will be cleared from chemical substances after debarking. These activities mainly take place in the largest timber exporting countries such as Sweden, Finland, Germany, France and Poland. The remaining 4,3% consists of tropical hardwood, which is extracted from Malaysia, Indonesia and Brazil as raw material or half-fabricates (Eurostat, 2011).

4.7 Secondary processing

In this part of the chain, the imported roundtimber is prepared for more specific applications. The timber is subject to treatments such as profiling, optimizing, gluing, upgrading and modification. The level of (chemical) treatment for some applications determine to a large extent whether or not used timber can be recycled or reused, i.e. whether the used timber products will be categorized as A-, B- or C waste. A-timber is untreated timber which can be recycled. B-waste is glued or painted timber which can also be recycled. Used timber in the C-category is treated with hazardous chemicals and can therefore not be recycled (Hasan et al., 2011, p. 695). The actors involved in secondary processing are the suppliers for the construction sector, furniture manufacturing, timber- and packaging industry.

4.8 Application of timber: three industries

After secondary processing, timber can be used for various applications. The three main application fields presented in this research are the paper- and pulp industries, pallet- and packaging manufacturing, and the construction sector. Together, these industries comprise approximately 88% of total European non-fuelwood applications (Faostat, 2011). Downstream manufacturing processes concern the production and recycling of timber and paper. These applications are discussed under the heading of ‘timber-based’ manufacturing; products that consists of a mixture of intermediate and end timber goods used in paperprint, packaging and construction.

4.8.1 Specification of timber product categories

To avoid the risk of double-counting of potential impacts of technical options, it is essential to specify the three major timber working industries. The paper and pulp industry covers the sum of newsprint, uncoated mechanical, uncoated and coated papers. These papers include news-, print- and writing paper, magazines, books, directories and commercial printing such as flyers. The packaging and pallet industry covers the manufacturing of case materials, cardboard, wrapping papers and other papers used for packaging (Eurostat, 2011, p. 56). Due to its similar purpose, pallet production is included in this category. The construction sector covers timber-based materials, including timber housing skeletons, window frames, stairs, walls, floors, and various timber-based panels. Due to the fact that paper- and cardboard packaging is manufactured through the paper and pulp industry, the potential improvements made by the reduction of end use option available to the packaging industry can be attributed to the paper and pulp industry. To minimize the risk of double-counting between these industries, estimates of the impacts of the reduction of end use option on the packaging industry is adjusted for the fraction of timber packaging.

4.8.2 Paper- and pulp industry

The largest timber working industry in Europe is the paper- and pulp production, which covers 47% of total timber use. According to the International Council on Forest and Paper Associations (ICFPA), the EU-27 produced ca. 75647 of pulp, paper and paperboard in 2010. Sweden (30,3%) and Finland (26,8%) are the main suppliers of paper and pulp; none of the remaining 25 member states contributed in excess of 7,1% to total production. Germany (20%), the United Kingdom (14,4%) and France (10,3%) are the main importers of pulp (CEPI, 2011, p. 35). Pulp can be used for a variety of paper and cardboard products. 65% of the products from this industry consist of news- and print paper, other printed paper such as magazines, books, commercial printing, directories, business papers, catalogues, but also food wrappings. Case materials make up 35% of the production. It is expected by the Netherlands Bureau for Economic Policy Analysis (CPB, 2008) that European production will increase in the range of 2,5 – 4,1% between 2005 and 2025, depending on the progress of production technologies and demand (p. 37).

Starting in 2006, the Confederation of European Paper Industries (CEPI) made the commitments to achieve a 66% recycling rate by 2010. CEPI achieved this commitment and, at the end of 2009, the recycling rate within the EU-27 was 72.2% (ICFPA, 2011, p. 33). This recycling rate includes all paper and cardboard products. High recovery rates of paper and feeding it back into the manufacturing system has a few positive effects: it reduces the use of raw timber materials, material costs, and increases product sustainability. As a complementary fibre source, recovered paper and cardboard helps to reduce the amount of paper in the waste stream, thereby reducing greenhouse gas emissions generated through paper decay. Considering the importance of consumer engagement in recycling programs, ICFPA member states continue to make significant efforts to raise public awareness about paper recycling programs and their positive effects on paper waste flows and use efficiency. European recycling rates continue to rise due to increased awareness and improved collection- and recycling systems. However, there paper recovery has technical and practical limits. A significant percentage of paper products are not suitable for recovery due to contamination in use, such as food wrappings, and various household papers. Other paper goes into (semi-) permanent use (archives and libraries), or is used in remote areas, which may be out of reach of recycling programs. In addition, cellulose fibers become shorter as their recycling trip number increases, which limits their usefulness for new paper products (ICFPA, 2011, p. 34).

4.8.3 Packaging industry

Ca. 35% of European timber (56333 kiloton) is used for the production of timber packaging. This branch consists for 65% of pallets, and for 35% of crates and other timber case materials. Pallets are used for the transportation of commodities in various branches, including retail and construction. Most of the timber packaging material are not owned by companies, but circulate in so-called 'pallet pools', which makes them more susceptible for repair and reuse. The raw timber materials make up 80% of the total costs of timber packaging. Considering the fact that timber packaging is a low-quality timber product, pallet- and crate producers seek to manufacture their products as cheap as possible. Therefore, the use of recovered timber can result in both financial gains and a reduction of waste timber Tjeerdsma and Klaassen, 2010, p. 8).

4.8.4 Construction sector

The Construction industry is the third major sector of timber use; 14% (CEI-Bois, 2010, p. 79). The Environmental Protection Agency (EPA) stated that: "Today, no other sector of industry uses more materials, produces more waste and has a lower recycling rate than the construction sector" (Lehmann, 2010, p. 162). Out of the 180 million tons of material used in construction the EU-27 each year, 15% consists of timber. The most relevant construction processes that have potential sources of timber waste generation are listed in table 2 on the following page.

Table 2: Origins and causes of timber waste during construction processes

Origins of waste	Causes of waste
Contractual	Errors in contract documents
	Contract documents incomplete at commencement of construction
Design	Design changes
	Design and detailing complexity
	Design and construction detail errors
	Unclear and unsuitable specification
	Poor coordination and communication (late information, last minute client requirements, slow drawing revision and distribution).
Procurement	Ordering errors (i.e. ordering items not in compliance with specifications)
	Over allowances (i.e. difficulties to order small quantities)
	Supplier errors
Transportation	Damage during transportation
	Difficulties for vehicles accessing construction sites
	Insufficient protection during unloading
	Inefficient methods of unloading
On-site management and planning	Lack of on-site waste management plans
	Improper planning for required quantities
	Delays in passing information on types and sizes of materials and components to be used
	Lack of on-site material control
	Lack of supervision
Material storage	Inappropriate site storage space leading to damage or deterioration
	Improper storage methods
	Materials stored far away from point of application
Material handling	Inadequate material handling
Site operation	Accidents due to negligence
	Unused materials and products
	Equipment malfunction
	Poor craftsmanship
	Use of wrong materials resulting in their disposal
	Time pressure
	Poor work ethics
Residual	Packaging
	Off-cuts from cutting materials to length
	Waste from cutting uneconomical shapes
Other	Weather
	Vandalism
	Theft

Source: adapted from: Osmani et al., 2008, p. 1149

The efficiency issues related to the construction sector can be categorized as demolition waste or construction waste. Waste occurring during the construction of new structures consists mostly of damaged material and packaging material. Waste from surplus and damaged materials at the end of a construction task contribute ca. 20% to total waste flows in construction, and are created by poor management practices. Intermediate and pre-cursor waste products are hazardous materials such as asbestos, tar or waste oil. Whether they are removed before demolition or not, strongly determines if C& DW flows are treated or disposed. Packaging material contributes 2% of total waste flows from construction sites, and much more when the fraction of C&D waste flows is not included.

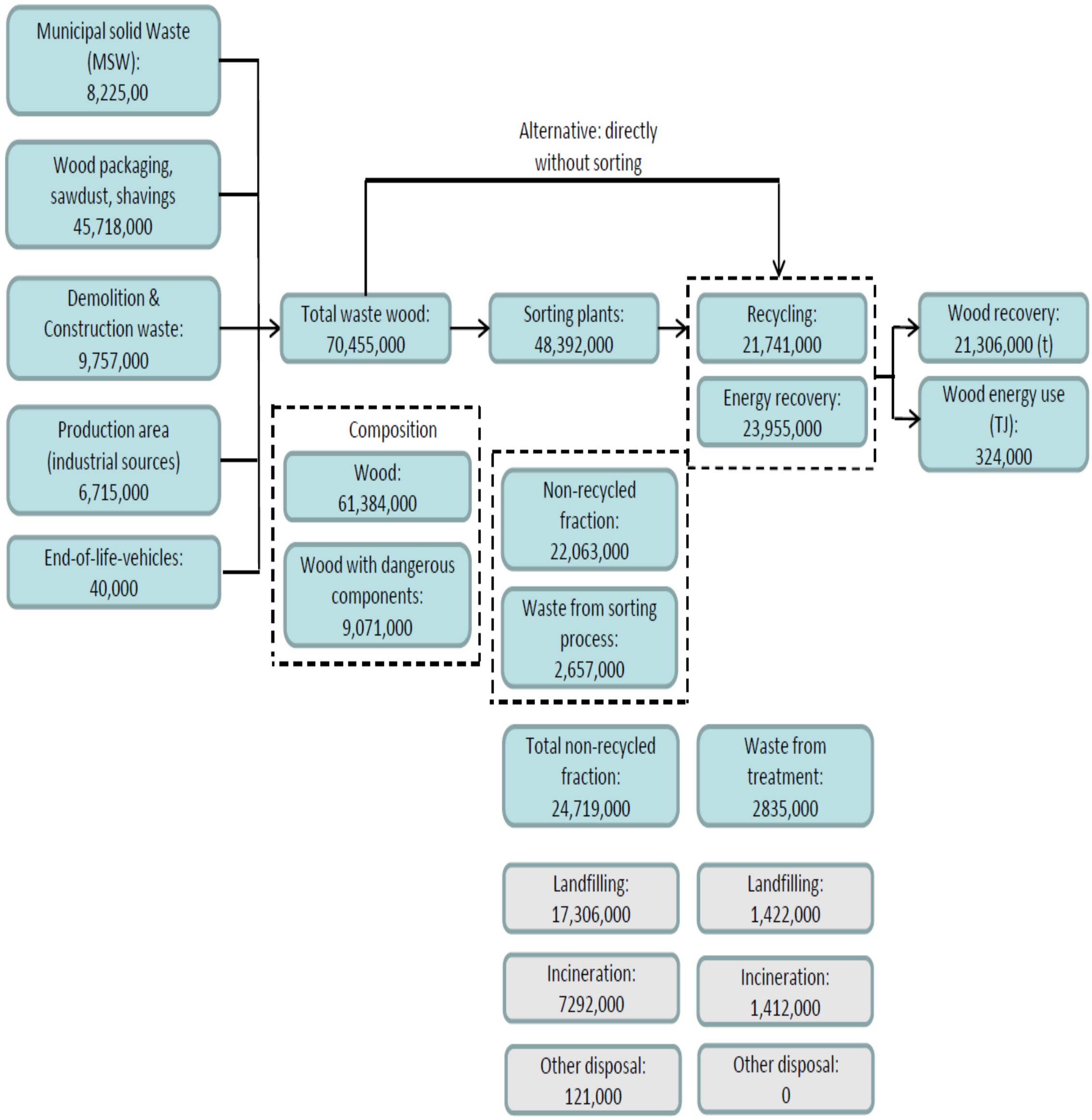
Demolition waste covers one third of total European waste generation, and has the lowest recycling level of all three industrial sectors (28%). Therefore, this is a major area of interest for resource use efficiency research. The demolition activities with the largest potential gains is the removal and treatment of hard surface covers, the demolition of existing structures, and the construction of new structures. Due to the poor performance of these activities, 72% of the stripped timber is disposed as mixed construction and demolition waste, together with other materials such as concrete, tiles and cement (EC, 1999). The mixing problem also occurs in the demolition of the structures themselves, where materials are often mixed and require additional efforts to separate in the C&D waste flow. However, considering the current situation, a large share of high-quality, clean timber is marked as mixed waste and is transported to landfills. To allow for exploration of how this waste flow can best be reduced, it is important to know that this flow consists for 33% of sawn timber, and 16% of timber-based panels (Tjeerdsma and Klaassen, 2010, p. 13).

4.9 Waste treatment: characteristics of the waste flow

The diagram depicted in figure 10 illustrates the waste flows that are generated by the major timber working industries. 65% of the timber waste consists of packaging waste such as pallets, crates, and cardboard. Construction contributes 14%, municipal solid waste 11%, and industrial processes 10%. Total construction timber consists for 15% of hazardous waste, which is incinerated at special treatment plants. The remaining 85% of non-hazardous timber waste is suitable for sorting. In practice, 65% of this non-hazardous timber waste arrives at the sorting plant. The remaining 35% of this fraction does not find its way to the sorting plant. Two third of the unsorted timber waste is disposed on landfills, one third ends up in incineration plants. During the sorting process, 4% of timber waste is discarded due to its chemical treatment. 47% of the sorted timber waste is selected for energy generation; the remaining 49% is recycled. During the waste treatment processes, 6% of the timber waste is discarded as landfilling or fuel wood. (Eurostat, 2011; Villanueva et al., 2010). It is concluded that, during the various phases of waste treatment, 46% of all timber waste is used for energy generation. The flow diagram indicates a large amount of timber waste suitable for recycling, is incinerated with energy recovery. Looking at developments in this sector, it is expected that the fraction of timber waste used for energy production will increase due to energy demands, thereby creating competition with the recycling industry. This issue will be elaborated on in the following chapter.

The collection and recycling of used timber shows poor performance compared to, for example, paper and glass. This is due to the fact that there is no well-structured network of timber waste producers, timber separators, and recycling companies. According to recycling monitoring reports, only firms that produce large amounts of timber waste adopt reuse and recycling strategies, since they are able to generate sufficient quantities of timber to outweigh the costs of collection and separation. These actors operate in the context of the European strategy of security and sustainable energy, designed by the European Commission (Villanueva et al., 2010, p. 118). In accordance with the European goal to increase the share of renewable energy up to 20% in 2020, member states are required to use timber for energy generation. With regard to this, the EC is considered an influential actor in determining how timber waste is applied. Apart from the energy policies, the Landfill Directive also influences the timber recycling market. This factor results into better separation of timber from non-timber material. Both factors (energy policy and the Landfill Directive), enhance the creation of a network of waste separators and recyclers who can, through trade of (mainly) high quality timber, determine how the timber waste is applied. It is suggested that renewable energy policies continue to foster competition between energy recovery and material recycling (p. 121).

Figure 10: Timber waste flow diagram in the EU-27 in 2009 (in rounded tonnes)



Source: Villanueva et al., 2010, p. 12

4.10 Technical options and their potential

Tables 3, 4 and 7 summarize the technical options that are available to the three timber sectors, with their potential impact on timber use efficiency and the actors involved in each option. In chapter two, five principles for material optimization and waste reduction were introduced by using industrial ecology literature. These principles are used to identify the technical options that can be used to improve timber use efficiency in the construction industry (WRAP, 2010) As can be seen, not all technical options are available to each application field. Due to a lack of data availability, statistics about the potential impact of avoided incineration or landfill can not be presented for each application field. In attributing the potential impacts to particular technical options, one should be aware of the risk of double-counting. A share of the cardboard produced by the paper- and pulp industry is used in the packaging industry. When estimating the impacts of a technical option applicable in the packaging industry, it is therefore useful to determine which material is concerned.

4.10.1 Paper and pulp industry

The measures that can be implemented for more efficient use of timber in the production of pulp and paper can be categorized as options that reduce the end use of paper required to provide the same service, and recycling. When combined, these measures contribute 25-40% to use efficiency (Hekkert et al. 1999 and 2002; CEPI, 2011; Eurostat, 2011). Used paper and paperboard can not be reused for another purpose product; this option is therefore not considered.

Reducing the amount of timber used for pulp and paper production can be achieved by implementing more efficient production technologies. In applying this option, paper manufacturers can save 2% of paper input (Hekkert et al., 1999, p. 23). Additionally, the production of graphical papers can be more efficient. Product standards require that newspaper weight is at least 42 g/m². Considering that 35% of the newspaper print weighs much more, large efficiency gains can be achieved with this option. When newspaper producers include this measure, pulp manufacturers can save 7% on material input for newspaper printing. For graphical papers, paper thinning can lead to a 15% efficiency gain for printing and writing (P&W) paper, and 10% for other graphical papers, such as books and magazines. Other options that have been explored to reduce the amount of paper needed to fulfill the same function, relate to behavioral change of end users. Such options include good housekeeping in offices and matching production with consumption. It is assumed that good housekeeping can result in a 10% decrease in paper use, based on historical experiences. A Dutch campaign by WWF to reduce paper use in firms was joined by over 140 companies, who all made efforts to reduce their paper consumption, mainly cut size paper. With regard to substitution option, excessive paper use can be avoided by reading from the screen instead of printed paper (SWMBC, 2002). The third option is to match the supply of paper with demand. Communication papers contain much more information than what they demand for. When papers only contain the demanded information, much paper can be saved. There are three ways to match supply with demand: personalization (individual-tailored marketing), profiling (based on demographic information) and customization (based on predetermined preferences). For newspapers, the option of personalization has the highest chance of success. Newspaper producers can offer consumers to choose the sections that they are interested in. Doing so will maintain the function of the paper (supplying information), and can result in a reduction of 20% in paper demand (van den Reek, 1999). For graphical and commercial printing, all three measures are suitable. It can be implemented through the technology of 'printing on demand' (POD), which is defined as "processing information in digital form with the primary objective of producing printed documents in optimal quantities within the shortest possible timeframe, with policy content selectively targeted (personalized) for the recipient" (Cap Ventures, 1996). It is estimated that this technical measure can lead to a paper demand reduction of 15-25% for graphical paper products with high market shares such as magazines, books and printing paper[10].

Table 3: Efficiency gains of technical options for paper and pulp industry in the EU-27

Technical options Paper and pulp (47%)	Options that require little or no behavioral change from end users	Options that require behavioral change from end users	Actors involved	Estimated potential impact on use efficiency	References
- Prevention of use (including resource substitution)	- Paper thinning	- Printing on Demand, personalization, and profiling - Obtain information online	- (News) paper producers, media, end users End users	10-20%; newsprint paper and other graphical papers such as magazines	Cap Ventures (1996); Lafleur and Fraanje (1997); Hekkert (1999); Hekkert et al. (2002); Van Den Reek (1999); SWMBC (2002)
Reuse	- Not applicable	- Not applicable	- Not applicable	- Not applicable	- Not applicable
Cascading / Recycling	- Paper collection systems	- Good housekeeping	- End users, recycling companies	15-25% (estimate); focusing mainly on offices	CEPI (2011)
Incineration or landfill	- Limiting or banning landfills - Restricting subsidies for incineration with energy recovery		- Waste processing companies, energy companies, public authorities	20-25% (estimate); based on data about paper used for energy generation and land filling	CEPI (2011); Eurostat 2011)

[10] See appendix 6 for complete list of technical measures to reduce paper demand for different paper products

4.10.2 Packaging industry

The main options discussed in the packaging industry focus mostly on creating and maintaining reuse and recycling systems of timber case materials, which can lead to efficiency gains between 7 and 15%. Innovative, non-timber packaging materials are assumed to have a large impact as well, although it is difficult to obtain data that supports this claim. The options available to the timber- and timber-based packaging industry require in most cases technical changes at the production plant. The three main options are: reduction of use (including substitution), and cascading (WRAP, 2011).

The first option relates to a reduction of the consumption of packaging. Timber use can be avoided by delivering materials and products without the use of pallets. Additionally, avoiding timber-based packaging in shipping operations can be achieved by using slip sheets, containers, top and bottom covers, and rolling carts. These material handling systems are more often reusable and recyclable (Hekkert et al. (2000; SWMBC, 2002). By using thinner packaging for beverages and food, the material input will decrease nearly by one third. Hekkert's research also concluded that reducing the thickness of mainly food packaging is possible without compromising packaging requirements.

Material substitution plays an important part in the prevention of use; this means that timber, as the ground material for pallets and packaging, can be replaced by secondary timber material from processing, such as flax- or hempshives (Fraanje, 1998). Substitution also includes replacing timber by non-fibrous material such as plastic, composite, and metal pallets. These types of pallets have the common characteristic that they are manufactured in one piece, which increases their lifespan. These pallets can be used in closed loop systems, where private third parties rent the pallets to suppliers who return them, to encourage reuse.

Third, reuse options can be applied by packaging return mechanisms. On the part of timber packaging, suppliers can be required to take back used pallets and crates. Repairing pallets can increase their trip number (i.e., the amount of handlings), 20 to 40 times more than pallets that are disposed when damaged. The majority of the 25% reused pallets are returned through repairing and maintenance in 'pallet pools', and are thus an important factor in improving the use efficiency of timber (Lafleur and Fraanje, 1997; Hobson, 2003).

Recycling of used timber is the fourth option. In this context, we refer to the cascading principle introduced in chapter two, which implies an extension of the lifespan of timber products. It is estimated by Lafleur and Fraanje (1997) that this option can contribute 7,3% to the total potential efficiency gains. In the European timber-consuming industries, the timber packaging industry is a major user of recycled timber. The ICFPA (2011) encourages a cascaded use of timber, whereby its lifespan is extended. The cascading principle can be applied on both the input- and output side of the timber packaging industry. On the input side, primary timber (e.g. timber beams) from the construction sector can be used for the production of pallets, crates and other timber case material. On the output side, pallets and crates can be used for the production of timber-based panels, playground cushion bedding, landscape mulch, animal bedding, soil amendments and incineration with energy generation. Applying resource cascading in the timber packaging industry involves the following steps:

- Pallets manufactured from used timber, derived from e.g. high-quality timber from the construction sector
- Sawing and cutting of pallets for timber-based panel industry, pallets, and chips / particles
- Soil amendments, Incineration with energy recovery

(ICFPA 2011, p. 32)

The net yield of the commodity timber can be increased by reusing the timber. The more frequently a timber product passes through the cycle, the longer its lifespan becomes. In doing so, less virgin timber is needed and the CO2 will be storage for an extended period. This requires using the timber quality to its full extent, i.e. to use it for the best possible application.

Table 4: Estimated potential impacts of technical options on use efficiency of timber in the packaging industry in the EU-27

Technical options in pallet and packaging (35%)	Options that require little or no behavioral change of end users	Options that require behavioral change of end users	Actors involved	Estimated potential impact on use efficiency	References
Prevention of use (Including resource substitution)	- Thinner packaging - Using other means of cover such as containers, cardboard covers, rolling carts - Composite pallets made from composite material (timber combined with flax- hamp shives / plastic)	- Use of larger containers for packaging	Packaging producers; transporters; composite pallet producers	15-20%	Lafleur and Fraanje (1997); SWMBC (2002); Lafleur and Fraanje (1997); Hekkert et al. (2002)
Reuse		- Enhancing repairing services - Pallet pool (e.g. Europallet); - Packaging return systems	Pallet producers; Europallet, end users	- 10-15%, based on trip no.; increase of 20-40 times compared to no repair. - Packaging return system already common practice, but needs enhancement.	Hobson, 2003; Lafleur and Fraanje (1997); Environmental Assessment Agency (2011); Lehmann (2011)
Cascading / recycling	- Use non-repairable pallets and crates for timber-based panels, such as fiber- and particle board	- Improved waste separation of cardboard packaging	Timber-based panel producers, fibre pallet producers, waste processing companies	7,3%	Fraanje (1998); ICFPA (2011); Lafleur and Fraanje (1997)
Incineration or landfill	- Limiting or banning landfills - No subsidies for incineration with energy recovery		Waste processing companies; energy producers; public authorities	- 15-20%, based on data about packaging used for energy generation and land filling	Eurostat (2011); Environmental Assessment Agency (2011); ICFPA (2011)

4.10.3 Construction sector

The various options that can be used to reduce construction waste in the construction industry are related to the five principles of designing out waste, introduced in section 2.2.1. For each principle, a technical option has been identified. The options selected for this research are: prefabricated construction, IFD (Industrial, Flexible and demountable construction, timber skeleton construction, glued timber, and selective removal of timber products and materials for reuse or recycling.

Table 5: Principles of designing out waste

Principles of designing out waste	Technical option
1. Design for off-site construction	Prefabricated construction
2. Design for deconstruction and flexibility	IFD (Industrial, Flexible, Demountable) construction
3. Design for waste efficient procurement	Timber skeleton construction
4. Design for materials optimization	Glued timber construction
5. Design for reuse and recovery	Selective removal of timber products and materials for reuse or recycling

Source: Adapted from WRAP (2010)

Prefabricated construction: Prefabrication as a construction technique provides the possibility to reuse entire elements of a structure. In this context, material substitution is important; timber-based panels are replaced by non-timber material such as carbon or plastics. Since the construction process takes place off-site, prefabrication techniques have several advantages over traditional cast-in-situ methods. First, off-site manufacture of construction elements results in a reduction of on-site labor activities, thereby providing a safe working environment. Second, in-situ construction of buildings with large quantities of architectural shapes is also reduced, which leads to less construction waste. Third, innovative techniques such as prefabricated- or IFD construction provides components of consistent standards and measurements, which ensures better quality. Moreover, prefabrication techniques generate less construction waste resulting from non-standard adjustment work. Fourth, prefabrication techniques lead to a shorter construction process, thereby minimizing the influence of weather conditions; the construction process can be accelerated by off-site manufacture of precast components in assembly factories (Baldwin et al., 2009, p. 2068). Actors from all disciplines can cooperate to achieve a reduction in construction timber waste. An example of this is the production of timber window frames, where designers and suppliers closely work together in the design phase to use prefabricated window components, which can be installed without generating on-site construction waste, and minimizing in-situ construction of areas with large quantities of construction materials. Although the initial setting cost of precast elements is higher than that of in-situ construction, precast techniques can be used in countries who have both developed both precast methods and cheap labor cost. This can result in significant reductions in production cost. Fifth, prefabrication methods can improve skills and know-how, labor safety, and motivate the construction industry to reduce construction waste through the use of innovative construction techniques. Reductions in construction waste can also be achieved through using less timber for formwork and a reduction in on-site wet trades, leading to less water pollution and less noise nuisance, due to less construction activities. Additionally, prefabrication techniques can improve overall waste management and disposal (Poon et al., 2004, p. 461). Various studies have proven that prefabricated construction allow actors in the design process to effectively minimize the amount of on-site construction waste, and is suitable for the design of structures. Innovative precast techniques can increase efficiency by material optimization. Through feedback by designers at the initiation of a project, they realize that precast methods can significantly reduce the amount of construction waste, and the technique is increasing in popularity. It is assumed that innovations of this kind will lead to fundamental changes in philosophies about waste management, and can provide actors in the design process with new methods to prevent construction waste (Baldwin et al., 2009, p. 2068).

Industrial, Flexible and Demountable (IFD) construction: Originally, the concept of IFD construction is the result of a Dutch innovation program, with the aim to challenge the construction industry to improve its material use efficiency. The characteristics of IFD construction are summarized in table 6. Considering that the primary incentive for industrial production of construction components is to both speed up the building process, and to prevent waste from occurring during construction, refurbishment and demolition. Flexible construction seeks to meet the user's demands and requirements during the first delivery of a building and potential changes made during following periods (Brand et al., 2003). The primary incentive for using demountable construction is the prevention of timber waste during the demolition phase. The concept of industrial, flexible demountable construction is not new. Designers, engineers and suppliers have been active in developing innovative construction products and concepts for the construction sector, which can be integrated into the IFD concept. Although IFD is originally a Dutch concept, its potential use covers the entire European construction market.

Table 6: Characteristics of IFD construction

	Characteristic	Explanation
Industrial	Assembly	Production preparation in the factory; on site only assembly; no improvisation on site
	Project independent product development	Repetitive use of developed product, reuse of knowledge and experience
	Weather independent	Building process does not depend on weather and wind
Flexible	Freedom of choice	There is enough attention for freedom of choice of first-use users
	Adaptability	Successive users adapt the building to their specific needs
Demountable	Building reuse	Buildings can be adapted to new functions
	Recycling	Building components or parts are suited for worthwhile reuse
	Waste reduction	The production of waste is reduced

Source: Vos and Van Den Brand (1999)

Already in 1997, a Dutch consultancy agency investigated the market potential of IFD construction (Damen, 1997). The main conclusion from this study was that the concept of IFD construction integrates economic and environmental interests, by providing solutions for material use efficiency, labor intensity and technology. According to the study, the use of industrial construction for factories, offices and schools has become increasingly common practice. Under extreme circumstances such as natural catastrophies, IFD construction techniques have proven to be an appropriate method, due to its short construction time, and that a uniform solution can be provided to meet large volume demands. In the conventional construction market however, IFD is less embraced, due to the fact that industrial and uniform construction is regarded by commissioners as non-creative (Brand et al., 2003, p. 56).

Timber skeleton construction: Timber-based construction is the predominant construction method in many countries, among which the United States and Northern Europe. This technique is increasingly being used in both residential and industrial construction. Timber-frame buildings are economical to build compared to other materials, and allow more flexibility to changes during the use phase. Timber skeleton construction has proven its inherent strength and durability. Furthermore, off-site production of the beams and planks used for construction demands little labour, and therefore prevents waste from occurring during this activity. However, on-site activities are more labour-intensive, and create much waste due to manual cutting and sawing of the timber material. A timber skeleton frame provides a cost-effective, quickly assembled and adaptable construction method. Although this concept is far from new, it is still important in this research, due to the fact that the environmental impacts of this technique are much lower than those of other materials such as metals or plastics. Moreover, timber skeleton construction provides better opportunities for selective removal and recycling compared to other materials such as concrete or stone. However, the amount of waste occurring during on-site operations can be high, which require the development of a strict material management plan.

Glued timber: Glued timber (also called glulam), is a timber product composed of several layers of timber planks, bonded together with durable adhesives such as glue. By bonding several smaller pieces of timber, one single construction unit can be manufactured. Most of these glued units are used as vertical or horizontal supportive beams, but also as curved or arched shapes for rooftops. Glued timber construction is the only technique that can be applied for curved shapes, thereby offering more flexibility in design and refurbishment compared to other materials. With regard to its efficiency, glued timber construction optimizes the timber fiber quality. In fact, this technique upgrades the value of timber, because it makes use of smaller pieces that would otherwise be used for a lower-quality purpose. Due to its composition, glued timber beams can be manufactured from various types of smaller trees. Thereby, it avoids relying on the harvest of old growth-dependent solid timber logs, and increases timber use efficiency early in the production process. Additionally, it reduces the overall amount of timber required when compared to solid timber logs by preventing disposal of timber due to knots and small defects in the component (Sathre and O'Connor, 2010, p. 77; Smulski et al., 1997, p. 2).

Selective removal of timber products and materials for reuse or recycling: In relation to the design for reuse and recovery, the separate removal and reuse or recycling of construction timber is identified as a relevant option in reducing the amount of timber ending up in the waste stream. The selective removal of easily accessible timber products with added value such as supportive beams and planks, makes them susceptible for recycling into fencing, walls or floors. Removing them early in the demolition phase strongly reduces the amount of timber in the waste stream. The option of selective removal is not a novelty, but it is suggested by Goverse et al. (2001) that implementation of this option can result in large efficiency gains (p. 54). In increase the impact of this option, timber waste management can be improved to cover not only on-site practices, but also down-stream processes such as timber treatment. This option involves cooperation between various actors including demolition agencies, recycling companies, and producers of timber-based panels, branch organizations and public authorities. Cooperation between these actors is crucial in encouraging selective removal and recycling of used timber, to Separate removal of, for example, supportive beams can be sawn into timber floor elements or fencing, which extends their lifespan drastically as opposed to direct incineration or land filling. Despite the lack of exact data on the potential impact of this option, it is assumed that separate removal of timber can increase the use efficiency to a large extent considering that, on a European level, 72% of construction timber is incinerated as mixed waste (EC, 1999). There are large variations in the fractions directed towards landfills among countries. This means that the impacts of more strict rules and regulations imposed on land filling will vary extremely.

Table 7: Efficiency gains of technical options for construction in the EU-27

Technical options Construction (14%)	Options that require little or no behavioral change	Options that require behavioral change	Actors involved	Estimated potential impact on use efficiency	References
Design for off-site construction	- Replacing timber-based construction material with carbon or plastic material	- Prefabricated roof-, wall- and floor elements	Licensing authorities; housing associations; designers; construction engineers; contractors; branch organizations; knowledge brokers	40-50% (estimate)	EC (1999); Tjeerdsma and Klaassen (2010); Villanueva et al. (2010)
Design for reuse and recovery		- Selective removal of timber products and materials for reuse and recycling - Application of timber waste in timber-based panels industry (MDF and OSB) - Application of timber waste for composite materials	Demolition contractors, recycling companies, timber-based panel industry, branch organizations, knowledge brokers	10-15% (estimate)	Fraanje (1998); Goverse et al. (2001); Tjeerdsma and Klaassen (2010) Villanueva (2010);
Design for deconstruction and flexibility		- IFD (industrial, flexible and Detachable) system	Commissioning authorities, designers, off-site manufacturers, contractors, demolition contractors	5-20% (estimate); little data available due to innovative nature of this option	Van Den Brand et al. (2003); Lehmann (2011); Goverse et al. (2001)Tjeerdsma and Klaassen (2010).
Design for waste efficient procurement	- Limiting or banning landfills - Restricting subsidies for incineration with energy recovery	- Timber skeleton construction	Public authorities, demolition contractors, companies	20-30; based on data about the use of timber material for reuse and recycling	Environmental Assessment Agency (2011); Eurostat (2011)
Design for materials optimization		- Glued laminated timber construction		10-20%; based on data about the use of upgraded timber	Baldwin et al. (2008)

4.11 Concluding remarks

In this chapter, the technical potential of various options to increase the efficiency of timber use across the three main industries of paper and pulp, packaging and construction has been assessed. As can be concluded from the literature assessment, the most substantial efficiency gains can be achieved in the construction industry. Therefore, the scope of this research narrows down to this sector. In the following chapter, it will be investigated to what extent the options, which are drawn from the five principles of waste reduction and material optimization presented in table 5 are implemented (WRAP, 20120, p. 14). In doing so, it can be determined whether there is a gap between the technical potential of these options to improve timber use efficiency and actual implementation practices, and what factors can explain this gap. These factors will be reflected on in the conclusions and discussion.

5 Results I: Analysis of scorecard

5.1 Introduction

In the previous chapter, the technical options have been specified together with their potential to reduce construction waste. In the following two chapters (five and six), the feasibility of their practical implementation will be assessed by using the data obtained during the interviews. The data generated by the interviews and scorecard will provide insights on the opportunities and barriers of implementation in a qualitative and quantitative manner. In this section, the analysis starts with assessing the results obtained through the scorecard, which is used to indicate the respondents' perspective on the importance of each option to improve timber use efficiency, as well as the difficulty to implement them. In doing so, it is the aim of this analysis to determine which technical options are regarded as important, and how they correlate with a certain level of implementation difficulty. Figure 10 illustrates the format used to generate the results of this scorecard. The low / high importance in waste reduction refers to whether a certain technical option makes a small / large contribution to waste reduction throughout the construction process as seen by the actors operating in the construction industry. Difficulty of implementation refers to whether certain factors (e.g. power and resources for implementation, attitude, communication with other stakeholders, economic conditions etc) promote or limit the adoption of certain technical options. The options that have a high impact on waste reduction must then be studied in greater detail, so that only those options that are the most beneficial to the construction industry are taken forward and considered by policy makers, companies and organizations (WRAP, 2010, p. 45).

A survey document was sent to a total of 35 respondents, including actors from the public sector, market parties, branch organizations and knowledge brokers. The group of respondents consisted of four licensing authorities, four commissioning authorities, four designers, four building contractors, four branch organizations, and five research agencies. Although 22 respondents agreed on conducting the interview, the total number of complete responses on the scorecard was 12. The main reason for no- or incomplete response rate is that respondents do not perceive the scorecard to be applicable to their position in the construction industry, or their practices. This applied mainly for the licensing authorities and branch organizations. This could be explained by the fact that the actors who are not directly involved in the use of technical options tend to be less informed about their importance and implementation. On this scorecard, respondents were given the opportunity to reflect their attitude towards the importance and implementation difficulty of each of the five technical options. For both parameters, values range from 1 to 5. A value of 1 or 2 reflects a low importance, whereas a value of 3 corresponds with a 'neutral' importance, and a value of 4 or 5 relates to a 'high' importance. As for the perceived implementation difficulty, a value of 1 or 2 reflects a 'low' implementation difficulty, whereas a value of 3 is labeled as 'neutral', and a value of 4 or 5 as 'highly difficult'. Table 8 and figure 11 depict the average scores on the importance and implementation difficulty per technical option, as perceived by the actors operating in the construction industry.

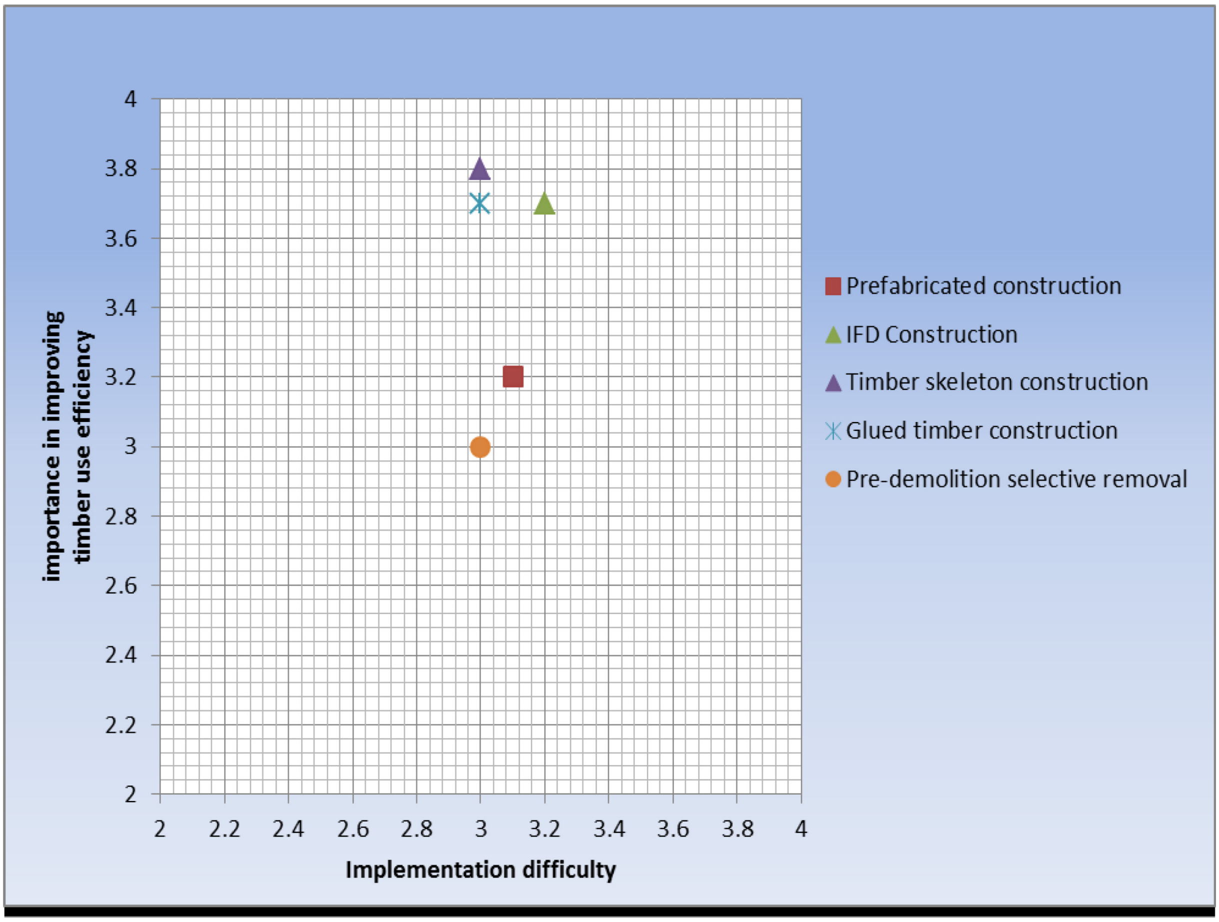
Table 8: Average scores on importance and implementation difficulty per technical option

Technical option	Estimated potential on timber use efficiency (%)	Average importance of each technical option	Average implementation difficulty per technical option
Prefabricated construction	40-50	3,2	3,1
IFD construction	10-15	3,7	3,2
Timber skeleton construction	5-20	3,8	3,0
Glued timber construction	20-30	3,7	3,0
Pre-demolition selective removal	10-20	3,5	3,0

Source: based on scorecard results

Table 8 demonstrates that technical options with a large potential to increase timber use efficiency are not necessarily perceived as more important than options with a lower potential. Moreover, the actors regard all technical options as almost equally difficult to implement, regardless their potential to improve timber use efficiency. Figure 11 depicts these results in a graph.

Figure 11: Relevance vs. difficulty grid



As demonstrated by the results in figure 11, the technical options do not deviate from each other; with regard to their importance, values range from 3,2 for prefabricated construction, to 3,8 for timber skeleton construction. With regard to their implementation difficulty, values range from 3 for timber skeleton construction, glued timber construction and pre-demolition removal, to 3,2 for IFD construction. The scorecard results demonstrate that there is no clear relationship between the importance of technical options in improving timber use efficiency, and the difficulty to implement them. This means that options which may have a large impact on timber use efficiency, are not necessarily difficult to implement compared to options with a low impact. Interestingly however, the most important conclusion that can be drawn based on these outcomes is that technical options that have already been implemented are considered to be more important in reducing timber waste than more innovative options. The results demonstrate that traditional on-site timber skeleton construction, which was regarded as more important than the more innovative option of prefabricated- or IFD construction, which were assigned scores of respectively 3,8 and 3,5. Although more research is required at this point, it could be distilled from the interviews that actors are better aware of the technical options that have already been in use for decades, as opposed to newer options that are still in development.

Tables 9 to 13 provide a detailed overview of the variations in attitudes between the different subgroups of actors, or about the factors that influence the feasibility of the various technical options. In order to obtain insight in these issues, the scorecard results are further specified per actor group. This results in an overview of which actor groups regard which factors to be important in determining the feasibility of improving timber use efficiency in the construction industry. Table 9 to 13 depict the average results per actor group. The eight factors that were drawn from the actor-based, institutional and policy content features in the governance framework, are used to determine the feasibility of implementing each technical option.

5.2 Prefabricated construction

Table 9: Scorecard results for prefabricated construction per actor group

Factor	Average implementation difficulty per actor group (0= no barrier; 5= large barrier)						Average implementation difficulty per factor (0= no difficulty, 5= high difficulty)
	L.A.	C.A.	Des.	Cont.	B.O.	K.B.	
Costs and benefits related to investing in technical option	4	4	2,7	3	2,5	1	2,9
Attitude towards technical option	2	2	2,7	4	3,3	2	2,7
Cooperation between actors in implementing or improving technical option	3	2	3,3	2	2	2	2,4
Adaptive capacity of market parties to implement technical option in construction practices	3	3	3,7	3	2,3	2	2,8
Innovative capacity of clients / designers / contractors	2	2,5	3	3	2,8	4	2,9
Rules and regulations with regard to implementation of technical option	2	2	2,7	5	2,5	3	2,9
Knowledge distribution about advantages and disadvantages of technical option	2	1,5	3	1	2,8	2	2,1
Costs of pre-demolition removal of timber products and materials for reuse and recycling	1	2	2	1	2,5	1	1,6
Average implementation difficulty score per actor group (0= no difficulty; 5= full difficulty):	2,4	2,4	2,9	2,8	2,6	2,1	

L.A.: Licensing Authorities
C.A.: Commissioning Authorities
Des.: Designers
Cont.: Contractors
B.O.: Branch Organizations
K.B.: Knowledge Broker

With regard to prefabricated construction, it appears that all actors involved in this research do not perceive the implementation of prefabricated timber construction as problematic, nor do they regard this option as a significant opportunity; values range from 2,1 for knowledge brokers, to 2,4 for licensing authorities, and 2,9 for designers. There are a few factors that play an important role in explaining the differences in attitude between market parties and the scientific community. First, private actors experience a lack of cooperation between commissioning authorities, designers and contractors to improve material efficiency. Another factor that explains the difference in attitude between private actors and the scientific community is the adaptive capacity of private actors to implement prefabricated construction as a means to improve timber use efficiency. Scientists hold a more positive perspective on the ability of market parties to adopt prefabricated construction than private actors. This can be explained as the difference between the ‘thinkers’ and ‘do-ers’; whereas scientists are not directly involved in the implementation process of innovations, they have a limited view on the practical barriers that private actors are confronted with. This viewpoint was supported by most market parties, including commissioning authorities, designers, contractors and branch organizations. Despite these variations, there is a shared vision on the opportunities of improving timber use efficiency: most actors agree on the opportunity provided by the low costs of selective removal of timber products and materials prior to demolition; on average, actors attached a value of 1,6. This implies that both public and private actors, as well as the scientific community, believe this factor to have a positive impact on improving timber use efficiency throughout the construction industry.

5.3 Industrial, Flexible and Demountable (IFD) construction

Table 10: Scorecard results for IFD construction per actor group

Factor	Average implementation difficulty per actor group (0= no barrier; 5= large barrier)						Average implementation difficulty per factor (0= no difficulty, 5= high difficulty)
	L.A.	C.A.	Des.	Cont.	B.O.	K.B.	
Costs and benefits related to investing in technical option	4	4	3	1	3,3	1	2,7
Attitude towards technical option	3	2,5	3,3	3	3,3	2	2,9
Cooperation between actors in implementing or improving technical option	3	2	2,7	3	1,5	2	2,4
Adaptive capacity of market parties to implement technical option in construction practices	3	3	2	2	2,8	2	2,5
Innovative capacity of clients / designers / contractors	4	3,5	2,7	3	2,8	4	3,3
Rules and regulations with regard to innovations in construction	3	3	2,7	4	2,3	3	3
Knowledge distribution about advantages and disadvantages of technical option	3	2,5	3	2	2,3	2	2,5
Costs of pre-demolition removal of timber products and materials for reuse and recycling	2	2	1,7	1	3,5	1	1,9
Average implementation difficulty score per actor group (0= no difficulty; 5 full difficulty)	3,1	2,8	2,6	2,4	2,8	2,1	

L.A.: Licensing Authorities
C.A.: Commissioning Authorities
Des.: Designers
Cont.: Contractors
B.O.: Branch Organizations
K.B.: Knowledge Brokers

With regard to IFD construction, the results show some degree of variation among public actors, market parties and scientists. Whereas the licensing authorities maintain a neutral perception towards the improvements that can be made with the technical option under study, market parties (2,4-2,8) and scientists (2,1) maintain a more positive attitude. According to the licensing authorities, initial investment costs and the innovative capacity of private actors impose barriers on the implementation of IFD construction. Market parties including commissioning authorities, designers and contractors regard the conservative character of the construction industry as a barrier to innovation. In addition, many private actors argue that contractors are lacking the capacity to include material efficiency considerations in their practices. This viewpoint is supported by scientists, who argue that contractors are lacking innovative capacity due to their focus on the cost price of construction. It was frequently mentioned during interviews with representatives from the scientific community, that the lack of innovative capacity and the conservative attitude of market parties is directly linked to the strong focus on price competition between contractors. In order to provide incentives for improving timber use efficiency, scientists argue that the selection process must be based on material efficiency, rather than on cost price. Equal to the earlier technical options under scrutiny, the costs of pre-demolition removal of timber products and materials are regarded as the best opportunity for improving timber use efficiency.

5.4 Timber skeleton construction

Table 11: Scorecard results for timber skeleton construction per actor group

Factor	Average implementation difficulty per actor group (0= no barrier; 5= large barrier)						Average implementation difficulty per factor (0= no difficulty, 5= high difficulty)
	L.A.	C.A.	Des.	Cont.	B.O.	K.B.	
Costs and benefits related to investing in innovative construction techniques	4	3,5	3,3	1	3,5	1	2,7
Attitude towards innovative construction techniques	3	2	3,3	3	3	2	2,7
Cooperation between actors in implementing or improving technical option	3	2	3	3	1,3	2	2,6
Adaptive capacity of market parties to implement or improve use of technical option in construction practices	3	2	3	2	2	2	2,3
Innovative capacity of clients / designers / contractors	4	3	3	3	2,3	4	3,2
Rules and regulations with regard to technical option	2	2,5	2	4	2,3	3	2,6
Knowledge distribution about advantages and disadvantages of technical option	3	2,5	2,3	2	3,8	2	2,6
Costs of pre-demolition removal of timber products and materials for reuse and recycling	3	2,5	2,7	2	3,3	1	2,8
Average implementation difficulty score per actor group (0= no difficulty; 5 = full difficulty)	3,1	2,5	2,8	2,5	2,3	2,1	

L.A.: Licensing Authorities
C.A.: Commissioning Authorities
Des.: Designers
Cont.: Contractors
B.O.: Branch Organizations
K.B.: Knowledge Brokers

Timber skeleton construction, a more widely used option in timber-based construction, is regarded as a technique that has proven its usefulness in construction throughout the last decades. The results with respect to this option are roughly equal to those for IFD construction; licensing authorities are more sceptical than market parties and scientists , referring to the lack of innovative capacity and the generally conservative attitude towards innovations. Interestingly, private actors regard the use of timber skeleton construction as a feasible option. This can be explained by the fact that this technical option is not considered a novelty within the construction sector. However, further research and development in material efficiency of this option is limited by the conservative attitude of market parties; interviews held with private actors indicated that the use of timber is frequently associated with high maintenance costs and therefore not widely used as a major construction material. The scientific community regards timber skeleton construction as a significant contribution to improving timber use efficiency. During interviews, various scientists supported this claim by arguing that the costs related to further product development and pre-demolition removal are neglectible compared to the efficiency gains that can be achieved by using this option. On the contrary, the scientific community regards the lack of innovative capacity on the side of market parties as a limitation on further improvements of timber-based construction. According to them, the transfer of knowledge to private actors involved in construction is limited, due to the lack of cooperation between market parties and researchers. According to various scientists involved in construction, the establishment of a cooperative network in which knowledge transfer between researchers and market parties is encouraged, is key to increase the innovative capacity of private actors to adopt timber skeleton construction.

5.5 Glued timber construction

Table 12: Scorecard results for glued timber construction per actor group

Factor	Difficulty score per actor group (0= no barrier; 5= large barrier)						Average implementation difficulty per factor (0= no difficulty, 5= high difficulty)
	L.A.	C.A.	Des.	Cont.	B.O.	K.B.	
Costs and benefits related to investing in technical option	4	3,5	3,3	1	3,5	1	2,7
Attitude towards technical option	3	2	3,3	3	3	2	2,7
Cooperation between actors in implementing technical option	3	2	3	3	1,3	2	2,3
Adaptive capacity of market parties to implement or improve use of technical option in construction practices	3	2	3	2	2	2	2,3
Innovative capacity of clients / designers / contractors	4	3	3	3	2,3	4	3,2
Rules and regulations with regard to implementation of technical option	2	2,5	2	4	2,3	3	2,6
Knowledge distribution about advantages and disadvantages of innovative construction techniques	3	2,5	3	2	2,8	2	2,6
Costs of pre-demolition removal of timber products and materials for reuse and recycling	3,1	2,5	2,7	2	2,6	1	2,8
Average implementation difficulty score per actor group (0= no difficulty; 5 full difficulty)	3,1	2,5	2,9	2,5	2,6	2,1	

L.A.: Licensing Authorities
C.A.: Commissioning Authorities
Des.: Designers
Cont.: Contractors
B.O.: Branch Organizations
K.B.: Knowledge Brokers

Scorecard results for glued timber construction indicate smaller variations among the different actor groups. Licensing authorities perceive this technical option as rather neutral; on average, public actors valued the feasibility of this technical option a 3,1. From their viewpoint, the investment costs and lack of innovative capacity of market parties to adopt glued timber construction are the main barriers that limit the feasibility of this option. Although market parties do not show significant differences, they maintain a slightly more positive view with regard to the implementation of this technical option. Reflecting on the outcomes in table 12, it can be concluded that market parties identify two major factors that serve as incentives for implementation: first, cooperation between actors throughout the implementation process is regarded as an incentive for implementation. Second, market parties view themselves as capable of adopting this technical option in construction projects. Interestingly, market parties perceive the innovative capacity of the construction industry to be a barrier to innovation. A possible explanation for this is provided by the interviews conducted with private actors. Throughout these interviews, commissioning authorities, designers and contractors frequently blame each other for non-cooperation and a general lack of innovative capacity to implement innovative construction techniques, while emphasizing their own willingness to commit to improving material efficiency. Knowledge brokers maintain the most positive attitude towards glued timber construction; they valued this technical option a 2.1. their main arguments for this are the low investment costs related to the implementation process and pre-demolition removal of timber materials. It was assumed during various interviews with scientists that private parties are lacking the innovative capacity to translate the research conducted by scientists into tangible construction projects. Consequently, they mentioned that this lack of knowledge transfer resulted in a discrepancy between the viewpoints of private parties and the scientific community towards the feasibility of implementation.

5.6 Selective removal of timber products and materials

Table 13: Scorecard results for selective removal of timber products and materials for reuse and recycling per actor group

Factor	**Difficulty score per actor group (0= no barrier; 5= large barrier)**						Average implementation difficulty per factor (0= no difficulty, 5= high difficulty)
	L.A.	**C.A.**	**Des.**	**Cont.**	**B.O.**	**K.B.**	
Costs and benefits related to investing in technical option	4	4	2,7	1	2,3	4	3
Attitude towards innovative construction techniques	2	2,5	3	3	1,7	4	2,7
Cooperation between actors in implementing or improving technical option	2	1,5	2,7	3	1,2	2	2,1
Adaptive capacity of market parties to implement technical option in construction practices	3	2	3	3	2	4	2,8
Innovative capacity of clients / designers / contractors	3	2,5	3	4	2,7	5	3,4
Rules and regulations with regard to technical option	2	2,5	3,3	5	2,7	4	3,3
Knowledge distribution about advantages and disadvantages of technical option	3	2,5	2,7	3	1,7	3	2,3
Costs of pre-demolition removal of timber products and materials for reuse and recycling	4	3	2,3	2	2,3	1	2,4
Average implementation difficulty score per actor group(0= no difficulty; 5 full difficulty)	2,9	2,6	2,8	3	2,1	3,4	

L.A.: Licensing Authorities
C.A.: Commissioning Authorities
Des.: Designers
Cont.: Contractors
B.O.: Branch Organizations
K.B.: Knowledge Brokers

With respect to the selective removal of timber products and materials prior to demolition, there are relatively small variations between the public sector, market parties and researchers. Licensing authorities and market parties have a neutral perspective on the implementation of selective removal of timber products and materials (2,9), whereas knowledge brokers (3,4) take a less positive stance. The licensing authorities appear to regard the investment costs in improving pre-demolition removal, reuse and recycling practices as the main barrier to further development of reuse and recycling opportunities. As can be concluded from the results in table 13, licensing authorities view their role as legal context setter as an opportunity for implementation; the rules and regulations with regard to implementation of selective removal received a value of 2. Private actors see two factors as major incentives for improving timber use efficiency through selective removal of used timber. First, cooperation between actors in implementing selective removal of timber is regarded as sufficient to maintain a reuse and recycling system. Second, the adaptive capacity of market parties to implement technical option in construction practices. Although most actors regard the system for selective removal of used timber as successful, the results require further explanation at this point. Although timber products and materials are separated prior to demolition, it can be concluded from various interviews with contractors and researchers that these products and materials are mainly used for incineration with energy recovery, and plywood industry. The results demonstrate that the scientific community supports the market parties, to the extent that cooperation between actors is sufficient to implement selective removal of used timber. However, their main concern is that private actors are lacking the innovative capacity to make better use of the quality of used timber. From interviews with researchers, it was frequently argued that market parties can cut production costs by reusing timber products and materials instead of using virgin material. Additionally, the results in table 13 support this claim; on average, researchers attached a value of 1 to the costs of pre-demolition removal of timber products and materials.

5.7 Synthesis of results

The scorecard analysis provides us with interesting details about the character and attitude of different actor groups towards the issue of timber use efficiency, which allows us to draw conclusions on the overall feasibility of improving timber use efficiency in the construction industry.
The results demonstrate that certain factors play a consistent role among all technical options in determining the feasibility of their implementation. Examples of these factors are the investment costs related to implementation, low innovative capacity of market parties, cooperation between actors and knowledge distribution. When reflecting on the perception of the different actor groups towards the implementation difficulty of the technical options, certain patterns can be discovered within each actor group. With respect to the licensing authorities, it appears that three factors are perceived as barriers to the implementation of technical options. First, the lack of cooperation between actors and the limited capacity of market parties to properly adopt technical options appears to be a weakness in improving timber use efficiency. The third factor refers to the initial investment costs of implementing new, or improving existing technical options. An interesting outcome is the fact that public actors have a positive view on their role as context setter, creating the rules and regulations for the construction industry. This vision is quite the opposite of market parties, who emphasize the lack of public involvement in encouraging timber use efficiency, and characterize them as conservative. According to market parties, the rules and regulations imposed on the construction industry are not focused towards improving materials efficiency in general, and is therefore regarded as a barrier. As opposed to licensing authorities, the scorecard results indicate that private actors view cooperation and innovative capacity of businesses involved in commissioning and contracting as major incentives for improving timber use efficiency. Among all

actor groups, the scientific community identified the most factors as opportunities for improving timber use efficiency. In their vision, both public and private actors need to change their focus in order to increase timber use efficiency. In line with the private actors, they regard the rules and regulations created by the licensing authorities as an important barrier to innovation. Scientists support their claim by arguing that policy makers fail to include efficiency considerations in their policy decisions. The current policy environment focuses mainly on reducing energy consumption during the use phase of buildings, thereby overlooking waste flows that are generated throughout the construction process. With respect to the private sector, scientists emphasize the lack of innovative capacity of commissioning authorities, designers and contractors to adequately address timber use efficiency. From various interviews with researchers, the problematic transfer of knowledge into tangible action. Despite the fact that there is substantial research available on how timber use efficiency can be improved, commissioning and contracting agencies show little progress in the adoption of knowledge.

Table 9 to 13 presented the main viewpoints of public authorities, market parties and the scientific community in terms of opportunities and barriers. By using a scorecard, an attempt was made to carefully determine the perspectives of the actors towards the issue of timber use efficiency in the construction sector. This has led to indications of which factors serve as incentives or disincentives for addressing this issue. On the public side of this analysis, rules and regulations play an important role in explaining the progress in improving timber use efficiency. Within the private domain, it was concluded that adaptive capacity and cooperation are major features that explain change. If agencies would exercise the ability to adopt innovations and cooperate in a skilful manner, the transition towards more efficient timber use can be achieved (Avelino and Rotmans, 2011, p. 796). Within the knowledge domain, the level of knowledge distribution is regarded as the most influential feature. According to scientists, commissioning and contracting agencies need to make better use of its capacity to learn from successes and failures with technical options, and to adjust their practices based on these lessons (Folke et al., 2005, p. 445). This section analyzed the factors that act as opportunities and barriers to improving timber use efficiency, by studying different timber-based technical options. However, if we want to explain why certain factors act as opportunities or barriers to improvement, or which (causal) relationships exist between actors, more systematic research is needed. Therefore, the following section will investigate these opportunities and barriers, by focusing on the actor-based, institutional- and policy features presented in the governance framework in chapter three.

6 Results II: Opportunities and barriers

6.1 Introduction

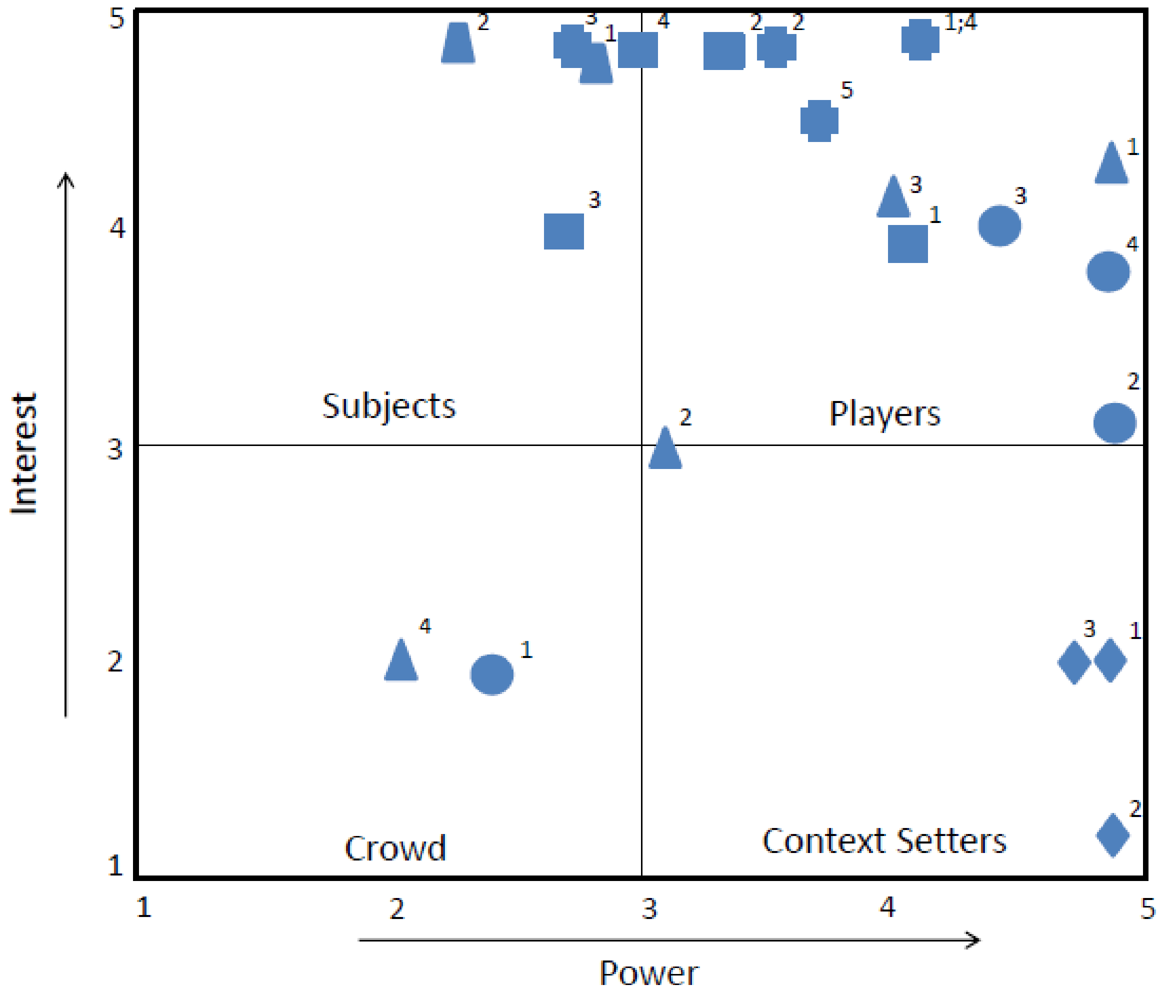
In this second analytical chapter, the results from the interviews are assessed by using the actor-based-, institutional- and policy features identified in the governance framework. The interviews provide a more detailed analysis of the main incentives or disincentives for actors to address the issue of timber use efficiency, with regard to actor-based characteristics, the institutional environment, and the policy context.

6.2 Actor-based features

The actor-based features aim to describe the characteristics of the single actor: Interests, power and resources, initiating potential, and contact with other stakeholders. Together, these aspects reflect the ability of actors to adopt technical options, and its position in relation to other actors. The starting point is the identification of Interests, because they reflect the intentions and behavior patterns of an actor, aimed at influencing the governance process. Power and resources describe the financial, physical and intellectual resources an actor possesses, and its power to mobilize these resources to achieve a certain goal. The initiating potential refers to the willingness of an actor to experiment with new phenomena, and to encourage other actors to do the same. The contact with other actors reflects the ability to engage in collective action to solve the barriers that limit the implementation of technical options. For each factor of the first two clusters (actor based- and institutional factors), all actors involved in the construction industry will be described in the following order: commissioning authorities, designers, contractors, branch organizations, and knowledge brokers.

Based on the interviews conducted with actors within the public, private and scientific domain, insights are obtained on their interests in participation, power, resources and contact with other actors. To be better able to condense the information provided by the actors, the qualitative information provided by the actors with regard to these features will first be assessed as 'low', 'medium' or 'high'. In order to determine the position of each actor in the power-versus-interest grid, these results will be assigned a quantitative value, ranging from 1 to 5. In practice, this means that the qualitative value of 'low' corresponds with the quantitative value of 1, 'low-to-medium' with a value of 2, 'medium' with a value of 3, 'medium-to-high' with a value of 4, and 'high' with a value of 5. The axes of the power-versus-interest grid are numbered accordingly.

Figure 12: Roles of actors in terms of power and interest



Source: Adapted from Bryson (2004, p. 30)

Actor group	**No. of actors**	**Symbol**	**Actors**	**Stakeholder position**
Licensing authorities	4	▲	Municipalities of Utrecht; Amersfoort; Zoetermeer; Delft	Partly Players, Context setters, Crowd
Commissioning authorities	3	◆	Housing associations Ymere; Rochdale; Eigen Haard	Context setters
Designers	4	●	Zecc Architects; LAM Architects; Greiner & Van Goor Huijten; Van der Breggen Architecten	Mainly Players, partly Crowd
Contractors	2	⏢	De Groot Vroomshoop; Schijf Groep	Subjects
Branch organizations	4	■	Centrum Hout; NBvT; BRBS; Veras	Mainly Players, partly Context Setters
Knowledge brokers	5	✚	TNO; Probos; Stichting Hout Research; Nyenrode Business University; W / E Advisors	Players

From the 'power-versus-interest' grid depicted in figure 14, it can be concluded that there are large variations among actors with regard to the interest in improving timber use efficiency, and the power to influence the progress of timber efficiency (Bryson, 2004, p. 22). At first sight, it can be inferred that the majority of the actors can be positioned as 'Players', which demonstrates a high level of interest in improving timber use efficiency, and a high level of resources and power to influence the construction industry. In order to obtain a better view of the feasibility of creating a coalition, the positions of the actor groups will be addressed individually.

It can be concluded from the grid that two out of four licensing authorities interviewed can be positioned as 'Players'. During the interviews with these actors, these actors demonstrated a high level of interest in timber use efficiency by their cooperation with research agencies to improve material efficiency. Furthermore, these actors appeared to have developed extended policy programs, with the aim to achieve policy goals that are higher than those imposed by the national government. These signs of involvement are prove of a high level of both interest and power, which makes them suitable partners in a collaborative network. However, the other two licensing authorities were characterized as a context setter and crowd. These actors demonstrated a low level of interest in addressing timber use efficiency, and their focus on material efficiency was limited to setting policy goals with regard to national policies in this field.

Table 14: Actor-based features of licensing authorities

A. Actor				B. Actor Position	C. Interests in participation		D. Resources		E. Power (ability to mobilize resources)		F. Regular contact with other actors	
A1. Actor Name	A2. Role	A3. Ambitions with regard to construction industry	A4. Status of involvement		Value		Value		Value		Value	
					Qual.	Quant.	Qual.	Quant.	Qual.	Quant.	Qual.	Quant.
1. Municipality of Utrecht	Licensing authority	Setting rules and regulations for construction	Actual	Supporter	High	5	High	5	Medium	3	High	5
2. Municipality of Amersfoort	Licensing authority	Setting rules and regulations for construction	Actual	Supporter	Medium	3	Medium	3	Medium	3	Medium	3
3. Municipality of Zoetermeer	Licensing authority	Setting rules and regulations for construction	Actual	Supporter	Medium/ High	4	High	5	Medium	3	High	5
4. Municipality of Delft	Licensing authority	Undisclosed	Potential	Medium supporter	Low/ medium	2	Undisclosed		Undisclosed		Undisclosed	

Source: stakeholder interviews

All three commissioning authorities are positioned as context setters. During the interviews, these actors expressed a moderate interest in improving timber use efficiency, and high level of power in the design process. Considering to their role as project initiators, these firms play an important role in specifying material efficiency requirements towards designers and contractors, which gives them the opportunity to integrate options for improvement of timber use efficiency. It appeared that none of the commissioning authorities included requirements with regard to timber use efficiency. All three commissioning authorities included in this research require contractors to use only certified timber in implementing construction projects. The predominant view on timber use efficiency is a liberal one: commissioning authorities do not demand designers and contractors to integrate specific construction techniques in their project designs. Besides a thriving CSR policy with regard to the use of certified timber, commissioning authorities devote hardly any attention to material efficiency in their project specifications, which can be explained by the lack of responsibility towards the impacts of material use.

Table 15: Actor-based features of commissioning authorities

A. Actor				B. Actor Position	C. Interests in participation		D. Resources		E. Power (ability to mobilize resources)		F. Regular contact with other actors	
A1. Actor Name	A2. Role	A3. Ambitions with regard to construction industry	A4. Status of involvement		Value		Value		Value		Value	
					Qual.	Quant.	Qual.	Quant.	Qual.	Quant.	Qual.	Quant.
5. Ymere	Commissioning authority	Project implementation	Potential	Medium supporter	Low/ Medium	2	High	5	High	5	High	5
6. Eigen Haard	Commissioning authority	Project implementation	potential	Medium supporter	Low	1	High	5	High	5	High	5
7. Rochdale	Commissioning authority	Project implementation	potential	Medium supporter	Low/ Medium	2	High	5	High	5	High	5

Source: Stakeholder interviews

With regard to designers, the grid depicts three out of four actors in this group as 'Players'. Following the interviews, these actors demonstrated a moderate interest in optimizing timber use. In general, they are given a large degree of freedom by commissioning authorities, which allow them to choose whether or not to adopt certain technical options. Throughout the interviews, it appeared that most designers value esthetic values over timber use efficiency, and are primarily concerned with meeting the requirements of commissioning authorities. However, there is consensus among these three designers that they can play a decisive role in adopting innovative techniques to reduce the amount of timber used in construction, i.e. by 'designing out waste' (WRAP, 2010). This means that they recognize their responsibility in using and recycling timber in an efficient manner; all three designers said they explicitly integrate timber use efficiency in their practices, mainly through prefabrication, and the reuse and recycling of timber products and materials. Furthermore, it was concluded from the interviews with these actors that the designers that which demonstrated a high level of interest in participation and knowledge resources, are smaller in size and power. Interestingly, these actors expressed the need for participation of more powerful actors such as commissioning authorities, to increase the demand for projects in which technical options for timber use efficiency are included.

The designer that is positioned in the grid as 'Crowd' expressed no interest in timber use efficiency; he emphasized that his company does not seek to integrate material efficiency considerations in their project designs. Furthermore, this actor demonstrated a low degree of power due to its limited resources and contact with other designers or actors from other groups.

Table 16: Actor-based features of designers

A. Actor				B. Actor Position	C. Interests in participation		D. Resources		E. Power (ability to mobilize resources)		F. Regular contact with other actors	
A1. Actor Name	A2. Role	A3. Ambitions with regard to construction industry	A4. Status of involvement		Value		Value		Value		Value	
					Qual.	Quant.	Qual.	Quant.	Qual.	Quant.	Qual.	Quant.
8. Zecc Architects	Project Designer	No specific interest in timber use efficiency	Potential	Medium opponent	Low/ Medium	2	Medium	3	Medium	3	Low	1
9. LAM Architecten	Project Designer	Designing construction projects; Integrating cradle-to-cradle concept in project designs	Actual	Supporter	High	5	Low/ Medium	2	Medium	4	Medium	3
10. Greiner & Van Goor Huijten	Project Designer	Designing construction projects project designs	Actual	Supporter	Medium/ High	4	High	5	Medium	3	High	5
11. Maarten van der Breggen Architecten	Project designer	Designing construction projects	Actual	Supporter	High	5	Medium	3	Medium	3	High	5

Source: Stakeholder interviews

The two contractors can be positioned as 'Subjects', due to their high level of interest but moderate level of resources and power. This has mainly to do with the role that is assigned to contractors; the implementation of construction projects. In line with the designers, they argued that commissioning authorities must take the responsibility in increasing the demand for technical options that improve timber use efficiency, by selecting contractors based on their efficiency performance instead of cost price of construction. The contractors involved in this research are characterized by their 'bottom-up' approach of improving timber use efficiency; in addition to being dependent on the commitment of commissioning authorities, one of the two contractors is also involved in commissioning (Driessen et al., 2011, p. 14). The contractor explained that this is an alternative way to improve timber use efficiency which the other, smaller-sized contractor also adopted, but argued to have insufficient resources and power to implement the technical options. Therefore, commissioning authorities are considered an essential partner in improving timber use efficiency. Interestingly, this actor group has the lowest respond rate among all actor groups; only two out of the ten actors approached for this research agreed on conducting an interview. The other eight rejected the interview request, for reasons of a lack of interest in the research topic. Additional information with regard to this issue was provided by various actors from other groups. The first argument refers to the traditional nature of contractors. According to many actors, the level of commitment of contractors can be explained by the traditional nature of the Dutch construction market. According to mainly researchers, contractors argue that the adoption of new techniques demands additional investments in training and equipment, which imposes a barrier on implementing them. A researcher argued that very few contractors integrate technical options in their projects that result a reduction of use, reuse and recycling of timber-based materials[11]. In conclusion, it can thus be argued that market parties are pointing at each other to initiate action to

[11] Interview with TNO on 13-2-2012

improve timber use efficiency. Moreover, these actors seem to prioritize other considerations such as construction cost and energy pricing over timber use efficiency.

Table 17: Actor-based features of contractors

A. Actor				B. Actor Position	C. Interests in participation		D. Resources		E. Power (ability to mobilize resources)		F. Regular contact with other actors	
A1. Actor Name	A2. Role	A3. Ambitions with regard to construction industry	A4. Status of involvement		Value		Value		Value		Value	
					Qual.	Quant.	Qual.	Quant.	Qual.	Quant	Qual.	Quant.
12. De Groot Vroomshoop	Contractor	Using innovative techniques to manufacture construction components that can be reused, while minimizing waste	Actual	Supporter	High	5	Medium	3	High	5	Medium	3
13. Schijf Groep	Contractor	Extracting Construction components from demolition site for upgrading and reuse	Actual	Supporter	High	5	Low/ Medium	2	Low/ Medium	2	Medium	3

Source: Stakeholder interviews

The four branch organizations demonstrate large variations with regard to their level of power, resources and contact. Two of these actors are positioned as 'Players' with a high level of interest in participation, and substantial resources and power, whereas the other two are depicted as 'Subjects', with low power and resources. The two branch organizations that are characterized as 'Players' are considered more influential in the construction industry, because they serve as coordination hubs for their members, and promote interests of the companies that are operating in their branch. Due to the powerful function these branch organizations fulfill, they are highly suitable partners for forming coalitions with other actors.

The two branch organizations that are depicted as 'Subjects' demonstrated the need to improve the reuse and recycling of timber products and materials. These organizations are relevant partners, specifically for promoting the reuse and cascaded recycling of timber. However, their resources and power are limited, thereby constraining their voice in the process of improving timber use efficiency.

In order to obtain a better understanding of the position of branch organization in the construction industry, their function has to be explained. Branch organizations use an integral approach to the construction industry. This means that they do not initiate innovations in the construction industry, but monitor developments in the construction sector, and translate these into training and education programs associated to their branch. This gives branch organizations a central role in establishing cooperation with actors from both the public- and knowledge domain. According to a representative of a branch organization for timber manufacturers, there is a main barrier which limits the improvement of timber use efficiency. This barrier refers to the cooperation between actors: commissioning authorities, contractors and researchers do not cooperate in improving timber use efficiency. The interviews with branch organizations pointed out that the essence of these barriers lies foremost in the market-based economy. The construction industry does not seek to close product cycles, but simply responds to price fluctuations. As long as the price of virgin timber remains low, there is no incentive to improve timber use efficiency. Another concern expressed by the branch organizations involved in demolition and recycling, refers to the role of public actors in the construction industry. Currently, the public policy regarding sustainable energy production encourages the incineration of used timber, instead of its reuse and cascaded recycling. In order to avoid adverse effects of this policy program on timber use efficiency, branch organizations emphasize the involvement of public authorities in coalition forming. Public authorities can create the conditions under which it becomes more attractive to take an integral approach to timber use. However, branch representatives argue that the impact of this development on timber use efficiency is still uncertain.

Table 18: Actor-based features of branch organizations

A. Actor				B. Actor Position	C. Interests in participation		D. Resources		E. Power (ability to mobilize resources)		F. Regular contact with other actors	
A1. Actor Name	A2. Role	A3. Ambitions with regard to construction industry	A4. Status of involvement		Value		Value		Value		Value	
					Qual.	Quant.	Qual.	Quant.	Qual.	Quant.	Qual.	Quant.
14. NBvT	Branch organization	Promoting collective interests of branch	Actual	Supporter	Medium/ High	4	Medium-High	4	Medium	3	High	5
15. Centrum Hout	Branch organization	Collecting and distributing knowledge, platform of communication between actors	Actual	Supporter	High	5	Low/ Medium	2	Medium	3	High	5
16. Veras	Branch organization	Promoting collective interests of branch	Actual	Supporter	Medium-High	4	Low/ Medium	2	Medium	3	Medium	3
17. BRBS	Branch organization	Promoting collective interests of the branch	Actual	Supporter	High	5	Medium	3	Medium	3	Medium	3

Source: Stakeholder interviews

Four out of five knowledge brokers can be positioned as 'Players', which are characterized by a high degree of interest in participation, knowledge resources, power and contact with interaction with other actors. These actors have a high interest in improving timber use efficiency, through the research and development of innovative techniques. The research institutes included in this research are involved in a large variation of activities, ranging from the development technical manuals and calculation instruments for determining sustainability performance of construction, to conducting on-site research to reduce building construction time. Researchers argue that these studies create opportunities for the use of prefabricated- and IFD construction. An important strength of research agencies related to the construction industry is that they are involved in each segment (i.e. from design to demolition) of the construction process. Therefore, research institutes are a potential partner in forming coalitions with all actor groups involved in the construction sector. Researchers act as a facilitator of knowledge and expertise about the technical options that can be used for improving timber use efficiency, by informing commissioning authorities, designers and contractors about sustainable use of wood as a construction material. As can be concluded from table 19, all knowledge brokers deal with a low level of power to mobilize their knowledge resources (i.e., all knowledge brokers were assigned a value of 2 for their level of power) In practice, this means that the distribution of knowledge throughout the construction industry is heavily constrained. All actors in the research domain argued that the main driver for this issue is the temporary, project-based cooperative networks of actors. The changing constellation of actors ignores the fact that knowledge distribution is best maximized by extending the professional and financial involvement of commissioning, designing and contracting actors beyond individual construction projects (Spoerri et al., 2009, p. 593).

Table 19: Actor-based features of knowledge brokers

A. Actor				B. Actor Position	C. Interests in participation		D. Resources		E. Power (ability to mobilize resources)		F. Regular contact with other actors	
A1. Actor Name	A2. Role	A3. Ambitions with regard to construction industry	A4. Status of involvement		Value		Value		Value		Value	
					Qual.	Quant.	Qual.	Quant.	Qual.	Quant	Qual.	Quant.
18. Probos	Knowledge broker	Timber research and product development	Actual	Supporter	High	5	High	5	Low/ Medium	2	High	5
19. Stichting Hout Research	Knowledge broker	Timber research and product development	Actual	Supporter	High	5	Medium/ High	4	Low/ Medium	2	High	5
20. W/E Adviseurs	Knowledge broker	Research and product development	Actual	Supporter	High	5	Medium	3	Low/ Medium	2	Medium	3
21. Nyenrode Business University	Knowledge broker	Participating in timber research in supply and construction	Actual	Supporter	High	5	High	5	Low/ Medium	2	High	5
22. TNO	Knowledge broker	Participating in timber use research	Actual	Supporter	High	5	High	5	Low/ Medium	2	High	5

Source: Stakeholder interviews

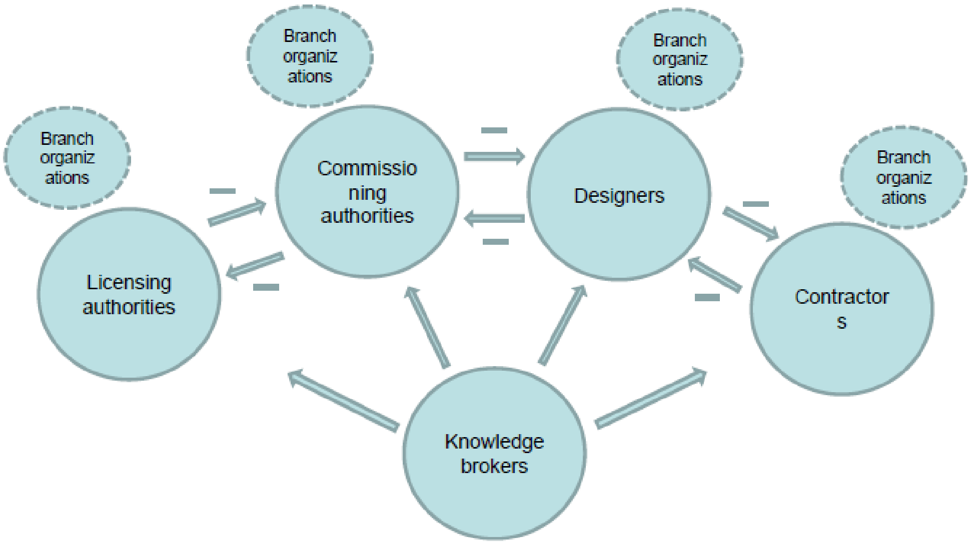
6.3 Synthesis of actor-based features

As can be seen in the grid, many actors are characterized by a high interest in participation in such a coalition; at least 20 out of the 22 actors involved in this research acknowledged that there are large efficiency gains to be achieved, and that collaboration is required in addressing this issue.
The 'power-versus-interest' grid in figure 12 demonstrates that there are substantial variations in the interests, resources, power and connections among the various actor groups involved in this research. Due to the fact that each actor group has its own specific actor-based characteristics, each actor group must be involved in creating a coalition for effectively addressing timber use efficiency. Licensing authorities are mainly positioned as 'Players', due to their involvement through creating the rules and regulations with regard to the construction industry. Additionally, some of these actors extend their commitment through the participation in research and development activities, which demonstrates their willingness to be involved in a collaborative network. Commissioning authorities are depicted as context setters, due to their high level of resources and power. In contrast, this group of actors seems to be less interested in addressing timber use efficiency, and emphasize their focus on energy costs instead of material efficiency. Designers and contractors, in the grid positioned

as moderate ‘Players’ and ‘Subjects’, expressed a high level of interest in creating a coalition of actors, but blame commissioning authorities for not including timber use efficiency as an integral part of construction projects. Although this perspective is common sense among all actors involved, contractors were regarded as having the most conservative attitude towards timber use efficiency; the largest contracting in the Dutch construction market refused commitment with this research. Knowledge brokers, mainly characterized as ‘Players’, pointed out that the gap that exists between the knowledge and production domain, due to the temporary nature of professional and financial involvement of actors in construction projects. According to various researchers involved in this research and governance literature (e.g. Sathre, R. and J. O’Connor (2010); Tykkä et al. (2010)), private firms involved in construction make little effort to encourage the accumulation and distribution of knowledge.

The interviews indicate that the knowledge and techniques required to build material-efficient construction is available, and the economic benefits of efficient design and demolition are well-known and documented in the literature used for this research. However, the most important barrier standing in the way of improving timber use is the non-alignment of incentives between those who provide buildings, and those who are going to use it. This is depicted in figure 13 as the “circle of blame” (Pearce, 2005, p. 481), a phenomenon that illustrates the competing priorities of actors. From the governance literature (e.g. Driessen and Glasbergen, 2000) it is understood that producers and consumers are interdependent. Producers need consumers to buy their products, and the consumer has no opportunity to change its behavior without the provision of products by the producer. In between the two groups, there is the retailer as a binding factor with his own priorities (p. 359). In the situation where designers and contractors seek to improve timber use efficiency in their construction-related practices, they often claim that commissioning authorities are not interested to fund such initiatives due to a difference in the configuration of priorities. Consequently, commissioning authorities are willing to integrate timber use efficiency considerations, but argue that licensing authorities do not provide them with incentives to do so. Vice versa, licensing authorities claim the market-based regulated construction process limits their power to impose efficiency requirements on commissioning authorities. Moreover, these actors blame the lack of interest in material efficiency on the side of designers and contractors. Knowledge brokers position themselves on the sideline of this circle of blame, and seek to create a cooperative network in which actors have a shared responsibility in improving timber use efficiency. In practice, it appears that this circle can only be broken by involving all actors ranging from design to demolition in order to establish cooperation and have a uniform understanding of how timber use efficiency can be achieved. A lack of cooperation and knowledge exchange about the economic benefits of certain construction techniques to optimize timber use limits the opportunities for implementation. The lack of cooperation and knowledge exchange explains to a large extend the traditional nature of contractors to include innovative timber construction techniques in their practices. These are aspects that have so far been neglected by both firms and policy makers, but can create opportunities for adopting efficient timber use techniques if properly addressed. According to Pearce (2005), a “virtuous loops of feedback and adaptation” can then be created within the construction industry and moreover, a rethinking in terms of communication over and marketing of innovative timber construction techniques p. 483). The following paragraphs will demonstrate how the circle of blame results in a lack of shared problem perception and non-alignment of priorities between actors

Figure 13: Circle of blame in the construction industry



Source: Based on Pearce (2005, p. 481)

Furthermore, it was argued by many actors that the diverse interests among commissioning authorities and designers on one hand and contractors on the other are also driven by financial incentives: the majority of the actors blame the problematic market-based bidding process: contractors are selected on the prices they offer, rather than on material use considerations. Simply introducing timber use efficiency strategies are not sufficient to solve this issue. Knowledge brokers emphasize the need to form networks between commissioning authorities, designers and contractors to with the same perception on material use to be successful in improving timber use efficiency. There are two reasons for this. First, the fragmentation of construction activities is an issue. As different actors focus on their own construction-related activities, it becomes difficult to maintain proper material management that covers all these activities. Whereas commissioning authorities (i.e. commissioning authorities) concentrate on energy efficient construction, research agencies show more interest in optimizing material use. Furthermore, it appears that contractors show little interest in adapting innovative techniques, due to the fact that they are primarily focused on competition with other contractors in the bidding process instead of material considerations. A second argument refers to the fragmentation of the different activities in the construction industry. It was frequently mentioned that a coherent system of commissioning authorities, designers, suppliers, contractors and demolition firms is lacking, which creates a disincentive for implementing material-efficient construction techniques. Consequently, there is no sense of shared responsibility in creating a system in which timber construction products and materials are used and reused.

Despite the fact that actors from all different actor groups demonstrate some degree of interest in participation, creating a collaborative network to address timber use efficiency is unlikely given the current barriers that exist with regard to competing priorities between actors. The lack of attention for innovation on the side of commissioning authorities, the conservative nature of contractors and the limited knowledge transfer have a negative impact on the process of forming a coalition between public authorities, market parties and scientists. If such a coalition is to be created, fundamental changes are needed. A first step forward is to reduce the non-alignment of interests between actors, and establishing a shared responsibility towards improving timber use efficiency. Key part of a possible solution to this issue is to involve researchers throughout the various phases of construction, to establish more continuous cooperation between actors. The literature used for this research provided no example of what such a collaborative network looks like. Therefore, additional research is needed.

6.4 Institutional features

The institutional settings of the construction industry determine how actors interact with each other. By investigating the model of representation, rules of interaction, procedures and practices related to the construction industry, we obtain insight on if, and how patterns of interaction can result in more or less accepted formal and informal rules, shared problem definitions and legitimized coalitions.

6.4.1 Licensing authorities

Chapter 5 showed that all technical options to improve timber use efficiency indicate some degree of difficulty, and can therefore not be implemented without the support from licensing authorities. In order to encourage implementation of these options, policy efforts are required. Based on the recommendations made by government officials included in the interviews, a few points of focus can be described at which policy arrangements can be directed: First, the process of commissioning construction projects by public authorities and commissioning authorities is problematic, to the extent that there is a strong emphasis on price competition. Commissioning authorities often select contractors who offer their services at the lowest price possible. This often results in a neglect of environmental issues such as material efficiency. Licensing authorities can intervene in this process by setting minimum requirements for construction quality, in addition to minimal standards for cost price and reuse of old timber. However, due to the liberal marked-based process of contracting, licensing authorities have no influence on this process and can therefore do little more than shaping the legal requirements for construction quality and material use.

A second point of focus mentioned by representatives from licensing authorities is the attitude of the Dutch construction industry towards timber use. Timber is not regarded as a part of the constructions sector, which also accounts for reuse and high-quality recycling of timber products and materials. The emphasis on non-timber materials is dominant across the construction market, which results in a standstill of the progress of improving timber use efficiency.

A third policy effort is directed at the attention for research and innovation of timber-based construction techniques. Despite the fact that pilot studies are starting to take off, public authorities can support this by commissioning building projects that use timber-based construction. In addition to such policy efforts, knowledge distribution can be increased across the construction market. Although the impacts of such research programs are still unknown, it is expected by government officials that this may lead to increased reuse of used timber products and materials. Such networks of knowledge would create alliances including a larger degree of knowledge-intensive actors such as universities, construction engineers and private research institutes. Moreover, this would stabilize the relationships between companies beyond individual projects and allow the sharing of knowledge about timber-based innovations. It is assumed that an enhanced flow of knowledge and expertise between actors can increase opportunities for collective action to address timber use efficiency.

6.4.2 Commissioning authorities

From many interviews, it appeared that commissioning authorities serve as a ‘hub’ with regard to communication with other actors about the use of timber construction materials. Commissioning authorities cooperate with designers to ensure that they meet the sustainability requirements laid down by the association. In order to implement their sustainability strategies with regard to material use efficiency and the use of certified timber, it is essential for commissioning authorities to form social networks with designers and contractors. An important driver to create these networks is to anticipate on the regulations imposed by the government. An environmental coordinator from a commissioning authority mentions that an important tool to communicate material sustainability towards designers and contractors is the material book. This book which describes the procedures for material selection in design and construction, to ensure that the most suitable and environmental friendly materials for a given project are identified from an extensive list of materials. He also mentions a pilot project where Eigen Haard collaborates with designers, contractors and demolishers to examine opportunities for the reuse of materials in new projects. With the goal to recycle 90% of all materials and reuse the remaining 10% it is the most ambitious project in the field of resource use efficiency. Depending on the results of this project, it is still unknown whether this project will become common practice.

A representative from Ymere points out that there is limited interaction with the contractors with regard to the use of materials. According to him, the association has no control over the efficiency of timber-based materials on construction sites. In general, material efficiency is considered the responsibility of contractors; higher efficiency of material use provides them with higher construction revenues[12]. Commissioning authorities recognize this lack of interaction as a serious problem for improving material use efficiency. One of the respondents[13] recalls examples of projects where autonomous decisions made by the contractors about the use of materials led to construction faults and concomitant maintenance efforts during the use stage. Therefore, process management needs to be improved in the form of on-site monitoring. With regard to the application of innovative timber-based construction techniques, he points out the importance of interaction between actors: “some contractors maintain close contact with suppliers of timber construction elements. For those contractors, the use of prefabricated- or timber skeleton construction elements is common practice”. However, commissioning authorities operating on the Dutch construction market remain quite traditional regarding innovative timber-based construction techniques. From the view of commissioning authorities, the lack of communication about material use efficiency and on-site monitoring are the main barriers that limit the feasibility of timber use efficiency. A frequently suggested solution among the commissioning authorities to overcome these barriers, is the cooperation between commissioning authorities, designers, innovative suppliers, and contractors.

6.4.3 Designers

Provided with a large degree of flexibility by commissioning authorities, designers have significant influence on the construction process, both through setting the contractual targets, as well as project specification prior to initiating the contractor selection procedure. Therefore, architects should consider how design practices influence the generation of construction waste. Once areas where construction waste is most likely to occur are identified and understood, they can be prevented or minimized. However, reality proved that such changes are not easy to make. There are two important reasons for this: First, the communication between designers and commissioning authorities regarding the use of innovative construction techniques appears to be constrained, which results in limited or no adoption of these techniques[14]. Second, interviews provided evidence that the considerable time frame involved extends way beyond the professional and financial commitment of commissioning authorities and designers. As buildings are sold and re-sold over a timeframe of decades, any interaction between the original client and designer become very remote, and thereby the beneficiary effects of innovative construction techniques (WRAP, 2010, p. 27).

It was frequently mentioned by architects that they have a decisive role to play in reducing wood waste by focussing on designing out waste. Architects, who have a large degree of freedom to

[12] Here, reference is made to the ‘circle of blame’ illustrated in figure 15
[13] Interview with Ymere on 29-12-2011
[14] Interview with Van der Breggen Architecten on 27-2-2012

fill in the client's requirements, need to address the impacts of design practices on the generation of wood waste. On the contrary, the findings also reveal that waste reduction is not seen as a responsibility of designers. In addition to this, designers appear to take the stance that wood waste is mainly generated during operations on the construction site itself, and rarely produced during the design process. Interestingly, some articles (e.g. Osmani et al., 2008; WRAP, 2010) argue that roughly one third of total construction waste arises from decisions made during the design process. The interviews furthermore indicate that a few constraints play an important role in limiting the potential of timber use efficiency, including the following: lack of interest from commissioning authorities; the attitudes of most designers towards material optimization and waste reduction; and lack of training of contractors all serve as disincentives to a successful and proactive implementation of material efficiency strategies during the design process (Osmani et al., 2008, p. 1147).

6.4.4 Contractors

A representative from a frontrunner contractor in the field of prefabricated- and IFD construction argues that the cost price of construction plays a dominant role in the practices of contractors. The price-driven interest of contractors results in a neglect of material efficiency considerations. Additionally, it is argued that the price-dominated construction process leads to a fragmentation of responsibilities in the design and construction process; various contractors are selected for different elements of a project. This fragmentation has serious implications for the adoption of efficiency-improving construction techniques. There is no cooperation between contractors, and hence no integral approach to timber use efficiency. With the presence of multiple contractors on a construction site, there is no shared problem perception or responsibility for the reduction, reuse or recycling of timber. In creating solutions to these problems, it is stressed by contractors that commissioning authorities and designers should take the lead in achieving this. Commissioning authorities can select contractors based on their material efficiency policies, instead of their cost price. According to them, commissioning authorities have to create more demand for innovative timber-based construction. From this starting point, the opportunities for improving timber use efficiency will increase rapidly[15].

However, the respondent also recognizes the mutual responsibility for both commissioning authorities and contractors in adopting innovations. The general attitude of contractors towards innovative timber-based techniques, is that most contractors are unwilling to integrate them in their practices. This lack of initiative is due to the traditional nature of contractors: this claim was supported by the fact that at least 80% of all contractors do not consider timber as a construction material for major components such as roofs, walls and floors[16]. The main barrier that explains this traditional fashion is twofold: First, the image of timber as a construction material is weak compared to non-timber materials such as concrete or metal, due to the risk of high maintenance costs throughout the lifespan of a building. Second, there is a lack of understanding how to translate the knowledge into tangible projects. It is argued by the contractor that the transfer of knowledge between researchers and contractors is weak, which results in distrust of innovations and overreliance on dominant materials such as concrete and metal. The mainstream thought in the construction sector is that contractors are followers in the construction industry, who respond to the requirements set by commissioning authorities instead of creating their own efficiency strategies. He expects that contractors will start to innovate when actively motivated by the demands of construction clients.

---

[15] Interview with De Groot Vroomshoop on 11-01-2012
[16] Interview with W/E Advisors on 3-01-2012

6.4.5 Branch organizations

Branch organizations function as a link between those who develop and design construction projects, and those who initiate and implement them through advising and training commissioning authorities, commissioning authorities and designers to improve timber use efficiency throughout the construction chain. Similar to research institutes, branch organizations are involved in generating and distributing knowledge about material use, by facilitating pilot projects with innovative construction techniques such as prefabricated-, IFD and timber skeleton construction. These projects were intended to create a spin-off effect towards commissioning authorities, designers and contractors to conduct similar projects. As indicated before by designers, this has not led to widespread use of these techniques. According to estimates by a branch organization representative, options such as prefabrication and IFD construction are applied in only ‘a handful’ of cases, but has already been received with enthusiasm by other designers. He supports his argument with two cases in the cities of Roozendaal and Enschede, where, a few years ago, respectively 246 and 211 houses were successfully renovated by using prefabricated timber skeleton constructions. Two frontrunner designers, in cooperation with two housing associations and contractors, embraced the concept of timber skeleton construction as a replacement for the worn-down concrete structure. This example illustrates that, once cooperation has been established, innovation can effectively be established. However, it is also acknowledged by branch organizations that wide scale improvements in material efficiency is lacking, due to the temporary nature of cooperative networks[17].

6.4.6 Knowledge brokers

As sources of knowledge and expertise, research institutes play an important role in introducing innovations in timber use efficiency. These agencies provide commissioning authorities, designers and contractors with technical know-how, manuals, and models as a means to calculate the sustainability of construction projects and examine the environmental performance of all constituent parts of a single house. These tools can be used to fill in the knowledge gaps and uncertainties on the side of commissioning authorities, designers and contractors about material use, but also energy consumption, safety, public health, accessibility and flexibility. These tools are regularly integrated in national sustainability purchases policies. Except for measurement instruments, research institutes are also involved in the development of technical construction techniques such as IFD and prefab construction.

Although research agencies cannot initiate large scale implementation themselves, they have the potential to increase the diffusion and accessibility of knowledge. Despite the large potential of these tools to trigger the adoption of advanced construction techniques, a representative from W/E Advisors regards the construction sector as traditional. According to him, timber is regarded as a low-quality construction material; it is high in maintenance and vulnerable compared to other materials. It was concluded from this interview that researchers support this claim by arguing that it is difficult to transfer the knowledge from scientists to commissioning authorities and contractors. Interestingly, he notes that commercial research institutes such as W/E Advisors and SHR have a limited concern to promote timber use efficiency. It is their core task to provide clients with value-free knowledge about timber use, without seeking to influence the behavior of actors involved in the construction sector. Moreover, this barrier illustrates the limited opportunities of research agencies to initiate change in timber use efficiency. Despite the purely technical involvement of research institutes in the construction sector, researchers recognize the large potential impacts their research on timber-based construction can have on improving its efficiency. (Tjeerdsma and Klaassen, 2010). Organizations which are specialized in the generation

[17] Interview with Centrum Hout on 9-12-2011

and distribution of knowledge seek to be in contact with all other actor involved in the design phase. These organizations can be involved in independent research, and in advising commissioning authorities, designers and contractors. Organizations such as W/E Advisors, Probos, Centrum Hout and Stichting Hout Research play an essential role in promoting the usefulness of their research in construction practices. An argument that was frequently mentioned by these organizations is the lack of communication between the various actors involved in design, construction and demolition with regard to timber use efficiency.

This lack of communication is caused by the many organizations existing in the construction industry, with fragmented interests and coordination. This leads to a neglect of industry-wide concerns such as material efficiency, which makes it difficult for public authorities to intervene.

The general attitude within the scientific community is that the establishment of a shared problem perception and distribution of responsibilities Are crucial to address the issue of material efficiency. In other words, the 'chain of blame' must be broken. In the current situation, commissioning authorities and designers regard timber use efficiency a responsibility of the contractor, who passes this issue to the demolisher. In order to solve this responsibility issue, designers must anticipate on reuse and recycling options of timber that is extracted during demolition. This will result in lower costs for removal, separation and processing of waste timber. In linking the actors related to the design phase to those involved in the demolition phase, everyone becomes 'owner' of the efficiency issue at hand. According to recent studies of the interviewed institutions, only frontrunner organizations, i.e. the early adopters demonstrate commitment to address this issue. It remains difficult to reach the vast majority of commissioning authorities, designers, and contractors.

6.5 Synthesis of institutional features

With regard to institutional features of the construction industry, it is important to reflect on the following: practices, procedures, model of representation and interaction mechanisms. Nearly all respondents argued that the traditional construction practices of contractors rule out any opportunity for adopting new waste-reducing techniques and strategies. Throughout the interviews conducted with researchers, arguments that were frequently mentioned as beneficial for the actor are the short construction period, cost savings, and better sustainability performance. Although manufacturing cost of the product itself tends to be higher than on-site construction, these costs can be earned back due to the reduced construction period and labor activities. Moreover, demolition companies argued that they benefit from prefab construction because of the short demolition period, and opportunities for reuse and recycling of the components[18].

It is believed by most actors involved in this research that commissioning authorities are the key player in introducing innovative techniques that optimize the use of timber. Their financial resources and position allow them to translate their environmental strategies into concrete projects, and set the project requirements for designers and contractors. The interviews revealed a few constraints with regard to improving timber use efficiency. The first limiting factor in doing so is the absence of material efficiency standards in their sustainability strategies. Instead, commissioning authorities grant a large degree of sovereignty to designers with regard to creating designs; none of the commissioning authorities included guidelines on material efficiency in their sustainability policies. In addition to this, there appears to be a lack of shared responsibility among commissioning authorities, designers and contractors towards the timber products and materials used. Consequently, there is no perspective on the alternatives of used timber after demolition. A third factor refers to the lack of knowledge about innovative timber-based construction techniques on the

[18] Interview with Schijf Timber trade and Demolition Works on 19-01-2012

part of commissioning authorities, designers and contractors. The fourth and last reason relates to the costs and benefits of various alternatives; treating and upgrading used timber appears to be more expensive than using virgin timber material. In addition to this, public authorities provide no legal or financial incentive to reduce, reuse or recycle used timber. Except for the pilot studies that have been conducted by researchers and private parties, these projects weren't followed up by large scale implementation. This indicates that social mechanisms of interaction and model of representation are mostly absent, which compromises the feasibility of forming a coalition between actors to address timber use efficiency.

6.6 Policy content features

The policy features discussed in this paragraph include the main policy instruments used to control and manage the construction industry, participation in research and development activities, and integration of policy strategies with other policy fields. It will be assessed whether and to what extend these features are present in the construction industry, and how they influence the feasibility of improving timber use efficiency. To enhance timber use efficiency in the construction industry, EU policies have created policies that monitor sustainability performance. Moreover, many public actors argue that the construction industry shifts towards a lean and material-efficient production, for both quality and cost reasons (Tykkä et al., 2010, p. 199). From interviews with local government officials presenting four municipalities, innovative timber construction techniques are considered to have a competitive and environmental advantage over traditional on-site assembly and construction of buildings. Despite the positive view on the construction sector, there are underlying concerns that a lack of engineering skills and conservatism in the construction industry may be serious constraints to improvement.

Interestingly, interviews indicated that there is a wide variation in attitudes towards and ambitions in improving sustainability in the construction industry. Whereas some municipalities have poorly developed sustainability agendas (Delft[19]), others take a more positive stance towards timber use efficiency (i.e. Amersfoort and Utrecht). The positive attitude towards timber use efficiency was supported by the idea to grant subsidies to contractors who reduce the amount of materials needed to meet the client's requirements. However, none of the municipalities have moved to the point of establishing a policy program to encourage efficient use of timber in construction projects.

Approaching the issue of timber use efficiency by using a policy perspective, involvement of the licensing authorities (i.e. public authorities) takes place through two different channels: through the implementation of policy instruments, and through the participation in national and European timber research and development. Furthermore, the link between construction policy and other policy fields is analyzed

[19] According to environmental coordinator, the local policy strategy was still in development and hence not available

6.6.1 Policy instruments

The policy agendas related to the construction industry are rather uniform across all municipalities included in this research. The following two instruments were frequently mentioned during the interviews:

- Assessment tools for calculating the sustainability performance of projects (e.g. EPG or BREEAM[20]); and
- Public procurement

The first instrument includes the use of various assessment tools to calculate the sustainability performance of construction projects. Recently, any commissioning authority applying for a construction permit is required to include the environmental impacts per unit of end product, to obtain an accurate view on the 'hidden environmental costs' of residential construction projects. Based on this information, public authorities can set standards for the efficiency of material use per category of building. In a hypothetical situation where contractors bid for a project plan, the client can select the one who can best meet these standards. He gives an example where this mechanism is already in use: according to the CO2- ladder in the sector of road- and waterway construction, the contractor that achieves the best scores (i.e. produces the lowest CO2-emissions) is compensated for its investment costs. It is expected by the municipality of that this philosophy can be used in the residential construction industry, but that it's unlikely to be implemented any time soon. A licensing authority representative emphasizes the limitations of the public sector to influence the construction industry: "For now, the market determines the availability, and thereby the efficiency of timber for construction". Additionally, the representative argues that the knowledge obtained by experiments with equal structures built with different types of timber, can be translated into calculation tools such as GPR and BREEAM to determine the sustainability of construction projects. With these instruments, construction firms can achieve certain BREEAM ratings. The idea is that commissioning authorities can gain additional BREEAM credits by improving their performance in two areas: waste minimization and waste recovery. By using these tools, municipalities can attach a sustainability performance score to timber use, which distinguishes between certified and non-certified timber[21]. At this point, licensing authorities do not yet use this sustainability performance instrument, and are lacking active strategies to improve timber use efficiency. This is mainly due to the fact that the use of instruments such as EPG or BREEAM do not impose any sustainability performance requirements on market parties, and can therefore not enforce commitment from these actors to implement technical options to improve timber use efficiency. Except for the sustainability performance measurement tools there are rules and regulations that are specified for the construction industry. However, conducting an extensive research on the legal context of construction is beyond the scope of this research and will therefore not be elaborated on.

The second instrument concerns public participation in improving timber use efficiency. None of the four licensing authorities included in this research had any policy arrangements in place to encourage the end users of buildings to be involved. Reflecting on the circle of blame mentioned in paragraph, it can be concluded that consumers (i.e. users of the buildings) are not included. However, their involvement is of vital importance to creating demand for buildings that use the technical options listed in chapter 4. According to a licensing authority representative, a first step to encourage the involvement of end users in the construction process is to raise public awareness about the importance of timber use efficiency in construction. However, the prioritization of energy consumption over material efficiency considerations limits the opportunities for implementing such programs. This issue will be explained in more detail in paragraph 6.6.4.

---

[20] See http://www.breeam.nl/ and http://www.rijksoverheid.nl

[21] Interview with municipality of Zoetermeer on 10-01-2012

6.6.2 Participation in research and development

The interviews also indicate that municipalities are participating in a national pilot study (VROM, 2008) to investigate opportunities to reduce and reuse materials such as timber. This research uses an integral approach to material- and product chains, in which product design is linked to the waste stadium. This means that there is increasing attention for 'design-for- recovery and reuse of products or materials (p.10). Although the results of this strategic research are still unknown, it is not expected by the municipalities that this will lead to more emphasis on innovation in material use efficiency. Furthermore, the results are meant as guidelines for where to focus on when developing new policies (p. 34).

6.6.3 Policy integration

National targets on the use of timber as biomass for energy generation have cross-sectoral relevance for waste reduction and material optimization in construction. At the moment, there is a strategy in place, which lays down the policy objectives in the field of energy generation from renewable resources, including timber. These objectives have potential negative impacts on increasing timber use efficiency, due to the fact that opportunities for high-quality reuse and recycling are constrained. It was recognized by various, both public and private actors, that the lack of a well-defined strategy without setting clear measurable targets for timber use efficiency, may result in a possible erosion of these policy objectives.
It was often argues that this tendency was further enhanced by subsidies for producing energy from biomass. The heavily subsidized biomass utilization of timber was found to be a threat to further developments of policies for increasing timber use efficiency. Hence, it can be concluded from the interviews that the integration of policy arrangements for increasing timber use efficiency might fail, due to the fact that this program would come into conflict with policy programs for energy production from biomass.

6.6.4 Science-policy interface

The interviews indicated that the degree of participation in research differs among municipalities, ranging from little or no involvement to active participation and the use of research results for the development of sustainability policies. The science-policy interface has proven to be successful in promoting innovations in timber use; the emphasis that some municipalities put on establishing participation in research projects resulted in the development of policy instruments aimed at supporting timber use efficiency (Tykkä et al., 2010, p. 204). However, it was concluded from all interviews with timber researchers, that various technical options with great potential are widely ignored by commissioning authorities and designers. Consequently, any follow-up in the form of professional and financial involvement is lacking. Government officials regard the transfer of knowledge into policy arrangements as problematic, which can partly be blamed by the short timeframe of the policy cycle. Innovation processes extend far beyond the four-year office term of a government representative, which often results in the abandonment of pilot studies. The second problem related to the science-policy interface is the learning and training of government officials on how to comprehend and translate knowledge into policy arrangements. It was recognized during interviews that, apart from participating in research projects, policy makers must also be educated about how to use knowledge in a balanced way. This means to avoid utilization, e.g. selective use of knowledge as to promote interests other than those of the general public. A third barrier is the prioritization of which policy domains are focused on, and which are put aside. This issue can be explained by the socio-political context in which policy issues are selected. The current emphasis placed on reducing energy consumption leads to a neglect of material efficiency considerations, which results in a low prioritization on the political agenda. The issue-driven demand for knowledge in policy making has serious implications on the innovation in timber use efficiency. Most interviewed government representatives admitted they do little more than complying with national regulations. However, one respondent demonstrated more ‘curiosity-driven’ approach in participating in timber research, and was willing to put the results of this research up for further political discussion. This illustrates that the prioritization of issues is not only in the hands of policy makers but can also be promoted by scientists, which poses an opportunity for science to introduce innovation on the policy agenda.

6.7 Synthesis of policy content features

When reflecting on the policy goals, instruments, integration with other policy fields and the science-policy interface, it can be concluded that the feasibility to improve timber use efficiency is limited. Throughout the interviews held with representatives from licensing authorities, it appears that there are no instruments available to encourage the implementation of technical options that improve timber use efficiency. Although there is increasingly attention for material efficiency through the development of tools such as BREEAM and EPG to measure the sustainability performance tools of construction, there are no rules and regulations which require market parties to implement technical options to improve timber use efficiency. The fact that there is little attention for material efficiency considerations must be seen in the larger socio-political context in which policy decisions are taken. Due to increasing energy consumption in households, policy makers emphasize energy production and consumption over material efficiency. Moreover, a policy program aimed at increasing timber use efficiency would compete with the policy agenda for increasing energy production from natural resources such as timber. Additionally, licensing authorities have very little power to intervene in the market-based process of contracting and construction, which is completely managed and controlled by market parties. This leads us to the conclusion that there is a lack of policy instruments to implement technical options for improving timber use efficiency, and thus little commitment by both licensing authorities and private actors. With regard to the science-policy interface, there appears to be a knowledge gap between policy makers and the scientific community. Due to changing constellations of actors and project-based, cooperation, there is no institutionalization of knowledge. Hence, market parties are hardly adopting innovative technical options that allow them to use timber in a more efficient manner. As both scientists and policy makers recognize the gap between scientists and policy makers, there are opportunities to close this gap. Accordingly, policy makers can start to develop construction design competencies to better understand and translate scientific results into policy arrangements. This learning strategy may contribute to better promote timber construction techniques. Given the current situation, the policy features of instruments, integration and science-policy interface do not indicate that timber use efficiency is to be improved.

The interviews held with government officials reflected a positive attitude towards timber construction techniques. However, most municipalities that were interviewed demonstrate that policies regarding timber use efficiency still receive little attention. One out of four respondents demonstrated extra commitment in improving timber use efficiency, whereas the other three remained more conservative. The common factor that constraints public authorities from exploring the opportunities to innovate construction, is the contemporary socio-political context in which policy issues are selected. The current tendency towards energy efficiency overshadows the issue of timber use efficiency, which results in a lack of progress in addressing this issue. Second, the timeframe of government office terms also acts as a disincentive for commitment to long term scientific research to investigate opportunities for timber use efficiency. Although this was not brought up by government representatives themselves, many others among which research institutes and designers recognised this barrier[22]. A third factor that constraints innovations in construction is the lack of timber-based engineering competencies, which limits the ability to understand and translate knowledge into tangible policy arrangements.

[22] Interviews with Van der Breggen Architecten on 27-2-2012

7 Conclusions and discussion

This concluding chapter contains an evaluation of the literature study, an overview of the main factors that determine the feasibility of improving timber use efficiency, a reflection on the research implications, and recommendations for future research.

The main question addressed in this research is:

"Which technical options, drawn from industrial ecology- and governance literature, are available to increase timber use efficiency in construction, and what factors, related to actor characteristics, institutions and policy content, determine the feasibility of the implementation of these technical options?"

To be able to answer the first part of this question, a literature study was conducted by using industrial ecology literature and governance literature. From this study, a few interesting observations were made. The literature research demonstrated that sustainability issues cannot be addressed by using industrial ecology knowledge alone. Addressing sustainability problems implies the need to redesign society; any research aimed at addressing these issues must therefore include a social science perspective. Moreover, the social science perspective can help in understanding the progress in implementing technical options to improve timber use efficiency. For this reason, both industrial ecology literature and governance literature were used for the desk research.

In the literature, several technical options were identified, which can be used to improve timber use efficiency: prefabrication, IFD construction, timber skeleton construction, laminated construction and selective removal of timber for reuse and recycling. The second part of the research question concerns governance literature, which provided ideas about how implementation of these technical options can be achieved. This literature study was complemented by empirical research, which consisted of interviews with various actors, including licensing authorities, commissioning authorities, designers, contractors, branch organizations and knowledge brokers. These interviews focused on obtaining insights on the factors related to actor-based characteristics, institutions and policy content that serve as opportunities or barriers to implementing the technical options. In addition to these interviews, a scorecard was used to obtain a view on the actors' perception by using the parameters of importance and difficulty of implementation.

The empirical research demonstrated that the vast majority of actors acknowledge the need to improve timber use efficiency in the construction industry. There is a shared belief that this can best be achieved by creating a coalition between the public sector, private companies and the scientific community. However, it was concluded from the interviews and analytical scorecard that there are a number of factors related to actor characteristics, institutions and policy content that serve as disincentives for actors to be involved in improving timber use efficiency.

From the actor-based viewpoint, competing priorities between public actors, private parties and the scientific community indicate that there is a need to align interests and responsibilities between the public sector, market parties and the scientific community. It appears that the lack of shared responsibility and cooperation results in the circle of blame, in which actors argue that others must take action to improve timber use efficiency. The competing interests that exist among market parties and the strong focus on reducing the cost price of construction leads to a fragmentation of interests, and a situation where individual actors are in pursuit of their own interests. A first step towards solving this issue is to create a more coherent actor network and shared responsibility with regard to timber use efficiency. However, the abovementioned factors demonstrate a low feasibility of implementing timber use efficiency.

From an institutional viewpoint, the analysis of the practices, procedures, model of representation and social interaction demonstrate that the construction industry is conservative with regard to adopting innovations. Due to the lack of capacity to innovate and learn on the side of commissioning and contracting firms, knowledge transfer about innovations in timber use efficiency is limited by the unwillingness to make investments in new technical options, and the lack of knowledge institution. As explained by the literature, investments in research and development of innovative timber-based construction options are lacking behind compared to other industries. The interview and survey results support this claim; most respondents argue that the costs of investing in innovative timber construction techniques form an important barrier to adopting new timber-based practices. In addition to this, researchers claim that the timespan of professional and financial involvement of actors in construction projects constrains the transfer of knowledge beyond individual projects. Due to the changing constellation of actors involved in construction, there is no continuous relationship between private actors and researchers. Therefore, a first step towards improving timber use efficiency is to establish long term relationships between the two domains, to increase the transfer and uptake of knowledge and expertise.

From a policy content viewpoint, the interviews indicate that the policy instruments utilized by licensing authorities are insufficient to address the issue of timber use efficiency; only one out of the four authorities interviewed demonstrated significant participation in research and development activities, whereas the other three made no additional efforts beyond the setting of policy goals, and implementation of rules and regulations. It can be concluded from the interviews that policy efforts to improve timber use efficiency are complicated by the competing agenda for sustainable energy production and policies for controlling energy consumption. Integrating timber use efficiency as part of public sustainability policy would conflict with the policy terrain of sustainable energy production. On a national scale, policy arrangements are implemented to increase the use of timber as biomass for energy production. This policy thereby interferes with the aim to maximize timber use efficiency through reuse and cascaded recycling. This conflict is deeply rooted in the socio-political environment in which actors operate prioritizes the use of timber for energy production over optimization of its use in the construction industry. Hence, cascading of timber has a low priority compared to energy production- and consumption.

Summarizing the factors that influence the feasibility of improving timber use efficiency in construction, it can be concluded that, despite the fact that most actors, related to the public, private or research domain, the feasibility of improving timber use efficiency in the construction industry can be considered low. Based on the results, it can be assumed that the creation of a coalition of commissioning authorities, designers, contractors, branch organizations and knowledge brokers to adequately address timber use efficiency is a difficult task at hand due to the competing priorities between actors. However, this does not mean that this research leaves us empty-handed. Instead, the results provide us with clear directions for further research. In this context, it is important to investigate how the knowledge gap between the construction industry and the scientific community can be solved to get rid of the traditional nature that is widely recognized in the construction industry.

Paragraph 2.3 introduced five research implications, which are drawn from the industrial ecology and governance literature: 1) firms changing their practices from short term profits to long term, corporate social responsibility practices. This research implication did not apply to this research; the results demonstrate that many actors prioritize the short term gains that can be achieved by reducing the cost price of construction, rather than to improve timber use efficiency by adopting new technical options. The second research implication provides that implementation processes of innovations must be analysed on the network or system level. This implication does not apply to this research, due to the fact that this would blur the perspectives and new insights provided by individual actors. The third implication provided by the literature argues that the progress of implementation must not be analysed as single-actor activities, but as a cooperative process involving multiple actors. This claim applies to this research, to the extent that cooperation between actors is considered as a relevant factor in analysing the feasibility of implementing technical options in the construction industry. Fourth, the literature emphasizes that actors operating in the private domain and scientific community are confronted with several policy agendas, which can influence the decision of individual actors. This research demonstrated that this implication is confirmed by this research; the policy agendas focus on energy efficiency and not on timber use efficiency. This resulted in the development of sustainability strategies within firms that prioritize energy efficiency over timber use efficiency.

Reflecting upon this research, the empirical research demonstrated some inherent difficulties that are related to data availability. It appeared that contractors were less willing to cooperate than other actor groups. This made it more difficult to find a sufficient amount of actors for this group, and more time-consuming. It is therefore recommended to approach relevant actors in an early stage of the research. Another limitation is imposed by the lack of analysis of the legal aspects of the construction industry. Extending the literature assessment may have resulted in a more detailed insight on the policy content implemented in the construction industry.

This research demonstrates that there is a need for additional research. It was concluded that governance arrangements for timber use efficiency are weak and unorganized, due to non-alignment of interests, a lack of innovative capacity and a knowledge gap between scientists, policy makers and market parties. A challenge for further research is to investigate under which conditions a cooperative network of actors can be established to address timber use efficiency. Research in this field can focus on:

1) the analysis of the variations between the innovation adoption processes of different industry branches; what lessons can be learned by the construction industry?
2) the analysis of the drivers behind the circle of blame; what are the causal relations that result in the lack of cooperation?
3) the analysis of the science-policy interface in the construction industry; what role do knowledge gaps play in the development of governance arrangements?
4) the analysis of relations between dominant governance systems and the ability of policy makers to influence in these systems.

8 References

Literature

Allenby, B.R. and W.E. Cooper (1994) *'Understanding industrial ecology from a biological systems perspective'*, Total Quality Environmental Management, Vol. 3, No. 3, pp.343–354.

Arts, B., and J. Van Tatenhove (2004). 'Policy and Power: A Conceptual Framework Between the 'Old' and 'New' Policy Idioms'', *Policy Sciences*, vol. 37, issue 1, pp. 339–356.

Avelino, F. and J. Rotmans (2011). A dynamic conceptualization of power for sustainability research, *Journal of Cleaner Production,* vol. 19, Issue 8, pp. 796-804

Brink, ten B. (2010). '*Rethinking Global Biodiversity Strategies: Exploring construction changes in production and consumption to reduce biodiversity loss'*. Netherlands Environmental Assessment Agency, The Hague.

Bruijn, de, P.J.M., and N. Maas (2005). Innovatie in de Bouw. TNO rapport EPS 2005-13.

Brugha, R., and Z. Varvasovsky (2000). 'Stakeholder analysis: a review', *Health Policy and Planning*, vol. 15, issue 1, pp. 239–246.

Bryson, J.M. (2004). 'What to do when stakeholders matter: Stakeholder identification and analysis techniques', *Public Management Review*, vol. 6, no. 1, pp. 21-53.

Carmona, M., F. de Matteis, L. de Andreis, C. Clemente, P. Civiero, M. Santangelo, M. Tambach, H. Visscher, G. Rembarz, M. Tamburini and L. Reale (2010). '*Housing for Europe. Strategies for Quality in Urban Space, Excellence in Design, Performance in Building'*. Available on the internet: <http://urbact.eu/fileadmin/Projects/HOPUS/outputs_media/hopus_final_LOW.pdf>. Accessed on 22-11-2011.

Cap ventures (1996) [Image]. US Print on Demand Market Forecast 1995_/2000: Cap Ventures Inc.

Confederation of European Paper Industries (CEPI) (2011). Key Statistics 2010.

Cooper, M. C., and L. M. Ellram (1993). 'Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy', *The International Journal of Logistics Management*, vol. 4, issue 2, pp. 13-24.

Driessen, P., C. Dieperink, F. Laerhoven, and H. Runhaar (2011). Course manual. Governance for Sustainable Development Practices. Utrecht University.

Driessen, P., C. Dieperink, F. Laerhoven, H. A. C. Runhaar, and J.V. Vermeulen (2011). '*Towards a conceptual framework for the study of shifts in modes of governance – Experiences from the Netherlands'*. University of Utrecht, pp. 1- 20

Driessen, P.P J., P. Glasbergen (red.) (2000). *Milieu, Samenleving en Beleid*. Elsevier Publisher, 474 p.

European Commission (1999). Report to DGXI. Construction and Demolition Waste management Practices, and their Economic Impacts. Report by Symonds, in association with ARGUS, COWI and PRC Bouwcentrum. Available on the internet at:

<http://ec.europa.eu/environment/waste/studies/cdw/cdw_chapter7-10.pdf>. Accessed on 15-09-11.

Eurostat (2011). Forestry in the EU and the world. A statistical portrait. European Union. Available on the internet at: <http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-31-11-137/EN/KS-31-11-137-EN.PDF>. Accessed on 12-08-2011.

Dellas, E. and P. Pattberg (2011). *Barriers and Opportunities in Biodiversity Governance. A feasibility Assessment of Strategies to reduce Biodiversity Loss*. Institute for Environmental Studies. Report W-11/003.

De Lopez, T.T. (2001). 'Stakeholder management for conservation projects: a case study of Ream National Park, Cambodia', *Environmental Management,* vol. 28, pp. 47–60.

Eden, C., Ackermann, F. (1998). *Making Strategy: the Journey of Strategic Management*. Sage Publications, London.

Ehrenfeld, J. (2004) 'Industrial ecology: a new field or only a metaphor?' *Journal of Cleaner Production*, Vol. 12, Issue 1, pp.825–831.

Environmental Protection Agency (2009). Recover Your Resources: Reduce, Reuse and Recycle Construction and Demolition Materials at Land Revitalization Projects. Available on the internet at: <http://epa.gov/brownfields/tools/cdbrochure.pdf>. Accessed on 14-09-2011.

(2010). Opportunity for stakeholder input on EPA's Hydraulic Fracturing Research Study: Criteria for selecting case studies. Available on the Internet at: http://www.epa.gov/ogwdw/uic/pdfs/hydrofrac_casestudies.pdf. Accessed on 5-10-11.

Edquist, C., (2004). '*Systems of Innovation — A Critical Review of the State of the Art'*. In: Fagerberg, J.,Mowery, D.,Nelson, R. (Eds.),Handbook of Innovation. Oxford University Press.

Erkman, S. (2002) *'The recent history of industrial ecology'*, in R.U. Ayres and L.W. Ayres (Eds.) A Handbook of Industrial Ecology, Cheltenham, UK: Edward Elgar Publishing Ltd., pp.27–35.

Falkner, R. (2003). 'Private Environmental Governance and International Relations: Exploring the Links', *Global Environmental Politics*, vol. 3, issue 2, pp. 72-87.

Fearon, J.D. (1998). 'Democracy and Deliberation', *Deliberate Democracy*, in J. Elster (Ed.) Cambridge: Cambridge University Press, pp. 44-68

Folke, C., T. Hahn, P. Olsson, J. Norberg (2005). 'Adaptive governance of social-ecological systems', *Annual Review of Environment and Resources,* Vol. 30, issue 1, pp. 441-473

Food and Agriculture Organization of the United Nations (2011). Forestry statistical yearbook. Available on the Internet: <http://www.fao.org/corp/statistics/en/>. Accessed on 10-08-2011.

Foray, D. and Grübler, A. (1996). 'Technology and the environment: an overview', *Technological Forecasting and Social Change*, vol. 53, no. 1, pp.3–13.

Fraanje, P.J. (1998). 'Cascading of pine timber'*, Resources, Conservation and Recycling*, vol. 19, issue 1, pp. 21-28.

Freeman, C. (1996). 'The greening of technology and models of innovation', *Technological Forecasting and Social Change*, vol. 53, no. 1, pp. 27–39.

Galli, R., and M. Teubal (1997). '*Paradigmatic shift in national innovation systems'*. In: Edquist, C. (Ed.), *Systems of Innovation*. Technologies, Institutions and Organizations. Pinter, London.

Gauthier, Y. (2009). 'The Construction of Chaos Theory', *Foundations of Science*, vol. 14, issue 3, pp. 153-165.

Glasbergen, P. (1992). 'Seven steps towards an instrumentation theory for environmental policy', *Policy and Politics,* Vol. 20, Issue 3, pp. 191-200

Glasbergen, P. and R. Groenenberg (2001). Environmental partnerships in sustainable energy, *Journal of European Environmental Policy,* Vol. 11, Issue 1, pp. 1-13

Goverse, T., M.P.Hekkert, P. Groenewegen, E, Worrell, R.E.H.M. Smits (2001). 'Wood innovation in the residential construction sector; opportunities and constraints', *Resources, Conservation and Recycling*, vol. 34, issue 1, pp. 53-74.

Graedel, T.E. and B.R. Allenby (1995) *'Industrial Ecology'*, Englewood Cliffs, NJ: Prentice Hall.

Hasan, A.R., H. Solo-Gabriele, and T. Townsend (2011). 'Online sorting of recovered timber waste by automated XRF-technology: Part II. Sorting efficiencies', *Waste Management*, vol. 31, issue 4, pp. 695-704.

Hekkert M.P., J. de Beer, Doin, R. van, and M. Kerssemeeckers (1999). Energiezuinig Productontwerp, Sectorstudie Grafisch Papier. Utrecht, The Netherlands: Utrecht University, Department of Science, Technology and Society.

Hekkert, M.P., L. A.J. Joosten, E. Worrell and W. C. Turkenburg (2000). 'Reduction of CO2 emissions by improved management of material and product use: the case of primary packaging', *Resources, Conservation and Recycling*, vol. 29, issue 1, pp. 33–64.

Hekkert, M.P., J. van den Reek, E. Worrell, W. C. Turkenburg (2002). 'The impact of material efficient end-use technologies on paper use and carbon emissions', *Resources, Conservation and Recycling*, vol. 36, issue 2, pp. 241-266.

Hobson, K. (2003). 'Thinking habits into action: The role of knowledge and process in questioning household consumption practices', *Local Environment*, vol. 8, issue 1, pp. 95-112.

International Council on forest and Paper Associations (ICFPA) (2011). Sustainability Progress Report. Available on the internet at: <http://www.icfpa.org>.

Jessop, B. (1998). 'The rise of governance and the risks of failure: the case of economic development', *International Social Science Journal*, vol. 50, no. 1, pp. 29–45.

Jonkers, I. (2011). Het rendement van hout – Een transitieperspectief. Nyenrode Center for sustainability.

Kamphorst, D.A. and M.M.P. van Oorschot (2011). Kansen en barrières voor verduurzaming van houtketens. Wageningen University & Research Centre, in collaboration with Environmental Planning Agency and Ministry of Economic Affairs, Agriculture and Innovation.

Kringloop Hout (2011). Available on the internet at: <http://www.kringloophout.nl/>. Accessed on 21-10-2011.

Kaufmann, D. and A. Kraay (2008). 'Governance Indicators: Where Are We, Where Should We Be Going?', *The World Bank Research Observer*, vol. 23, issue 1, pp. 1-30.

Kickert, W.J.M. E.H. Klijn, J.F.M. (eds.) (1997). '*Managing Complex Networks. Strategies for the public sector'.* Sage Publications, London

Korhonen, J. (2004) 'Industrial ecology in the strategic development model: strategic applications of industrial ecology', *Journal of Cleaner Production*, Vol. 12, pp.809–823.

Knoeri, C., C. R. Binder, and H. Althaus (2011). 'Decisions on recycling: Construction stakeholders' decisions regarding recycled mineral construction materials', *Resources, Conservation and Recycling*, vol. 55, issue 11, pp. 1039-1050.

Kuiper, J. and R. Jans (2001). Nederlands houtgebruik in beeld. Uitgave Stichting ProBos, Zeist.

Lafleur, M.C.C., and P. J. Fraanje (1997). 'Towards sustainable use of the renewable resource timber in the Netherlands – a systematic approach', *Resources, Conservation and Recycling*, vol. 20, issue 1, pp. 19-29.

LAP (2007). Landelijk Afvalbeheerplan 2002-2012 (LAP). VROM.

Lehmann, S. (2011). 'Optimizing Urban Material Flows and Waste Streams in Urban Development through Principles of Zero Waste and Sustainable Consumption', *Sustainability*, vol. 3, issue 1, pp. 155-183.

Lemos, M.C. and A. Agrawal (2006). 'Environmental Governance', *Annual review of environment and resources*, vol. 31, pp. 297-325.

Leek, N.A., J. Oldenburger, and A. Winterink (2009). De markt van gebruikt hout en resthout in 2007. ProBos, Wageningen.

Lundvall, B.-Å. (1992). *National Systems of Innovation: Towards a Theory of Interactive Learning*. Pinter, London.

Mantau U., Wagner. J., and Baumann J. (2005). 'Stoffstrommodell Holz - Bestimmung des Aufkommens, der Verwendung und des Verbleibs von Holzprodukten', *Müll und Abfall*, vol. 6, issue 1, pp. 309-315.

Merino, del Rio M., P. I. Gracia, and I.S.W. Azevedo (2010). 'Sustainable construction: construction and demolition waste reconsidered', *Waste Management & Resources*, vol. 28, issue 2, pp. 118-129.

Mitchell, R. K., B.R. Agle, and D.J. Timber (1997). 'Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts', *Academy of Management Review*, vol. 22, pp. 853–86.

Mongabay (2011). Available on the internet at: <http://news.mongabay.com/2011/0202-international_year_of_forests.html. accessed on 21-10-2011>.

National Research Council (1995). '*Science, policy and the coast: improving decision making'.* Washington, DC: The National Academies Press.

Nordman B. (2000). Personal Communication with B. Nordman. Berkeley, CA: Lawrence Berkeley National Laboratory, 2000. Cited In: Hekkert, M.P., J. van den Reek, E. Worrell, W. C. Turkenburg (2002). 'The impact of material efficient end-use technologies on paper use and carbon emissions', *Resources, Conservation and Recycling*, vol. 36, issue 2, pp. 241-266.

North, D.C. (1990). *Institutions, Institutional Change and Economic Performance.* Cambridge University Press, Cambridge

OECD Environment Directorate (2010). '*Global Forum on Environment. Policy Instruments for Sustainable Materials Management: Working Document'.* Available on the Internet at: <http://www.oecd.org/dataoecd/15/34/46096632.pdf>. Accessed on 22-11-2011.

O' Toole, L. and R.S. Montjoy (1984). 'Interorganizational policy implementation: a theoretical perspective'. *Public Administration Review,* pp. 491-503

Overmeeren, A., v. Gruis, and M. Haffner (2010*). 'Institutional and Organizational Change in Social Housing Organisations in Europe: Inspection of commissioning authorities, the Dutch and the English way'.* Available on the Internet at: <http://www.enhr2007rotterdam.nl/documents/W16_paper_VanOvermeren.pdf>.

Parris, T. M. and W. Kates (2003). 'Characterizing a sustainability transition: Goals, targets, trends, and driving forces'. *National Academy of Science*, vol. 100, issue 14, pp. 8068–8073.

Pearce, D. (2005). 'Do we understand sustainable development?' *Building Research & Information*, vol. 33, issue 5, pp. 481-483.

Poon, C.S, T.W.A. Yu, L. Jaillon (2004). 'Reducing building waste on construction sites in Hong Kong', *Construction Management and Economics*, vol. 22, issue 1, pp. 461–470.

Probos (2010). '*Kerngegevens Bos en Hout in Nederland'*. Available on the Internet at: <http://www.probos.nl/home/pdf/kerngegevens2010.pdf>. Accessed on 22-08-2011.

Reed, M. S., A. Graves, N. Dandy, H. Posthumus, K. Hubacek, J. Morris, C. Prell, C. H. Quinn, L.C. Stringer (2009). 'Who's in and why? A typology of stakeholder analysis methods for natural resource management', *Journal of Environmental Management*. vol. 90, issue 5, pp. 278-288.

Reek, J. van den (1999). '*Reduction of CO2 Emission by Reduction of Paper Use for Publication Applications'*. Utrecht, The Netherlands: Utrecht University, Department of Science, Technology and Society.

Rhodes, R. (1996). 'The new Governance: Governing without government', *Political Studies*, vol. 44, issue 3, pp. 652-667.

Rossy, A., P. T. Jones, D. Geysen, and K. Bienge (2010). '*Sustainable Materials Management for Europe. From efficiency to effectiveness'*. Report executed by Sustenuto, Catholic university of Leuven, and Wuppertal Institute for Climate, Environment and Energy. Available on the Internet at: <http://www.euractiv.com/sites/all/euractiv/files/SMMfor%20EuropeStudy_0.pdf>. Accessed on 22-11-2011.

Scharpf, F.W. (1978). 'Interorganizational policy studies: Issues, concepts and perspectives'. In: '*Interorganizational policy making'. Limits to coordination and central control.* Hanf, K., F.W. Scharpf (eds.), Sage Publications, London

Scott, W. R. (2004). "Institutional theory", pp. 408-14 in: Encyclopedia of Social Theory, Ritzer, G. (Ed.) Thousand Oaks, CA: Sage.

Solid Waste Management Coordination Board (SWMBC) (2002). Office Paper Reduction Demonstration Project: Final Report. Available on the internet at: <http://www.swmcb.org/sites/default/files/files/OfficePaperReport.pdf>. Accessed on 26-10-11.

Stichting Kringloophout (2011). Available on the internet at: <http://www.kringloophout.nl/monitoring-recycling/percentage-2006-2009>.

Sathre, R. and J. O'Connor (2010). A synthesis of research on timber products and greenhouse gas impacts, 2nd edition. Vancouver B.C. FP Innovations. Available on the internet at: <http://www.forintek.ca/public/pdf/Public_Information/technical_rpt/TR19%20Complete%20Pub-web.pdf>. Accessed on 21-2-2012.

Sathre, R. and L. Gustavsson (2006). 'Energy and carbon balances of timber cascade chains', *Resources, Conservation and Recycling*, vol. 47, issue 2, pp. 332–355.

Smulski, S., R.C. Moody, and R. Hernandez (1997). Engineered wood products-A guide for specifiers, designers and users. Madison, WI: PFS Research Foundation, pp. 1-39.

Spoerri, A., D.J. Lang, C.R. Binder, and R.W. Scholz (2009) Resources, conservation and recycling, Vol.: 53, Issue: 10, pp. 592-600

Stoker, G. (1998). 'Governance as Theory: five propositions', *International Social Science Journal*, issue 155, pp. 17-27.

Tjeerdsma, B.F., and R.K.W.M. Klaassen (2010). Ketenstudie bouwgerelateerd hout; vermindering milieudruk hout in bouw- en sloopafval. SHR, Wageningen.

Tong, C., G.B. Song, B.R. Chen, W. H. Ye (2008). 'Macroeconomic efficiency of use of non-renewable resources in the industrial economy during a period of rapid economic growth in China', *Resources, Conservation and Recycling*, issue 52, pp. 737–746.

Tykkä, S., D. McCluskey, T. Nord, P. Ollonqvist, M. Hugosson, A. Roos, K. Ukrainski, A.Q. Nyrud, F. Bajric (2010). Development of timber framed firms in the construction sector Is EU policy one source of their innovation? *Forest Policy and Economics*, vol. 12, issue 3, pp. 199-206.

Van Den Brand, G., H. van Gurchom, and T. Damen (2003). IFD building in Europe. A blueprint for production and delivery of customer satisfaction oriented buildings. Technische Universiteit

Eindhoven, pp. 55-60. Available on the Internet at: <http://www.irbnet.de/daten/iconda/CIB13471.pdf>. Accessed on 20-2-2012.

Van Tatenhove, J., B. Arts, and P. Leroy (2000). *Political modernization and the environment. The renewal of environmental policy arrangements.* Kluwer Academic Publishers, Dordrecht

Vermeulen, W.J.V. (2006). 'The social dimension of industrial ecology: on the implications of the inherent nature of social phenomena', *Progress in Industrial Ecology – An International Journal*, vol. 3, issue 6, pp. 574–598.

Vermeulen, W. J.V., Y. Uitenboogaart, L.D.L. Pesqueira, J. Metselaar, M.T.J. Kok (2010). Roles of Governments in Multi-Actor Sustainable Supply Chain Governance Systems and the Effectiveness of their Interventions. The Netherlands Environmental Assessment Agency.

Verschuren, P. and H. Doorewaard (1999). Designing a research project. Publisher Lemma Utrecht, 215 p.

Villanueva, A. K., L. S. Delgado, Z. Luo, p. Eder, S. A. Catarino, D. Litten (2010). Study on the Selection of Waste Streams for End-of-waste Assessment- Final Report. JRC Scientific and Technical Reports, pp. 369. Available on the Internet at: <http://publications.jrc.ec.europa.eu/repository/handle/111111111/14333. Accessed on 1-11-2011>.

Vos, H., van den Brand, G. (1999). IFD Building starting points. Bouwwereld.

VROM (2008). Naar een ketenaanpak in het afvalbeleid. Ervaringen van zes pilotketens. Available on the internet at: <http://www.agentschapnl.nl/sites/default/files/bijlagen/Naar_een_ketenaanpak_in_het_afvalbeleid.pdf>. Accessed on 24-2-2012.

VROM (2011). Cijfers over Wonen, Werken en integratie. Available on the internet at: <http://cowwi.datawonen.nl/>. Accessed on 12-12-2011.

Wapner, p. (1997). Governance in Global Civil Society. In *Global Governance: Drawing insights from the environmental Experience*, edited by Oran R. Young, pp. 65-84. Cambridge: MIT Press.

WRAP (2011). Home Improvement Sector Commitment. Interim Progress Report. Available on the Internet at: <http://www.wrap.org.uk/downloads/MST937_HISC_2011_Report_8.ac334616.11168.pdf>. Accessed on 4-11-2011.

BouwCarrousel. <http://www.bouwcarrousel.nl>. Accessed on 27-2-2012.

List of interviews:

Architect (2012). Interviewed by Marc Leijtens, Rotterdam, February 27, 2012.

Architect (2012). Interview conducted by Marc Leijtens, Amsterdam, January 21, 2012

Architect (2012). Interview conducted by Marc Leijtens, Utrecht, January 14, 2012

Architect (2012). Interview conducted by Marc Leijtens, Wageningen, February 12, 2012

Branch organization representative (2011). Interview conducted by Marc Leijtens, Almere, December 9, 2011

Branch organization representative (2012). Interview conducted by Marc Leijtens, Bussum January 18, 2012

Branch organization representative (2012). Interviewed by Marc Leijtens, Zaltbommel, January 24, 2012

Branch organization representative (2012). Interview conducted by Marc Leijtens, Uithoorn, January 26, 2012

Commissioning authority representative (2012). Interview conducted by Marc Leijtens, Amsterdam, December 19, 2012

Commissioning authority representative (2012). Interview conducted by Marc Leijtens, Amsterdam, December 29, 2011

Commissioning authority representative (2012). Interview conducted by Marc Leijtens, Amsterdam, January 11, 2012

Contractor (2012). Interview conducted by Marc Leijtens, Vroomshoop, January 16, 2012

Contractor (2012). Interview conducted by Marc Leijtens, Uithoorn, January 26, 2012

Licensing authority representative (2012). Interview conducted by Marc Leijtens Utrecht December 15, 2011

Licensing authority representative (2012). Interview conducted by Marc Leijtens, Zoetermeer, January 10, 2012

Licensing authority representative (2012). Interview conducted by Marc Leijtens, Amersfoort, January 13, 2012

Licensing authority representative (2012). Interview conducted by Marc Leijtens, January 17, 2012

Researcher (2012). Interview conducted by Marc Leijtens, Utrecht, January 4, 2012

Researcher (2012). Interview conducted by Marc Leijtens, Wageningen, January 11, 2012

Researcher (2012). Interviewed by Marc Leijtens, Delft, January 20, 2012

Researcher(2012). Interviewed by Marc Leijtens, Wageningen on January 30, 2012

Researcher (2012). Interview conducted by Marc Leijtens, Breukelen, February 21, 2012

List of tables and figures:

Table	Title	Page
Table 1	Actors related to the construction industry	27
Table 2	Origins and causes of timber waste during construction processes	38
Table 3	Efficiency gains of technical options for paper and pulp industry in the EU-27	42
Table 4	Estimated potential impacts of technical options on use efficiency of timber in the packaging industry in the EU-27	44
Table 5	Efficiency gains of technical options for construction in the EU-27	45
Table 6	Characteristics of IFD construction	46
Table 7	Efficiency gains of technical options for construction in the EU-27	48
Table 8	Average scores on importance and implementation difficulty per technical option	51
Table 9	Scorecard results for prefabricated construction per actor group	53
Table 10	Scorecard results for IFD construction per actor group	54
Table 11	Scorecard results for timber skeleton construction per actor group	55
Table 12	Scorecard results for glued timber construction per actor group	56
Table 13	Scorecard results for selective removal of timber products and materials for reuse and recycling per actor group	57
Table 14	Actor-based features of licensing authorities	62
Table 15	Actor-based features of commissioning authorities	63
Table 16	Actor-based features of designers	64
Table 17	Actor-based features of contractors	65
Table 18	Actor-based features of branch organizations	66
Table 19	Actor-based features of knowledge brokers	67

Figure	Title	Page
Figure 1	Research framework	9
Figure 2	Cascading of timber	13
Figure 3	Governance framework	17
Figure 4	Roles of actors in terms of power and interest	20
Figure 5	Process of case study selection	26
Figure 6	Format of power-versus interest grid	29
Figure 7	industrial round timber production in the EU-27 (1961-2009)	31
Figure 8	Timber production in the EU-27 in 2010	32
Figure 9	Timber flows in the EU-27	33
Figure 10	Timber waste flow diagram in the EU-27	40
Figure 11	Importance vs. difficulty grid	51
Figure 12	Roles of actors in terms of power and interest	61
Figure 13	Circle of blame in the construction industry	69

9 Appendices

Appendix 1: Scorecard for assessing the relevance and difficulty of implementing technical options related to the construction sector

Exploratory research to the feasibility of implementing options that improve timber use efficiency in construction

Question 1.1: Below, there is a selection of five options that can be applied to increase the efficiency of wood use in the construction sector. According to your opinion on its importance in improving timber use efficiency, attach a value (ranging from 1(not important) to 5 (important)) to each option.

	Not important 1	2	3	4	Important 5
Prefabricated construction (roof-, wall- and floor) components					
IFD (Industrial, Flexible, Demountable) construction system					
Wood skeleton Construction (on-site)					
Glued laminated timber					
Selective removal of timber products and materials for reuse and recycling					

Question 1.2: Why do you think a certain option is (not) important in improving timber use efficiency?

Question 2:

On the next page, a number of factors are depicted, which can form potential opportunities or barriers for the implementation of options that can improve timber use efficiency in construction. Determine whether you perceive each factor as a potential opportunity or barrier to implementing each option, by attaching a value to each factor (from 1 (opportunity) to 5(barrier))

Option 1: Prefabricated construction (roof-, wall- and floor) components

	Opportunity 1	2	3	4	Barrier 5
Costs and benefits of investing in this option					
Attitude towards using this option					
Cooperation with other actors through the exchange of knowledge and experience)					
Usability of this technique in practices of firms					
Innovative capacity of clients / designers / contractors to adapt this option					
Rules and regulations concerning the implementation of this option					
Communication and learning about costs and benefits of this option					
Rules and regulations concerning reuse and recycling of timber products and materials					

Option 2: IFD (Industrial, Flexible, Demountable) construction

	Opportunity				Barrier
	1	2	3	4	5
Costs and benefits of investing in this option					
Attitude towards using this option					
Cooperation with other actors through the exchange of knowledge and experience)					
Usability of this technique in practices of firms					
Innovative capacity of clients / designers / contractors to adapt this option					
Rules and regulations concerning the implementation of this option					
Communication and learning about costs and benefits of this option					
Rules and regulations concerning reuse and recycling of timber products and materials					

Option 3: Wood skeleton construction

	Opportunity				Barrier
	1	2	3	4	5
Costs and benefits of investing in this option					
Attitude towards using this option					
Cooperation with other actors through the exchange of knowledge and experience)					
Usability of this technique in practices of firms					
Innovative capacity of clients / designers / contractors to adapt this option					
Rules and regulations concerning the implementation of this option					
Communication and learning about costs and benefits of this option					
Rules and regulations concerning reuse and recycling of timber products and materials					

Option 4: Glued timber construction

	Opportunity 1	2	3	4	Barrier 5
Costs and benefits of investing in this option					
Attitude towards using this option					
Cooperation with other actors through the exchange of knowledge and experience)					
Usability of this technique in practices of firms					
Innovative capacity of clients / designers / contractors to adapt this option					
Rules and regulations concerning the implementation of this option					
Communication and learning about costs and benefits of this option					
Rules and regulations concerning reuse and recycling of timber products and materials					

Option 5: Selective removal of timber products and materials for reuse and recycling

	Opportunity				Barrier
	1	2	3	4	5
Costs and benefits of investing in this option					
Attitude towards using this option					
Cooperation with other actors through the exchange of knowledge and experience)					
Usability of this technique in practices of firms					
Innovative capacity of clients / designers / contractors to adapt this option					
Rules and regulations concerning the implementation of this option					
Communication and learning about costs and benefits of this option					
Rules and regulations concerning reuse and recycling of timber products and materials					

Appendix 2: Interview guide for actors involved in the construction industry

(Using the aspects from the governance framework as a checklist).

Actors:

1. Licensing authorities: Municipality of Delft, Zoetermeer, Amersfoort and Utrecht
2. Commissioning authorities: Ymere; Eigen Haard; Rochdale
3. Designers: LAM Designers; Zecc Designers; Greiner & Van Goor Huijten; Van der Breggen Architecten
4. Contractors: De Groot Vroomshoop; Schijf Groep
5. Branch organizations: Centrum Hout, Dutch Association of Timber Manufacturers (NBvT)
6. Knowledge brokers: TNO Construction; Probos; SHR; Nyenrode Business University; W/E Advisors

Questions:

- To what extent does your organization consider timber use efficiency in its practices?

- What are the most important considerations with respect to timber use efficiency when designing and constructing projects? Keeping in mind the factors that influence these considerations.

- What is your perspective on material efficiency in designing construction projects?

- What measures did you implement or recommend in construction designs with respect to resource use efficiency over the past 5 years?
  - What role does IFD (Industrial, Flexible, and Detachable) construction play in your project designs or recommendations?
  - What other options did you apply to improve timber use efficiency?

- Do you think that, with regard to future availability of renewable resources, there is a need to apply the concept of 'life cycle thinking' (i.e. cradle-to-cradle use of materials) in your project designs?

  - How do you include the concept of 'life cycle thinking' in your project designs? Keeping in mind the level of chemical treatment and reuse or recycling after use

- What are your experiences with these measures, and what can you say about their impact on the efficiency of timber use?
- In what ways does your organization collaborate with actors involved in residential construction, to exchange knowledge (technological/scientific expertise) about timber use efficiency?

  - Why do you think this cooperation is important in the context of timber use efficiency?

- What are the main barriers that limit your organization from implementing these practices (e.g. costs and benefits)?

- Which actions are needed to enhance the impact of reduction/reuse/recycling strategies of timber in the construction sector, and by who? Keeping in mind the feasibility of implementing certain technical options related to these strategies

- o Are there any other parties that need to collaborate with this stakeholder in order to increase resource use efficiency?

- • Going forward, what actions do you think are needed in the way construction and demolition currently take place, in order to help increase the acceptance of options related to reduction, reuse or recycling of timber?

Questions for actors involved in the construction industry

Actors: Association of Recycling, crushing and sorting (BRBS), Association of demolishers (Veras)
Demolition contractor: Schijf Group timber trade and demolition works

- • How familiar is your organization with the concept of material use efficiency in demolition practices?

- • To what extent does your organization reuse or recycle timber construction materials?What are the reasons to do this?

- o Does prefab- or modular timber construction play an important role during demolition practices?

- • During demolition practices, does your organization remove used timber prior to crushing of the material?

- • What external pressure do you experience in separating and reusing or recycling timber material?

- • What are your experiences with the selective removal of timber material; do you consider it a useful method of reusing or recycling timber material?

- o What determines whether timber material is subject to selective removal?

- o What is the reason for (not) doing this?

- • In what ways does your organization collaborate with the stakeholders related to the design phase to exchange knowledge (technological/scientific expertise) about reuse or recycling of construction materials?

- • What is, in your opinion, needed to enhance the impact of reuse/recycling practices on timber use efficiency?

- • Who is in the position to take action in stimulating the implementation of these options?

- o What contribution can be made by the public authorities to improve the feasibility of these options?

Appendix 3: Function and designation of forests in the EU, 2010

	Protected area	Primary designated function (selection)					Habitats Directive
		Production	Protective of soil and water	Conser-vation of bio-diversity	Social services	Multiple use	Protected land areas for biodiversity
EU (1)	20 356	88 586	13 880	17 443	2 904	30 993	58 609
EA (1)	14 283	49 213	8 048	12 082	913	24 396	37 238
Belgium	209	0	99	209	:	370	307
Bulgaria	313	2 864	469	22	253	319	3 284
Czech Republic	740	1 994	252	333	78	0	785
Denmark	40	299	0	40	0	146	317
Germany	2 754	0	0	2 897	0	8 179	3 457
Estonia	213	1 472	258	208	0	279	757
Ireland	58	317	:	83	1	:	755
Greece	164	3 595	0	164	0	0	2 147
Spain	2 499	3 716	3 583	2 100	399	8 375	12 351
France	313	11 904	245	202	57	3 546	4 672
Italy	3 265	4 073	1 791	3 265	20	0	4 306
Cyprus	95	41	0	3	13	49	75
Latvia	610	2 658	128	498	70	0	729
Lithuania	433	1 523	209	198	66	164	908
Luxembourg	:	28	0	0	0	59	40
Hungary	424	1 289	290	424	26	0	1 397
Malta	0	0	0	0	0	0	4
Netherlands	83	4	0	90	0	271	349
Austria	659	2 323	1 420	108	35	0	898
Poland	187	3 768	1 901	434	1 004	58	3 440
Portugal	700	2 026	234	171	0	1 025	1 601
Romania	1 746	3 169	2 543	317	374	0	3 148
Slovenia	241	387	76	575	75	140	636
Slovakia	1 104	129	342	81	236	1 145	574
Finland	1 925	19 197	0	1 925	77	958	4 309
Sweden	1 435	20 901	35	2 950	0	4 317	5 696
United Kingdom	145	908	5	145	120	1 593	1 666
Iceland	0	6	4	0	6	13	:
Liechtenstein	4	2	3	1	1	0	:
Norway	167	6 042	2 762	167	0	1 094	:
Switzerland	90	492	10	90	64	0	:
Montenegro	13	348	52	27	0	0	:
Croatia	54	1 581	82	54	38	165	:
FYR of Macedonia	:	804	0	0	0	0	:
Turkey	269	7 896	1 900	859	4	675	:

(1) Sum of available data for the Member States

Source: FAO (Global FRA, 2010), Eurostat (env_bio1)

Appendix 4: Economic value of non-timber products in EU, 2005

	Value of non-wood products / industrial roundwood	Plant products		Animal products		
		Food	Ornamental plants	Hides, skins and trophies	Wild honey and beeswax	Bush meat
	(ratio)	(tonnes)		(units)	(tonnes)	
Bulgaria	0.03	:	:	:	:	:
Czech Republic	0.19	40 960	:	216 570	0	9 578
Denmark	:	:	71 000	:	:	:
Germany	0.22	:	:	:	:	34 000
Estonia	:	:	2 000	37 500	:	913
Spain	0.56	12 018	:	3 040	39 114	21 723
France	:	:	:	:	6 300	:
Italy	1.57	79 155	:	:	:	:
Cyprus	:	:	:	:	811	:
Latvia	:	:	:	37 800	:	1 500
Lithuania	0.09	3 800	3 000	30 000	:	1 250
Netherlands	:	:	6 000	:	:	362
Austria	0.12	:	:	:	:	:
Poland	:	15 088	843	:	:	10 456
Portugal	1.10	:	:	:	:	:
Slovenia	0.11	550	1 200	20 000	2 300	1 000
Slovakia	0.04	1 155	255	22 470	:	1 688
Finland	0.05	47 000	309	355 000	:	9 279
Sweden	0.04	35 860	14	177 200	:	16 790
United Kingdom	0.30	162	162 545	:	183	3 500
Iceland	:	:	92	0	0	0
Norway	:	462	:	:	550	1 700
Switzerland	:	19 000	5 517	33 110	:	7 586
Croatia	0.01	400	:	:	:	:
Turkey	0.00	9 979	152	:	:	:

(1) No information available for those Member States that are not presented.

Source: FAO (Global FRA, 2005 and 2010)

Appendix 5: Standardized default factors to convert cubic metres of solid timber to oven-dry tonnes of timber material

	Roundwood, industrial roundwood, sawnwood, other industrial roundwood, pulpwood, chips, particles, fuelwood, wood residues		Charcoal	Average for wood panels	Paper & paperboard, pulp, recovered fibre, recovered paper
1. Density (oven-dry tonnes per m^3 of solid wood product or oven-dry per air-dry tonne of pulp or paper product)	Temperate species	Tropical species	0.9 oven-dry tonne (air-dry tonne)$^{-1}$	0.628 oven-dry tonne m^{-3}	0.9 oven-dry tonne (air-dry tonne)$^{-1}$
	0.45 oven-dry tonne m^{-3}	0.59 oven-dry tonne m^{-3}			

Appendix 6: Effect of technical reduction measures on paper demand for newsprint and other graphical papers

Measures	Book	B.P[a]	Cat[a]	CP[a]	Cut.s[a]	Direct[a]	Insert	Mag[a]	Misc.[a]	NP[a,b]
Efficient paper production	−2%	−2%	−2%	−2%	−2%	−2%	−2%	−2%	−2%	−2%
Efficient paper printing	−2%	−2%	‘2%	−2%	−2%	−2%	−2%	−2%	−2%	−2%
Decreasing paper weight	−10%	−15%	−15%	−15%	−15%		−15%	−10%	−15%	−7%
Good housekeeping		−10%			−10%					
Duplex copying and printing					−22%					
Personalized newspapers										−20%
POD	−25%		−25%	−15%			−80%			
DAP					+4%[c]					−18%

[a] B.P, Business papers; Cat, catalogues; CP, commercial printing; Cut.s, cut size; Direct, directories; Mag, magazines; Misc, miscellaneous; and NP, newsprint.
[b] 20% reduction minus 2% that is already part of the baseline scenario.
[c] +4% of newsprint consumption.

Source: Hekkert et al. (2002), p. 255