This dissertation introduces guidelines for a uniform terminological system for paper recycling. Different terminological systems related to material recycling in the paper industry were compared with each other. It became obvious that a state of chaos exists with respect to how terminology is used in the paper recycling industry. Globally, there are several terminological disciplines and material stream frameworks in use. Often, different terms are being used for the same matter; and often, the same term is being used to refer to different matters depending on author, region, and time. A comprehensive uniform framework for materials streams and stages in the paper recycling industry was developed. This framework is called the Detailed Wheel of Fiber. A method for quantifying the different material streams and stages in the material system of the paper industry was developed. In this study, different material streams and stages were quantified by using a common denominator, the roundwood equivalent.
Paper Industry Material Recycling

Revealing and Rectifying the Chaos in Terminology

Ilpo Ervasti

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Science, at a public examination held at the lecture hall TU1 of the school on 29 December 2016 at 12.

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Abstract

The objective of this doctoral dissertation was to create guidelines for a comprehensive, uniform terminological system for paper recycling. The uniform system should be such that it can be used globally, cross all geographical regions, and it should meet the needs of all stakeholders in the field.

The objective was divided into four sub-objectives. Firstly, to provide a comprehensive analysis of existing terminological systems for paper recycling. Secondly, to provide a comprehensive analysis of existing frameworks for describing the material streams and stages in the paper recycling industry. Thirdly, to create a comprehensive, uniform framework for describing the material streams and stages in the material chain of the paper recycling industry. And, fourthly, to present a method to quantify the material streams and stages in the material chain of the paper industry.

An exploratory research approach was used. This approach is appropriate especially when the research problem or research focus is not clear. This dissertation uses both qualitative and quantitative research data.

Numerous journal articles, conference papers, books, and other research reports were used as sources of research data. In addition, a wide range of publications by various industry associations and individual companies as well as official and unofficial statistics, and definitions were utilized.

It became obvious that a state of chaos exists with respect to how terminology is used in the paper recycling industry. A comprehensive analysis of existing frameworks dealing with material streams and stages related to paper recycling was done. After this, a comprehensive uniform framework for material streams and stages in the paper recycling industry was developed. This framework was named the Detailed Wheel of Fiber. A method for quantifying the different material streams and stages in the paper industry was developed. In this quantification a common denominator, the roundwood equivalent (RWE) was used.

Keywords recovered paper, recycling, paper industry, terminology


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Tiivistelmä

Tämän väitöskirjatutkimuksen tavoitteena oli kehittää suuntaviivat kattavalle ja yhdennemukaiselle terminologiselle systeemille, joka koskee paperin kierrätystä. Tämän yhdennemukaisen terminologian tulisi olla sellainen, että sitä voidaan käyttää maidenmanlaajuisesti, kaikilla maantieteellisillä alueilla, ja sen tulisi kattaa alan kaikkien sidosryhmien tarpeet.


<table>
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<tr>
<th>Avainsanat</th>
<th>keräyspaperi, kierrätys, paperiteollisuus, terminologia</th>
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This study was conducted at Aalto University in the Department of Industrial Engineering and Management.

Several skillful and helpful experts have been of assistance during the research project. I am most grateful to them for the time they have given to me.

I am most grateful to my supervisor, Professor Ilkka Kauranen, who has helped me clarify the subject for an academic research study. He has also given me valuable comments, advised and guided me through the bureaucratic process, and arranged the facilities for me to make this project possible.

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Finally, I thank my friends, my two daughters Minttu and Enni, as well as all my relatives who have supported me in my work. Especially, I am grateful to my spouse Merja Siren, who has understood and supported me during these busy years of research. To them I owe this publication.

Espoo, December, 2016
Ilpo Ervasti
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List of Abbreviations and Symbols

**Abbreviations**

ACOR  Australian Council of Recyclers  
AF&PA  American Forest & Paper Association  
ARP  Acceptance of recovered paper  
AuRPS  Australian recovered paper specifications  
BIR  Bureau International Recycling  
CEPI  Confederation of European Paper Industries  
CEN  European Committee for Standardization  
COST  European Cooperation in Science and Technology. European intergovernmental network for cooperation in research  
CPO  Computer printouts (recovered paper grade)  
CTP  Centre Technique du Papier – Paper Research Center - France  
DIP  De-inked pulp  
EC  European Commission  
EcoPaperLoop  Eco Design for the Enhancement of Central Europe Paper Based Product Recycling Loop. A Project funded by European Union regional development fund  
EEA  European Environment Agency  
EN 643  European list of standard grades of recovered paper  
EPA  Environmental Protection Agency – United States  
ERPA  European Recovered Association  
ERPC  European Recovered paper Council  
EU  European Union  
Europe  As a statistical region Europe consists of EU 27 + Norway and Switzerland  
Eurostat  The statistical office of the European Union  
FAO  Food and Agricultural Organization of the United Nations  
FOEX  A private company to provide pulp, paper and recovered paper price indexes  
FEFCO  The European Federation of Corrugated Board Manufacturers  
Framework  Term used to describe different MFAs (Material Flow Accounts) and material flow diagrams  
GOST  National standards of the Russian Federation and CIS (Commonwealth of Independent States) countries  
HMP  Hard mixed paper (recovered paper grade)  
HSE  Health and Safety Executive – the United Kingdom  
IEA  International Energy Agency
Ingede International Association of the Deinking Industry - Germany
ISRI Institute of Scrap Recycling Industries – United States
Kraft Unbleached (sulphate) wood pulp
LCA Life Cycle Assessment
MFA Material flow account
MOW Mixed office waste (recovered paper grade)
MRF Material recovery facility
Net trade Product exports – product imports
OCC Old corrugated containers (recovered paper grade)
OECD The Organization for Economic Co-operation and Development
OI, OIN Over-issue news (recovered paper grade)
ONP Old newspapers (recovered paper grade)
OMG Old magazines (recovered paper grade)
PAB Paper and board
Paper In this present study includes paper and board
PB Paper and board
PPI Pulp and Paper International - Magazine
PRASA Paper recycling association of South Africa
PRPC Paper Recycling Promotion Center - Japan
PTS Papier Technische Stiftung – Paper Technology Foundation - Germany
P&B Paper and board
QM form Quality monitoring form
RCF Recycled fiber
RCP Recovered paper
RP Recovered paper
RR Recovery rate
RWE Roundwood equivalent. RWE corresponds to 1 m³ of solid wood measured under bark
SFA Substance flow analysis
SFS Finnish standards association
SOW Sorted office waste
TSK Sanastokeskus - The Finnish terminology centre
UN United Nations
UPM United paper Mills – private forest industry company
UR Waste paper utilization rate
VDP Verband Deutscher Papierfabriken – German Papermills' Union
WBN White blank news (recovered paper grade)
WP Waste paper
### Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>E</td>
<td>Energy</td>
</tr>
<tr>
<td>h</td>
<td>height</td>
</tr>
<tr>
<td>m³</td>
<td>One cubic meter of SOLID wood measured under bark</td>
</tr>
<tr>
<td>M</td>
<td>Mass</td>
</tr>
<tr>
<td>MC</td>
<td>Mass content of wood</td>
</tr>
<tr>
<td>MCD</td>
<td>Mass of dry wood</td>
</tr>
<tr>
<td>MCG</td>
<td>Mass of fresh (green) wood</td>
</tr>
<tr>
<td>NT</td>
<td>Net trade (material exports – material imports)</td>
</tr>
<tr>
<td>p</td>
<td>Pressure</td>
</tr>
<tr>
<td>t</td>
<td>Metric ton</td>
</tr>
<tr>
<td>toe</td>
<td>Ton of oil equivalent. Energy released by burning one ton of crude oil</td>
</tr>
<tr>
<td>Vt</td>
<td>Velocity (100 / (100 – collection rate [%]))</td>
</tr>
<tr>
<td>Σ</td>
<td>Σ is used to indicate e.g. the total sum of individual wood pulp grades</td>
</tr>
</tbody>
</table>
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**IV.** Ervasti, I., 2016. Wood fiber contents of different materials in the paper industry material chain. *Silva Fennica* vol.50 no. 4 article id 1611, 1-22.

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**Figure 1. Publications and the outline of the study**
Author’s Contribution

Publication 1: For publications I and II, Ilpo Ervasti served as the principal author. The author played a major role in planning and carrying out the data collection. The author also analyzed the data and wrote the first draft manuscripts for both publications. The final versions of the publication manuscripts were written jointly with co-authors who helped to sharpen the objective of the manuscripts, reduce the amount of text, and focus the findings into clearly worded statements.

Publication 2: For the publication III Ilpo Ervasti acted as the second author. He collected and analyzed data related to raw material end use in the paper industry. The Wheel of Fiber framework, which was used as the basic framework in this publication, was previously developed by the author together with Professor Ilkka Kauranen (Ervasti and Kauranen, 2011). The author also contributed to the data collection process and analysis. He also acted as a co-writer of the manuscript.

Publication 3: For publications IV, Ilpo Ervasti planned and conducted the study by himself and also wrote the manuscript.

Publication 4: Ilpo Ervasti planned and conducted the study by himself and also wrote the manuscript.
1. Introduction and background

A basic prerequisite for communication is that the parties involved use the same definitions for terms. If the sender does not use the same definition as the receiver, then communication becomes obscure, misunderstandings can occur, or the messages may not even be understood at all by the receiver. Every field of society and science needs to build a systematic terminology with generally accepted, uniform definitions for terms. Guidelines for building such a systematic terminology have been discussed, for example, by de Keizer and Abu-Hanna (2000), Christensen (2006), Van de Ven (2007), and Locke and Golden-Biddle (1997).

The use of terms related to material recycling in the paper industry is currently in a state of chaos. Even the basic term, describing the recycled material recovered paper, has not been defined unequivocally: there are several different definitions for the term recovered paper. In this present study, the term recovered paper is defined as material that is collected (used) paper and processed in accordance with any particular regional or global recovered paper classification system. Globally, there are a great number of different terms used interchangeably for recovered paper. These terms include, for example, the following terms: paper broke, paper for recycling, paper stock, RCF, recovered fiber, recovery paper, recycled fiber, recycled paper, RP, scrap paper, secondary fiber, secondary paper, used paper, and waste paper. Each of these terms have been used and defined by different organizations and literary sources. In this study, the term recovered paper was selected to describe the recycled material for several reasons. It describes the material well and the term is used by several organizations, such as the Australian Council of Recyclers (ACOR), the American Forest and Paper Association (AF&PA), the European Cooperation in Science and Technology (COST E48), the FAO, the Paper Recycling Association of South Africa (PRASA), and the Japanese Paper Recycling Promotion Centre (PRPC). European organizations like the Confederation of European Paper Industries (CEPI), the European Recovered Paper Council (ERPC), and the European Committee for Standardization (CEN / EN 643) have used the term recovered paper, but since 2011 these European organizations have replaced the term recovered paper with the term paper for recycling.

Recovered paper is collected from several different sources, such as households, industrial sources, trade sources, printing sources, converting sources, and landfills. Collection, sorting, and transportation, as well as trading habits
and the various motivations of individuals to recycle, vary greatly between regions. For example, a refugee girl collecting paper in a landfill area in Riyadh, Saudi Arabia, is motivated by the monetary compensation that she will receive when selling the material to a local trader (figure 2).

![Figure 2. Young refugee girls collecting paper from a landfill area in Saudi Arabia for money. (Foto: Ilpo Ervasti)](image)

In this study, the word term covers all of the different material stages and streams of the paper and board industry, from fiber material to recycling. For example, old corrugated containers (OCC), old newspapers, recovered paper, RP, recovered paper recycling, recovery, recycling rate, and waste paper are all considered terms. This study concentrates on material streams related to the paper industry sector. In this study, the term paper refers to both paper and paperboard.
Globally, there is not even a general definition for the recycled material itself, *recovered paper*. Examples of definitions that different organizations and sources have used for the term *recovered paper* are shown in table 1.

<table>
<thead>
<tr>
<th>Source</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AF&amp;PA (2008)</td>
<td>paper stock consisting of several grades</td>
</tr>
<tr>
<td>AuRPS (2002)</td>
<td>the specifications do not make a clear distinction between the terms recovered paper, waste paper, and recycled fiber. The terms have been used interchangeably. Recovered paper consists of 15 individual grades and a quality comparison has been made with the Institute of Scrap Recycling Industries (ISRI).</td>
</tr>
<tr>
<td>BIR (2013)</td>
<td>no actual definition, but different sources, such as industry, business and households, as well as corresponding grades, are sources of recovered paper</td>
</tr>
<tr>
<td>Bobu et al. (2010)</td>
<td>EN 643 defines the quality of the <em>recovered paper and board</em> grades most commonly traded in Europe</td>
</tr>
<tr>
<td>COST E48 (2010)</td>
<td>the same as the ERPC (2006) definition</td>
</tr>
<tr>
<td>EN 643 (2002)</td>
<td>no definition for <em>recovered paper</em> as such, but gives a general description of the standard grades by defining what they do and do not contain</td>
</tr>
<tr>
<td>EN 643 (2013)</td>
<td><em>paper for recycling</em>. A new term to replace <em>recovered paper</em>. Natural fiber-based paper and board suitable for recycling and consisting of a) paper and board in any shape and b) products made predominately from paper and board, which may include other constituents that cannot be removed by dry sorting, such as coatings and laminates, spiral bindings, etc.</td>
</tr>
<tr>
<td>ERPC (2006)</td>
<td><em>used paper and board separately collected</em> and, in general, processed according to EN 643</td>
</tr>
<tr>
<td>ERPC (2011)</td>
<td><em>recovered paper is called paper for recycling</em>. Used paper and board separately collected and, in general, pre-processed according to EN 643.</td>
</tr>
<tr>
<td>Hamburger (2012)</td>
<td><em>recovered paper consists of several recovered paper grades</em>. A detailed form consisting of 24 pages defines in detail what <em>recovered paper</em> may and may not include. It also defines the general conditions for acceptance of recovered paper.</td>
</tr>
<tr>
<td>Körkkö (2012)</td>
<td>a <em>recovered paper</em> stream contains all of the materials that became attached to the paper during its production and printing, e.g. fibers, fiber fines, mineral fillers, printing ink, and adhesives. In addition, a certain amount of extraneous matter, e.g. sand, glass, metal, and plastic originating from the recovered paper collection, handling and storing, are also present. It consists of a mixture of various types of paper in which, for example, the ONP/OMG ratio may vary.</td>
</tr>
<tr>
<td>Putz (2010a)</td>
<td>relates to separately collected and processed material according to EN 643</td>
</tr>
<tr>
<td>Ristola (2012)</td>
<td>separately collected and sorted discarded paper</td>
</tr>
</tbody>
</table>

To be able to define material-related terms reliably and quantify the material streams in material systems, it is necessary to form a clear picture about the material itself and how the material stream systems work. It is also important to understand the most essential stages and streams in the system. Additionally, it is important to define their mutual relations, how the material flows between stages, and how to quantify the various stages and the streams.

Environmental awareness is the most important motivation when trying to improve the paper collection rates in Europe (Miranda et al., 2009) (see figure 3).
For instance, citizens may separate waste materials into different bins at source, without the need for monetary compensation.

There is no global, generally used system to uniformly define different terms related to material recycling in the paper industry. However, several different global and regional organizations have their own recovered paper classifications systems and definition systems for terms related to paper recycling, but none of these systems has been generally adopted. For example, though the Food and Agriculture Organization (FAO), a global organization, as well as several regional organizations, have their own lists of terms and their own definitions, still no uniform, globally adopted terminological system exists. Many authors misleadingly use terms from more than one organization at the same time without mentioning it.

The chaos in the use of terms related to material recycling in the paper industry is so severe that it is difficult, for example, to compare different literature sources with each other. Material recycling in general plays an important role in different sectors of society. Due to concerns about the environment, climate change, and the optimal utilization of natural resources, attention has increasingly been paid to reducing waste, to the effective utilization of raw materials, to material recycling, and to the proper disposal of waste.

Resource efficiency is one of the most important challenges currently faced by the European Union (EU) and other geographical communities. Resource-efficient utilization of raw materials is needed for sustainable growth (EC, 2013). Easily understandable and robust indicators are essential for improving how resource efficiency is measured and for underscoring the importance of different nations, business sectors, and disciplines consistently using the same definitions related to resource efficiency. However, such standardization is challenging in practice.
In this study:

- different terms related to material recycling have been identified and analyzed as comprehensively as possible. These terms have been used in different literature sources and in material stream frameworks related to the paper industry. Depending on the literate source and time, different terms are used for the same matter; likewise, often the same term is used to refer to different matters;
- a new material stream framework has been developed. The framework is called the Detailed Wheel of Fiber. The framework includes those material streams and material stages found in different literate sources. The material streams and material stages are marked with letter symbols;
- the Detailed Wheel of Fiber and its letter symbols are used to uniformly define recycling-related terms;
- different material streams and stages in the paper industry have been quantified. To be able to compare the material contents of the different streams and stages with each other, the material was divided into three main components: fiber, a non-fiber component, and water. The European region was used as a case study when quantifying the material streams;
- a set of conversion factors has been developed. These conversion factors make it possible to convert the fiber contents of paper, wood pulp, and recovered paper into to comparable units. In this study, roundwood equivalent (RWE) is used as the common denominator. One RWE corresponds to 1 m$^3$ of wood measured under bark.

Special attention has been paid to different terms which have been used both in the literature sources and the identified paper industry material flow frameworks. These terms may consist of several different words like recovered paper recycling rate. For this reason terms used have been denoted in italics.
2. Study objective

For all those who have worked in the field of paper recycling, it has long been obvious that inconsistencies and various un-clearities in the terminology of this field do indeed exist. Since the terminology in the field of paper recycling does not fulfil all the requirements for unambiguous communication, negative consequences have resulted and several attempts have been made to fix the situation. These attempts have, at best, addressed individual issues that have emerged and, as such, they have remained separate patchwork solutions. No concerted effort to create a comprehensive, uniform terminological system for paper recycling has been made until now.

The objective of this research study was to create guidelines for a comprehensive, uniform terminological system for paper recycling. The uniform system should be such that it can be used globally, cross all geographical regions, and it should meet the needs of all stakeholders in the field.

In physics and chemistry, there is a uniform terminological system in use. Different terms have same definitions and they are defined globally using common letter symbols. For example, height = h, mass = M, energy = E, and pressure = p. In medicine, Latin terms are used to define different parts of the human body and different diseases at a global level.

The new terminological system for paper recycling should endure over time so that, with the exception of possible minor amendments, the basics of the new system will not need any modifications. In this study, the terminological system is presented at the conceptual level, and different terms have been given letter symbols in alphabetical order. Later, if needed, it will be possible to assign letter symbols to the different terms, which will better describe the terms in question.

A starting point in creating a new terminological system is to thoroughly investigate the existing terminological system in use. In the case of paper recycling, this means investigating many parallel systems, as there is no single terminological system in use for paper recycling. An analysis of the existing situation is one independent end-result of this research study, because an all-inclusive picture of the terminological systems used around the world does not exist. Such a description of the extant situation will also reveal the nature and magnitude of the task of creating a new uniform terminological system: It will reveal whether amendments based on the existing system will be sufficient or if a new conceptual foundation is even needed when creating a new terminological system. An important consideration is that any new system needs to take into ac-
count the existing practices in the field in order for the new system to be accepted and be taken into use. A prerequisite of the present study is that the proposed guidelines for a new system makes no compromises in clarity or in logic because of trying to accommodate itself to the starting point represented by the old systems.

The first sub-objective of this study is, thus, to provide a comprehensive analysis of existing terminological systems for paper recycling. The different systems will be compared with each other. Their possible deficiencies will be revealed. The analysis will include the various systems being used in Europe, North America, and Japan. Systems that are currently being used by the major stakeholders in the field are also included. When inconsistencies in the terminological systems are found, an attempt will be made to understand why there are differences between the systems.

A new terminological system for paper recycling must be based on a thorough understanding of the material streams and stages in the material chain of paper recycling. Several frameworks for describing the material streams and stages in paper recycling have been introduced in the extant literature and are being used by practitioners. Similar to the situation concerning the terminological systems, the extant frameworks are not consistent and there has not been a concerted effort to comprehensively analyze the extant frameworks.

Accordingly, the second sub-objective of this study is to provide a comprehensive analysis of existing frameworks for describing the material streams and stages in the paper recycling industry. The different frameworks will be compared with each other. Their possible deficiencies will be revealed. A representative group of known frameworks presented in the academic literature or those being used by industrial organizations or other relevant organizations are included in the present study. When inconsistencies in the frameworks are found, an attempt will be made to understand why there are differences between the various frameworks.

The third sub-objective of this study is to create a comprehensive, uniform framework for describing the material streams and stages in the material chain of the paper recycling industry. This framework will be based on a thorough understanding of the material streams and stages in the paper industry. Existing frameworks will be accommodated in the new framework with the intention of including in the framework all the material streams and stages that are part of the existing frameworks. The creation of a comprehensive, uniform terminological system for paper recycling is only possible if it is based on a rigorous understanding of the material streams and stages in the material chain of the paper recycling industry. Such an understanding is represented by the new framework of the material chain that will be created in this study. The new terminological system will only be unambiguous if the corresponding new framework is unambiguous.

The fourth sub-objective of this study is to present a method to quantify the material streams and stages in the material chain of the paper recycling industry. The materials in the paper recycling industry consist of different compo-
nents, such as fiber, water, and non-fibrous components. Each of these compo-
nents behaves differently in the material chain. To quantify fibrous materials in
the material chain, a common denominator is necessary: the term RWE is the
common denominator. The quantifying of the streams and stages is done from
the viewpoint of creating the necessary thorough understanding of the material
chain in the paper recycling industry, and this is part of the foundation work for
creating a comprehensive, uniform terminological system for the paper recy-
cling industry.
3. Study structure

The structure of this study is presented in figure 4. First, the study describes the objective, problem formulation, and data collection process. After this, the data was analyzed, the main findings are presented, and conclusions are drawn.

Objective:
- To create guidelines for a uniform terminological system for paper recycling

Sub-objectives:
- Analysis of terminological systems
- Analysis of existing material frameworks
- Creation of a uniform framework
- Quantification of material streams and stages

Data collection and analysis:
- Use of terms
- Different frameworks
- Paper industry raw material use

Qualitative analysis:
A) no uniform global terminological system exists
B) no uniform global raw material framework exists

Development:
1) a new material framework the "Detailed Wheel of Fiber"
2) guidelines for a new terminological system to define terms related to recycling

Combination:
framework, terminology, and raw material end use data

Figure 4. Structure of the study
4. Study methodology

4.1 Data collection

This study uses both qualitative data and quantitative data. Qualitative data was used in publications I and II. Quantitative data was used in publications III and IV.

4.1.1 Qualitative research approach

A qualitative research approach was used in publications I and II. Usually, different players interpret matters and pose questions based on their own particular understandings and points of view. The same matter can be understood and described in many ways. The starting point in qualitative research is a description of the actual situation. A basic assumption is that the reality of any given situation is complicated. Researchers must take into account the fact that reality cannot randomly be cut up into different pieces. Different occurrences may be interconnected. In qualitative research, the study phenomenon should be studied holistically. Generally, in qualitative research it is essential to find and reveal facts rather than verify existing claims.

An exploratory research approach was used in the study. This approach can be used if the research problem or research focus is not clear. Exploratory research often uses material from available literature, case studies, and focus groups. The exploratory study approach is useful when the purpose is to learn more about a particular phenomenon or obtain new insights into it in order to develop a hypothesis or formulate a more precise problem. Exploratory research is useful for gaining experience while formulating a relevant hypothesis for more precise research. It often occurs before we know enough to make conceptual distinctions or posit explanatory relations.

Bontis (1998) notes that, for example, in an exploratory study the component analysis and path analysis are incorporated a priori into a theoretical and measurement model, and thus the parameters are estimated in this specific context.

After the problem had been formulated, several sources were identified and relevant written sources were selected and used at the design stage of data collection. A detailed literature review was then carried out.

The following search engines, databases, and organizations were used to identify and collect material for this research study: Aalto University library services,
Ask.com, Bing, Google, Google Scholar, Infomine, Start page, Yahoo News, and Yahoo Search.

Numerous journal articles, conference papers, books, and other research reports were used as sources of research data. In addition, a wide range of publications by various industry associations and individual companies as well as official and unofficial statistics and definitions on the field were utilized. The reference lists of the publications included in the literature study were reviewed in order to identify additional sources. In terms of geographical regions, the main emphasis was given to Europe, the U.S., and Japan.

A comprehensive literature review was carried out to obtain a detailed picture of the terminology and material frameworks currently in use. The existence of chaos in the existing terminology was illustrated by, for example, analyzing the FAO terminology. This case test shows that it is not possible to unambiguously understand the terms used by the FAO based on the present terminological system. The main reason for this situation is that several different material frameworks and terminological systems are currently using different terms and different definitions.

A material framework was developed. The Detailed Wheel of Fiber (Ervasti, 2015; Ervasti et al., 2016b), is based on the Wheel of Fiber framework (Ervasti and Kauranen, 2011) which describes material recycling at a general level.

In addition, components from several different material frameworks used in the paper industry were adopted. The Wheel of Fiber framework was successfully tested using ten different material frameworks for the paper industry (Ervasti, 2015). Even the test of the CEPI (2013a) framework, which is the most complex of the tested frameworks, was carried out successfully. All streams and stages of the CEPI framework can be defined using the Detailed Wheel of Fiber framework. Before the Detailed Wheel of Fiber framework, no existing framework could be used to uniformly define all the existing, incoherent material frameworks in the paper industry.

4.1.1.1 Data collection – qualitative data

The sources referred to in the study include several different international and regional organizations as well as scholars whose publications were cited during the research process. The use of terms and their definitions were analyzed for all the sources (Ervasti, 2015).

The identified and analyzed organizations are shown in table 2. The table also shows the geographic coverage of each of the organizations.
It must be noted that the geographical coverage of an organization can be wider than indicated in the table. For example, American recovered paper grade classifications (ISRI) are also in use in a number of importing countries (Kirpa Impex, 2013).

4.1.1.2 Data collection with respect to terms

Each document was carefully scrutinized in order to select from the text any definitions of terms related to recycling in the paper industry. In many cases, the sources did not provide any definitions for the related terms being used. In such cases, the author of this study used his best judgment to establish what particular definition the source had used. In some cases, the definitions for the terms that had been used could be determined by making calculations based on the statistical material given in the source. In many cases, however, it was not possible to figure out what definition had been used for the terms in question.

4.1.1.3 Data collection with respect to frameworks

Ten different frameworks related to material streams in the paper industry were identified and analyzed in detail (Ervasti, 2015). Four of the frameworks were published by researchers and six were published by organizations. Though in this study only the word “framework” is used, in the original sources the authors had used words like paper system, recovered paper balance, paper recycling loop, material stream, and fiber stream chart.

Material streams and the different stages of the frameworks were compared with each other. The various stages of the different frameworks could not necessarily be compared with one another. The identified stages of the different frameworks were grouped into five stages, which are common for all frameworks. For example, there is great variation between the definitions and terms used to describe the paper consumption stage. The Wheel of Fiber framework identifies five stages: paper consumption, recovered paper collection, recovered paper utilization, paper production, and other options (Ervasti and Kauranen,
2011). Other options refers to recovered paper used for end uses other than paper manufacturing, including also its energy use. This term also includes the volume of paper not collected and disposed of paper.

### 4.1.2 Quantitative research approach

Several sources of data were used to define the production and consumption volumes of different materials as well as to convert the different materials into RWEs. These sources include CEPI (2011), COST E-48 (2010), FAO (2010), FAO / UNECE (2010), the Forest Legality Alliance (2014), the Global Timber Organization (2015), Indufor (2013), Keränen and Ervasti (2014), and Pöyry (2006).

The basic year for statistical material is 2010. The reason for selecting this particular year is that detailed statistics from several sources, including raw material uses for different paper grades, are available for this year. Additionally, data from later years that cover all EU countries with the same detailed grade distribution are not available. Quantification of amounts of non-fibrous components in recovered paper (Keränen and Ervasti, 2014) and quantification of fiber contents of different paper industry materials (Ervasti, 2016; CEPI, 2011; Indufor, 2013) use this data. Additionally, collection and utilization statistics for global recovered paper as well as wood material statistics were available for the same year. This study uses European-level data to quantify the material streams. The European figures are sums from the 27 individual EU countries.

### 4.2 Analysis of collected data

#### 4.2.1 Analysis of qualitative data

During the analysis phase, all data from the literature review, including the definitions from the different sources, were compared with each other. If differences in the definitions were discovered, the reasons for these differences were analyzed. Special emphasis was given to detecting if the differences were associated with a particular geographical region, the organization providing the definition, or the time period in question. Hundreds of different terms related to recycling were identified. Examples of the identified terms related to paper recycling are presented in this study. The most commonly used terms and their definitions were listed and sorted based on the source.

#### 4.2.2 Analysis of quantitative data

The quantitative material analysis involved six steps. The use of the term stage relates to material and its movement within the material framework. Likewise, the different materials at different streams and stages were quantified.

At first, the entire material chain of the paper industry was described by dividing it into relevant stages, corresponding materials, and the relations between these stages. For example, wood pulp production is related to pulpwood consumption, whereas paper production is related to the consumption of wood
pulps and recycled fibers. The Detailed Wheel of Fiber framework is used to describe the material chain.

Second, the different raw materials used in paper production were assigned grade-specific quantifications. The different wood pulp grades and non-fiber material volumes needed to produce different paper grades were quantified. This was done by using existing raw material furnish tables for European paper production (CEPI, 2011; Indufor, 2013).

Third, the amount of pulpwood consumption for a ton of wood pulp was quantified. This calculation was done separately for different wood pulp grades by using unit consumption figures (RWE consumed) / (ton of wood pulp produced).

Fourth, different materials at different stages of the framework were divided into three material components, namely dry fiber (0% water), water, and non-fiber components.

Fifth, two different fiber material chains are described and compared with each other. The two chains are the virgin fiber chain and the recycled fiber chain. Due to terminological and quantification inconsistencies with respect to the recycled fiber chain, it is important to define and analyze these fiber material chains separately.

Sixth, the (dry) fiber components of different materials were converted into RWEs using calculated conversion factors. By taking into account differences in the material component, including moisture differences between the different materials, it was possible to calculate the RWE content for total paper, total wood pulp, and total recovered paper. The conversion factors used to convert different material totals into RWEs were produced by dividing the material-related RWE volumes by the corresponding material volumes. The structure used for the quantitative analysis, including all six steps, is shown in figure 5.
Study methodology

Figure 5. Quantitative analysis — different steps
5. Publications

5.1 Publication I: A global, comprehensive review of literature related to paper recycling. A pressing need for a uniform system of terms and definitions

A global, comprehensive review of terms and definitions related to paper recycling was conducted in this article. The terms and definitions related to paper recycling have varied over the course of time. Different terms and different definitions for the same term are currently being used in different geographical regions and by different organizations. The definitions are different based on varying conceptions of waste paper as a raw material. Definitions for how to make various calculations related to paper recycling activity are inconsistent. Even such fundamental basic definitions as how to calculate recycling rate and paper consumption are not uniform.

It could be concluded that there is no uniform system of terms and definitions related to paper recycling, and the implications of this deficiency are profound. For example, it is difficult to reliably compare statistics from different times and from different geographical regions. It is not possible to measure whether targets for recycling activities are met if the terms describing the targets are not uniformly defined. In cases where data for recycling targets are reported, the lack of uniform terminology can, for example, impede the necessary transparency between different stakeholders and may allow for deception. The authors conclude that the use of terms related to recycling is currently in a state of chaos. There is a pressing need to develop a uniform system of terms and definition for terms related to paper recycling.

5.2 Publication II: Paper Recycling Framework, the “Wheel of Fiber”

At present, there is no reliable method in use that unequivocally describes material streams in the paper industry and makes it possible to compare geographical regions with one another. A functioning paper industry Material Flow Account (MFA) that uses uniform terminology and standard definitions for terms and structures is necessary. Many of the presently used, general-level MFAs, which are called frameworks in this publication, stress the importance of input
Publications

and output streams but do not provide a uniform picture of material recycling. The paper industry is an example of a field in which recycling plays a key role. Additionally, terms related to paper industry recycling, such as collection rate, recycling rate, and utilization rate, are not defined uniformly across regions and over time. Thus, reliably comparing material recycling activity between geographical regions or providing regional summaries is often difficult or even impossible. The objective of the publication was to offer a partial solution to the problem of not having a reliable method in use that unequivocally describes material streams and material stages in the paper industry. This was done by developing a new material stream framework for the paper industry in which the stream and stage structure support the use of uniform definitions for terms related to paper recycling. This new framework was termed the Detailed Wheel of Fiber.

5.3 Publication III: Amount of non-fibrous components in recovered paper

Paper recycling is now a central issue in papermaking. How to properly understand material streams as a part of the total material chain as well as fibrous and non-fibrous component streams needs further clarification. These streams were studied at the European level, with special focus on Germany and Sweden. Non-fibrous components are discussed in terms of materials that hamper the processing of recovered paper. Resource-efficiency improvements, in conjunction with economic benefits, are currently being sought and recycling has been able to fulfil both of these needs. The main drivers for maximizing the use of recovered paper in paper manufacturing have been improved over the last few decades. These drivers are cost, environmental image, and good technical properties that can be used as raw material.

The increased recycling rate has reduced the quality of the collected paper, produced recycled paper, and replaced virgin pulp. Also, recycling as a process, like deinking, produces large amounts of waste material that create large challenges with respect to proper utilization. These problem areas are addressed in this publication, too.

One area of focus in the analysis of the statistical information was to provide an estimation of the share of non-fibrous components and fiber volumes of paper in Europe.

According to findings of the study, only about 41% of the fiber used in paper production comes back to circulation through recycling in Europe in 2010. This is a considerably lower than the currently used term recycling rate (69%) indicates.

5.4 Publication IV: Wood fiber contents of different materials in the paper industry material chain

At present, there are no means for reliably comparing the wood fiber contents of different material streams within the material chain of the paper industry. In
this publication, conversion factors were developed that make it possible to quantify RWE values for different paper industry-related materials in the material chain. These conversion factors apply to wood pulp, paper, and recovered paper. The following conversion factors were calculated:

- 1 ton of wood pulp is equivalent to 4 RWEs
- 1 ton of paper is equivalent to 3.1 RWEs
- 1 ton of recovered paper is equivalent to 3.0 RWEs

By using the conversion factors calculated in this study, it can be stated that the volume of 222 million tons of recovered paper collected at the global level for utilization purposes corresponds to 666 million RWEs and 167 million tons of wood pulp. This volume is approximately the same as 1.6 times the total removal of wood in Europe (EU27), or the total annual removal of wood in the USA, Canada, and Brazil combined.
6. Results

6.1 Recovered paper terminology

After collecting the qualitative data, the analysis was conducted. Different sources use and define paper recycling-related terms based on their own needs and for their own purposes. Great regional differences appear. Definitions for the terms have also changed over the course of time.

6.1.1 Recovered paper classification systems

Several geographical regions and countries as well as several different organizations have their own classification systems for recovered paper trade grades. While the contents of these classification systems are close to each other, they are not the same. Fourteen different classification systems were identified (Ervasti, 2015). AF&PA, ISRI (PS-2009), and CEPI have published lists for recovered paper grades. In Europe, CEN has twice, in 2002 and in 2013, published a list of Standard Grades of Recovered Paper. In Eurostat trade statistics, recovered paper is divided into four recovered paper grades. The FAO also divides recovered paper into four grades. The Japanese Paper Recycling Promotion Center (PRPC) has published its own recovered paper list of recovered paper grades for Japan. Russia (GOST 7933, TU 5422-004-47975996-2003), the Australian Recovered Paper Specifications (AuRPS), and the Paper Recycling Association of South Africa (PRASA, 2013) also have their own grade classification systems for recovered paper, paper stock, or waste paper. Additionally, companies like the Austrian company Hamburger Containerboard and the Indian company Kirpa Pulp & Paper Impex have published their own recovered paper classification lists.

Table 3 shows how select organizations divide recovered paper into different grades. The number of recovered paper grades related to these classification systems is also shown in the table. The organizations mentioned have detailed lists and definitions describing recovered paper grades.
Table 3. Examples of recovered paper grades and groups used by different organizations for trade and statistical purposes (Ervasti, 2015)

<table>
<thead>
<tr>
<th>Organization</th>
<th>Region / Country</th>
<th>Number of recovered paper grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF&amp;PA, 2008</td>
<td>USA</td>
<td>33 paper stock grades, divided into 5 statistical groups and further into 4 groups by combining pulp substitutes and high grade de-inking grades into one group</td>
</tr>
<tr>
<td>AuRPS, 2002</td>
<td>Australia</td>
<td>15 recovered paper grades</td>
</tr>
<tr>
<td>CEPI, 2006a</td>
<td>Europe</td>
<td>57 recovered paper grades divided into 4 groups</td>
</tr>
<tr>
<td>EN 643, 2002</td>
<td>Europe</td>
<td>57 standard grades, divided into 5 groups</td>
</tr>
<tr>
<td>EN 643, 2013</td>
<td>Europe</td>
<td>95 standard grades, divided into 5 groups</td>
</tr>
<tr>
<td>Eurostat trade statistics, 2012</td>
<td>Europe</td>
<td>4 recovered paper grades and 1 recovered paper-based pulp</td>
</tr>
<tr>
<td>FAO, 2010</td>
<td>Global</td>
<td>4 recovered paper grades</td>
</tr>
<tr>
<td>GOST 7933 (Russia)</td>
<td>Russia</td>
<td>20 recovered paper grades</td>
</tr>
<tr>
<td>Hamburger, 2013</td>
<td>Europe</td>
<td>12 recovered paper grades</td>
</tr>
<tr>
<td>Kirpa, 2013</td>
<td>India</td>
<td>recovered paper is divided into 16, 31, 46, or 55 different grades depending on the geographical origin of the material</td>
</tr>
<tr>
<td>PRASA, 2009</td>
<td>South Africa</td>
<td>16 recovered paper grades</td>
</tr>
<tr>
<td>PRPC, 2005</td>
<td>Japan</td>
<td>29 grades, divided into 9 statistical groups, 5 export grades, and 4 recovery grades</td>
</tr>
<tr>
<td>PRPC, 2010</td>
<td>Japan</td>
<td>26 grades, divided into 9 statistical groups, 5 export grades, and 4 recovery grades</td>
</tr>
<tr>
<td>PS-2009 (ISRI)</td>
<td>USA</td>
<td>51 standard grades of paper stock and 34 special grades</td>
</tr>
</tbody>
</table>

Several organizations mentioned in table 3 also give limits for the maximum share of prohibitive materials, outthrows, non-paper components, garbage, or total unwanted materials. Such organizations include AuRPS, EN 643 (2013), Hamburger, Kirpa, PRASA, GOST 7933, and PS-2009 (ISRI).

In many countries or regions, local recovered paper grade terms related to local practices are still in use. For example, in Europe sorted graphic paper for de-inking is also called 1.11, de-inking grade recovered paper, or sorted graphic paper for de-inking, D 39, according to the old German VDP list, or simply de-inking grade. Additionally, a great number of terms in local languages are still in use.

Globally, paper that has been collected and sorted so that it fulfills any generally accepted grade definition of any organization, mentioned in table 3, can be called recovered paper. It is difficult to compare the different grades used by
Results

different organizations with each other. However, in several countries the individual recovered paper grades of different organizations can be grouped into four main statistical groups such that these groups are more or less comparable with each other. Each of these principal statistical groups may have several different sub-grades depending on, for example, the raw material being used, the source, the chemical contents, the degree of sorting, and the end use purpose. The statistical groups are as follows:

- mixed grades (figure 6);
- old corrugated containers and kraft grades (figure 7);
- old newspapers and magazines (figure 8);
- high grade de-inking and pulp substitutes (figure 9);

While the contents of the grade definitions are close to each other, they are not necessarily the same. For example, according to CEPI Special Recycling Statistics (2003), old corrugated containers and kraft consists of the following (EN 643) trade grades: 1.04, 1.05, 4.01, 4.02, 4.03, 4.04, 4.05, 4.06, 4.07, 4.08, and 5.04. In the USA, the Institute of Scrap Recycling industries (ISRI) has its own definitions for different recovered paper grades. Figure 7 shows old corrugated containers and kraft grade bales used in Oman.
Recovered paper collection systems vary greatly depending on the region and collection source. In many Western European countries, consumers recycle paper without compensation. However, in several developing countries, like in China, citizens sell used paper to traders for monetary compensation (figure 8).

The best white grades of paper, such as high grade deinking and pulp substitutes from printing houses, are used as raw material to produce, for example, tissue paper and printing and writing paper as well as carton board. This normally takes the form of trade between companies. Figure 9 shows the storing of high grade deinking and pulp substitutes in St. Petersburg.

6.1.2 Great number of terms in use

The combined number of identified individual recovered paper grades used by all of the organizations identified is 445 (Ervasti, 2015). Many of the organizations have given their own codes and abbreviations for recovered paper grades. If all the names, codes, and abbreviations used by the identified sources are summed up, the total number of different terms related to individual recovered paper grades is close to 800 (Ervasti, 2015). This figure only includes terms that
are expressed in English. Many of the terms consist of several words, such as recovered paper collection, recycling for paper for recycling, recovered paper recovery rate, and waste paper utilization rate. The combinations of words greatly increase the number of terms.

6.1.3 Comparison of selected terms

The European Union uses recycling rate to indicate material recycling activity in different industry sectors. Material recycling targets have been set by the European Union as well as by different industry organizations, such as the Federation of the European Paper Industries (CEPI). In this study, attention is paid to clarifying whether it would be possible to reliably define a recycling rate for the paper industry using the definitions presently available.

To show how the same term is defined differently by different authors and organizations, two terms were selected for closer examination. These terms are recycling and recycling rate. The reason for selecting these terms is that both the European Commission and the European paper industry have published unequivocal targets for the paper recycling rate for the years to come.

In many cases, the cited sources used terms without defining them or without mentioning if they had used a definition provided by a certain organization or a certain author.

Recycling rate is used to indicate the level of material recycling activity in a particular region or country. The three voluntary recycling declarations for the European paper industry, declarations signed in the years 2000, 2006, and 2011, have set targets for the recycling rate.

The term recycling, or recycling rate, was used by 36 of the cited literature sources. The term recycling was defined in 11 cases, whereas the recycling rate was defined in 13 cases. Those sources that did not define these terms seemed to assume that the definitions for these terms are generally known. A close reading of the context or definition demonstrates that in 18 of the cases, the sources in fact meant collection based on how it is defined in the European CEPI’s annual and special recycling statistics prior to 2006. In 2006, the term recovered paper net trade was included in the calculation formula for recycling. This means that the calculation formulas for both recycling and collection turned out to be the same.

When the term recycling was defined by different sources, the definitions used by these sources varied significantly. For example, the different ways in which the various sources have defined recycling are presented in table 4.
Table 4. Definitions of the term recycling used by different sources (Ervasti et.al. 2016a)

<table>
<thead>
<tr>
<th>Source</th>
<th>Definition of the term recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIR, 2013</td>
<td>includes sorting, baling, shredding, washing, bleaching, pressing, and rolling</td>
</tr>
<tr>
<td>COST E48, 2010; Grossmann 2009</td>
<td>reprocessing of recovered paper in a production process either to produce saleable paper or to produce some other saleable product, typically including composting but excluding energy recovery</td>
</tr>
<tr>
<td>ERPA, 2000</td>
<td>reprocessing of recovered paper in a production process for the original purpose or for other purposes, including composting but excluding energy recovery</td>
</tr>
<tr>
<td>ERPC, 2006</td>
<td>reprocessing of recovered paper in a production process to form new paper and board</td>
</tr>
<tr>
<td>European Council 1994; Barrio, 2006</td>
<td>reprocessing in a production process for waste materials for the original purpose or for other purposes, including organic recycling but excluding energy recovery</td>
</tr>
<tr>
<td>Göttsching, 1996</td>
<td>utilization, processing in the paper industry within the observed country</td>
</tr>
<tr>
<td>Hamm, 2010</td>
<td>production of recycled fiber pulp for the manufacture of paper and board</td>
</tr>
<tr>
<td>Levlin, 2008</td>
<td>recovered paper used for papermaking, including utilization outside Europe</td>
</tr>
<tr>
<td>Palmer, 1997</td>
<td>refers to recycled material</td>
</tr>
<tr>
<td>Sukigara, 2003</td>
<td>recycling of fiber assemblies made from knitted sweaters and clothing</td>
</tr>
<tr>
<td>Villanueva et al., 2007</td>
<td>the term recycling refers to material recycling</td>
</tr>
</tbody>
</table>

Text analysis plays an important role in defining terms. A good example has to do with efforts to define the term recycling in a European context. By combining different definitions for terms like collection, recycling, and utilization derived from different sources, it can be shown that the definitions for the different terms are sometimes the same. The following discussion illustrates this fact.

According to ERPC (2011), paper recycling is the reprocessing of used paper in a production process into new paper and board. It should be noted that this definition does not mention the place of processing. The ERPC (2005) defines utilization in the context of paper and board industries as the use of recovered paper as raw material put into pulp at the paper mill. For this reason, it would be easy to assume that recycling is equal to utilization. The ERPC (2011) further defines recycling rate as the ratio between the recycling of used paper and paper consumption. Here, the numerator also includes the net trade of paper for recycling. The total utilization (reprocessing) of recovered paper is the sum of recovered paper utilized domestically and exported from the region for utilization purposes. This means that the ERPC is assuming that the exported volume of recovered paper will be utilized in the destination country. Thus, the total sum of domestically utilized recovered paper and net traded volume of recovered paper utilized abroad is equal to recycling.

Recovered paper collection (CEPI, 2013a) is the sum of the utilization of recovered paper (domestically) and net trade. Thus, it is equal to recycling. In fact:

- recycling = utilization
- recycling = collection
This leads to the final conclusion that, based on these definitions, it can be claimed that: recycling = utilization = collection. Also, the recycling rate and collection rate are then equal to each other because in both cases the divisor in the calculation formula, that is to say, paper consumption, is the same. However, it is more difficult to quantify the utilization rate exactly, while it is impossible to define what share of the exported recovered paper in the destination country is used for paper production. Additionally, there are currently several different definitions for paper consumption (Ervasti, 2015).

In this context, the author of this study would like to point out that it is not only important to define the terms uniformly, but also to select uniform symbols for the terms related to paper recycling. This would make it easier to define the ratios between the terms in formulas.

The definitions concerning recycling rate used by different sources vary quite significantly. The different ways in which the various sources have defined recycling rate are presented in table 5.

Table 5. Definitions for the term recycling rate used by different sources (Ervasti, 2015)

<table>
<thead>
<tr>
<th>Source</th>
<th>Definition of the term recycling rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ackerman et al., 2010</td>
<td>refers to the recovery rate</td>
</tr>
<tr>
<td>Barrio, 2006</td>
<td>((B+C) / A), where (A) = packages placed on the market, (B) = material recycling and (C) = organic recycling and use for other purposes</td>
</tr>
<tr>
<td>CEPI Annual Statistics, 2006; Special Recycling Statistics, 2005</td>
<td>((\text{recovered paper utilization}) / (\text{paper and board consumption}))</td>
</tr>
<tr>
<td>CEPI Annual Statistics, 2008</td>
<td>((\text{recovered paper utilization} + \text{net trade}) / (\text{paper and board consumption}))</td>
</tr>
<tr>
<td>EPA, 2012</td>
<td>((\text{total recycled by weight}) / (\text{total discarded and recycled by weight}))</td>
</tr>
<tr>
<td>ERPA, 2000</td>
<td>the ratio between recovered paper utilized for recycling and paper and board consumption</td>
</tr>
<tr>
<td>ERPC, 2006 and COST E48, 2010</td>
<td>the ratio between RP (recovered paper) utilized for recycling, including RP net trade and paper and board consumption</td>
</tr>
<tr>
<td>Kaila, 2010</td>
<td>((\text{recycling}) / (\text{potential}))</td>
</tr>
<tr>
<td>Klimek, 2011</td>
<td>((\text{waste paper utilization}) / (\text{paper consumption})) w/o trade</td>
</tr>
<tr>
<td>Klimek, 2011</td>
<td>((\text{waste paper collection}) / (\text{paper consumption}), including trade)</td>
</tr>
<tr>
<td>Levlin (2008)</td>
<td>recovered paper used for papermaking, including utilization outside Europe</td>
</tr>
<tr>
<td>Miranda &amp; Blanco, 2010</td>
<td>((\text{RP utilization in paper industry}) / (\text{paper consumption}))</td>
</tr>
<tr>
<td>PRASA, 2012</td>
<td>((\text{recovered recyclable paper}) / (\text{recoverable paper}))</td>
</tr>
</tbody>
</table>

In general, recycling rate is the ratio between paper recycling and paper consumption. During the data analysis process, several different definitions for recycling rate, paper recycling, and paper consumption were identified. This means, in fact, that recycling rate can be calculated in a number of different ways.
When terms do not have generally accepted, uniform definitions, the authors should clearly indicate what definitions they are using or what they mean when selecting a certain term in order to avoid creating confusion amongst readers. Since there are different definitions for almost all terms related to recycling, the author of this study suggests that all authors should always define the terms that they use in their texts and statistics.

Many sources have used case-specific symbols for selected terms. For example, Berlund and Söderholm (2003) have expressed the ratios between terms with symbols and formulas. However, the use of such symbols and formulas cannot be recommended because the terms used are case specific. Recovery rate is expressed with the formula $RR = \frac{((WP\ cons) + (WP\ ex - WP\ im))}{(PB\ cons)}$. In this formula, $RR$ = recovery rate, $WP\ cons$ = waste paper consumption, $WP\ ex$ = waste paper exports, $WP\ im$ = waste paper imports, and $PB\ cons$ = paper consumption.

The Japanese PRPC (2012) uses the following formula to calculate recovery:

$$H = (G + G' - E + F),$$

where $H$ = recovery, $G$ = recovered paper supply, $G'$ = deinked market pulp shipments, $E$ = imports of recovered paper, and $F$ = exports of recovered paper.

Palmer et al. (1997) use the formula

$$(W = Q - R)$$

to define waste, where $Q$ = total consumption of goods, $R$ = recycled volume, and $W$ = waste disposed.

Klimek (2011) also uses several formulas to define selected terms:

Utilization rate $= D / A$, recycling rate without trade $= D / B$, and recycling rate with trade $= C / B$. In the formulas, $A$ = paper production, $B$ = paper consumption, $C$ = waste paper collection, and $D$ = waste paper utilization.

Barrio (2006) expresses recycling rate with the following formula:

$$(B + C) / A,$$

where $A$ = packaging placed on the market, $B$ = material recycling, and $C$ = organic recycling and use for other purposes.

Additionally, CEPI (annual statistics, 2007) defines utilization rate as follows:

$$(E / G).$$

In its formula, $E$ = total use of recovered paper and $G$ = total paper production.

These examples show that there are great variations both in the formulas and in the symbols used when defining terms. In the future, it is important that different recycling-related terms have uniform definitions and uniform symbols. This would make it easier for different players in the field to explain what they
really mean when discussing issues related to recycling. Symbols should be defined at the same time that a uniform terminological system is developed.

6.1.4 Terms related to time

The situation pertaining to European definitions and their comparability to definitions in other regions is ambiguous. Some terms that previously were included in the European lists of definitions are not listed there anymore. The latest lists of definitions in the European Declaration on Paper Recycling (ERPC, 2006, 2011) no longer include a definition for recovery. In the recent annual CEPI statistics, recycling rate and utilization rate are listed, but collection rate, which was included previously, has now been omitted. Additionally, the European Declaration on Paper Recycling for 2011–2015 (ERPC, 2011) claims that the term recovered paper is outdated and that paper for recycling should be used instead.

It is quite natural to drop some terms from the lists of definitions as times change. For instance, as recycling has become even more desirable ethically and waste paper or recovered paper has become increasingly important as a source of raw material, several industry associations have dropped the use of the term waste paper in favor of recovered paper to avoid the material being associated with solid waste. Another trend has been that the export and import of recovered paper has increased on a global level and recovered paper has clearly established itself as an international trade commodity.

Also, the grade definitions for different recovered paper grades change over time. For example, the European List of Standard Grades of Paper and Board for Recycling (EN 643, 2013) differs from the previous European List of Standard Grades of Recovered Paper and Board (EN 643, 2002). The number of individual grades has increased from 57 to 95. Additionally, new definitions, such as the share of non-paper components and total unwanted materials, have been added for individual grades. This same process of changing the grade descriptions is also occurring in the United States. When comparing the Institute of Scrap Recycling Industries’ (ISRI) Guidelines for Paper Stock PS-2013 with PS-2009, it can be noted that there are differences between 13 grades where either the name, definition, or number code of the grade has been changed. On some occasions, a grade has even been removed from the list. Grade definitions have also changed in Japan. When comparing the PRPC (2012) list of Japanese standard qualities for recovered paper with the corresponding list from the year 2005 (PRPC, 2005), many changes can be found: for instance, the total number of individual grades has been reduced from 29 to 26. At the same time, the number codes for 20 different recovered paper grades have been changed.

6.1.5 Terms related to organization and region

Many organizations have published their own classification lists for individual recovered paper grades. The documents analyzed for this study were from 14 different organizations. Of them, 12 were regional organizations and 2 were
companies that have published their own classifications and definitions or lists for individual recovered paper grades.

There is no generally accepted system for comparing the individual recovered paper grades with one another. In many cases, trade between the seller and the buyer and quality requirements are based on a separate mutual agreement and samples.

In the field of recycling within the paper industry, even the basic terms that include the words recovery or recycling do not have a generally accepted, uniform meaning. For example, in the United States the definition provided by the American Forest and Paper Association (AF&PA, 2008) defines recovery rate as the ratio between the recovered paper collection and new supply of paper, whereas in Europe the definition provided by the Federation of European Paper Industries (CEPI, 2013a) defines recycling rate as ((paper for recycling utilization) + (net trade of recovered paper)) / (total paper consumption). Based on their respective definitions in the U.S. and Europe, new supply of paper and paper consumption mean nearly the same thing. Thus, recovery rate as it is defined in the U.S. and recycling rate as it is defined in Europe mean the same thing, even though the terms being used are different. However, in 2006 CEPI changed its use of terms in its statistics: What is today defined as recycling rate (ERPC, 2011) was, according to the definition provided prior to 2006 (ERPA, 2000), called collection rate. All in all, the three different terms—recovery rate, collection rate and recycling rate—can mean the same thing depending on the geographical region, the organization providing the definition, and the point in time during which the term was used.

Even the term recovery itself has been defined differently in several regions. In Japan, the Japanese Paper Recycling Promotion Centre (PRPC, 2010) defines recovered paper recovery (H) as follows: (recovered paper supply, G) + (shipments of de-inked market pulp with yield of 80%, G') – (recovered paper imports, E) + (recovered paper exports, F'). A formula is provided to define the term recovery (H=G+G'-E+F), but this formula and the letters used in the formula only clarify different terms used in the corresponding data table, “trends in recovered paper recovery rate” is how the publication puts it. In the PRPC (2010) framework, the term recovered paper shipment for mills is used instead of recovered paper supply. In Europe, the European Recovered Paper Association (ERPA, 2000) defines recovery as a principle of waste management policy consisting of re-use, material recycling, composting, and energy use, as well as exports for similar purposes. It can be mentioned that, according to the definition provided by the European Recovered Paper Association (ERPA, 2000), recycling of paper consists of the reprocessing of recovered paper in a production process for its original purpose or for other purposes and composting, but it excludes energy use.

The American Forest and Paper Association (AF&PA, 2008) defines recovery as (domestic consumption of recovered paper) + (exports of recovered paper) – (imports of recovered paper). This is the same formula that the CEPI used to calculate recovered paper collection in Europe prior to 2006. Since 2006, this
formula has been used to define recycling in order to calculate the regional recycling rate.

6.1.6 Terms related to material stream stages

When material flows in the system between stages, terms related to the material itself tend to change accordingly. For example, if we assume that the paper consumption stage (newspapers) is the first stage of recycling, then the terms related to newspapers change as material moves through the system. According to Ervasti (2015) the terms change according to the stage as follows:

- the first stage: paper (consumed). In the paper stage, the terms relate to the end products themselves, such as newspaper and printed matters. Paper products may consist of several different materials. For example, a printed newspaper consists of paper (newsprint) and printing ink;
- the second stage: material is called waste paper or household waste. The main share of newspapers are collected from household sources. Due to the degree of converting, contamination, or mixing with other waste materials, the quality of this material varies. A certain amount of waste paper is always lost when waste paper is converted into recovered paper through the collection and sorting process;
- the third stage: recovered paper. This stage is closely related to the recovered paper collection stage and raw material utilization stage in the Detailed Wheel of Fiber. Terms related to newspapers are now exchanged for terms like old news and magazines, de-inking grades, ONP, etc.;
- the fourth stage: recycled fiber. In the terminological framework, this stage includes fibers after the recovered paper has been processed into a fiber form again. In this stage, terms like de-inked pulp, DIP, recycled fiber, and recycled pulp are used;
- the fifth stage: paper produced. Paper is manufactured using recycled fiber, such as de-inked pulp as raw material. The paper in question is termed, for example, recycled paper or newsprint. It should be noted that the terms related to the paper produced stage differ from the paper consumption stage terms. After printing and delivery to market, newsprint is once again in the form of a newspaper.

Terms defining the material itself change as the material moves through the material chain (Ervasti, 2015). Figure 10 provides examples of how the terms change at different stages of the recycling system and with respect to different products.
Different stages of recycling terminology

Figure 10. Different stages of the material stream and related terms (Ervasti, 2015)

*) Note: The number of different grades of recovered paper used by different organizations varies considerably. In most cases, these organizations have their own names, abbreviations, and codes for individual recovered paper grades. For example, the European recovered paper classifications system (EN 643, 2013) divides recovered paper into 95 trade grades.

The terms related to the paper produced stage and paper consumed stage are quite close to one another. There are, however, some differences between the terms that are used. Terms related to the paper consumed stage are converted products or printed products, which have been consumed either by printers, converters, or consumers. For example, terms like newspaper, containerboard, and boxes relate to the paper consumed stage, whereas terms like newsprint, case materials, liner, and fluting relate to the paper produced stage.

6.1.7 Different groups of terms

Based on the previous analyses, it is obvious that the terminology used in the field of recycling within the paper and board industry does not fulfill the criteria of uniform definitions for terms, while many different definitions for several terms could be identified. How then should the terminological system be improved? A suggestion of a solution to this problematic situation this is given in this study. In this study, a preliminary suggestion is made for a new terminological system.

The suggestion for a new system is based on the material recycling chain, which refers to the material flow from paper that has already been used and
that, after the collection and sorting process, is being treated as raw material for the production of recycled paper. Other points of departure for the new system include the fact that the existing terminological systems need to be altered so that the new system will be as consistent with the existing systems as possible, allowing for a smooth transition for users.

However, if more than one inconsistent terminological solution is used at the same time, then a decision needs to be made regarding what to include in the recommended new system. If the existing terminological system has some illogical patterns or misleading or even incorrect parts, then obviously it should not be part of the recommended new system. In developing a new terminological system, certain basic issues should be taken into account.

The material recycling chain varies depending on, for example, the country and the material. The new terminological system should be so general in nature that it covers all contexts. It should support reliability and validity in communication between all stakeholders. A sound terminological system should be unambiguous as a whole, there should not be any vaguely defined terms, and there should not be redundancy.

Developing a uniform terminological system would include systematic detailed list of terms and their definitions. In this study, the word “term” refers to all the different stages of the paper and board industry, from raw material utilization to recovered paper collection and recycling. Different terms can be grouped roughly for example into eight groups as shown in table 6.
Table 6. Different groups of terms and examples of corresponding terms (Ervasti, 2015)

<table>
<thead>
<tr>
<th>Term group</th>
<th>Examples of terms in the group</th>
</tr>
</thead>
</table>
| 1. material related terms. | a) terms and abbreviations describing the material at general level: recovered paper, waste paper, recycled fiber, recycled paper, RP, RCF, OMG, News, OCC  
   b) terms related to names of different trade grades of recovered paper. For example by EN 643, PS-2012, PRPC and AuRPS |
| 2. statistical terms which relate to stage and flow. Terms can be quantified | utilization, collection, recycling, consumption, export volume, production, shipment |
| 3. activity terms relate to relations between terms and activity level | utilization rate, collection rate, recycling rate, (adjusted) waste paper net recovery rate, recovery rate |
| 4. terms which may have a different meaning and definition depending on region, organization and time | recovery, waste paper, recycling. Additionally, for example in different regions and in their classification systems number “4” refers e.g. to different recovered paper grades including terms like heavy letters, mill wrappings, kraft grades, boxboard cuttings, tabulating cards and paper sacks |
| 5. different terms which may have the same meaning depending for example on region and time | a) (material) recycled fiber - recycled paper - waste paper – recycled paper  
   b) (statistical & activity) recovery- collection – recycling |
| 6. terms which refer to action or doing something | recovery, collection, sorting, recycling |
| 7. terms which cannot be quantified or which are difficult to be quantified reliably | recovery (in Europe), re-use, (adjusted) paper consumption, recovered paper use for other purposes outside paper industry, RP used for energy recovery, volumes related to individual recovered paper trade grades |
| 8. terms which relate to several of the above mentioned groups | recovery and collection may relate to action and different statistical terms |

This study has identified that the same terms are defined in different ways and that there is a great variation in the use of different terms. The fact that the same term may occur in several term groups increases confusion. Systematic description and additional research work is needed to develop a new uniform terminological system related to paper recycling. In this development work it is important to first group different fields of terminological chaos by taking into account varying use of terms related, for example according, to the above list, (table 6).

It is possible to carry out the grouping of terms by describing and comparing systematically the use of different individual terms and by taking into account variations which are dependent on the researcher, organization, region, and time. For example, the definition of a certain term may vary between different
organizations and regions. Also, a term like collection can be understood to be a statistical term or it can relate to the pick-up action. Such separate uses of the same term can be confusing although it is not incorrect.

6.2 Example of the use of terms. Case: FAO

Global definitions are necessary. The United Nation’s Food and Agriculture Organization (FAO) is a leading organization that produces global recovered paper statistics. Every third year between 1997 and 2010 the FAO has published four sets of global statistics (Recovered paper data) on recovered paper (FAO, 1997, 2004, 2007, 2010). These publications include statistical data from 33 to 37 countries, depending on the publication year. The FAO publication from the year 2010 uses several terms related to paper recycling, but the most interesting definitions for them have to do with the relations between terms or the activity level. FAO recycling terminology includes, for example, the following terms:

- waste paper net recovery rate
- adjusted waste paper recovery rate
- recovered paper in fiber use rate

However, even though the FAO is a global and highly respected organization, its principal terms are not commonly in use (Ervasti, 2015). The author of this study did not come up with any explanation for why the FAO terms are not widely in use. One of the reasons for this situation is that these terms are not based clearly on any framework and, due to a lack of reliable data, they are difficult to quantify.

6.3 Frameworks

6.3.1 General

Material streams in the paper industry, including paper recycling, offer an interesting sector for material stream analysis. Fibers are part of the biomass stream and originate from forests and annual plants. After having been utilized for the first time to produce paper, the fibers acquire a new life through recycling.

In this study, the streams and stages related to paper and recovered paper have been described in detail and an emphasis has been placed on the role of recycling in the material streams. Recovered paper is today the most important fiber component by volume in the paper industry. Nevertheless, the continuous injection of virgin fiber and other materials into the system is necessary in order to replace the lost material.

In material frameworks, the ratios between different streams and stages can be identified and quantified. In the paper industry, related terms include recovered paper utilization, recovered paper recycling, paper consumption, and paper production. In addition, there are terms that describe the relations between
these basic terms. Such terms can be used to, among other things, indicate the material recycling activity level within the industry. For example, the recycling rate is the ratio between recovered paper recycling and paper consumption.

Material Flow Account (MFA) is one term that is generally used for a framework. MFA can be understood as a concept covering the analysis of bulk streams of specific materials, such as paper, plastics, metal, and glass, through an economic system. In this study, MFAs are termed frameworks.

A framework shows the amount of physical inputs into an economy, material accumulation in the economy, and outputs to other economies or back to nature (Eurostat, 2001). In this context, economy can be understood as an individual country or a geographical region. Any economy-wide framework and balances, as well as indicators derived from them, provide information on the material and energy that enter into and leave an economy (Eurostat, 2001). The material balance principle leads to the assumption that total inputs = total outputs + net accumulation. All material streams have an origin and a destination.

Many organizations and scholars have developed and used frameworks to define material streams and material recycling in the paper industry. In fact, with a paper industry framework, the input streams not only turn into output streams, but output streams also turn to input streams. For example, one region’s exports of recovered paper is another region’s imports. When several regional frameworks are linked with each other via these material streams, they form a network of frameworks. In several traditional frameworks, the generated waste is regarded as an output stream, but through material recycling it turns into an input stream.

For the purposes of this study, ten different frameworks related to material streams in the paper industry were identified (Ervasti, 2015). These frameworks are used in different geographical regions by different organizations. Each of the literature sources uses a different name for its framework. The sources and names for the frameworks are shown in table 7.

Table 7. Different material stream frameworks in the paper industry and their names (Ervasti, 2015)

<table>
<thead>
<tr>
<th>Source</th>
<th>Name of the framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villenueva et al. (2007)</td>
<td>The Paper System</td>
</tr>
<tr>
<td>Indufor (2013)</td>
<td>Wood raw material flows within and between the various subsectors in EU forest-based industries</td>
</tr>
<tr>
<td>CEPI (2013a)</td>
<td>The European Fiber Flow Chart</td>
</tr>
<tr>
<td>Davidsdottir et al. (2005)</td>
<td>System Boundaries for Pulp and Paper Production</td>
</tr>
<tr>
<td>Pento (1994)</td>
<td>Material Flows of Printing Papers in Germany</td>
</tr>
</tbody>
</table>
Even when the terms describing of the streams and stages in the analyzed frameworks were the same, they do not necessarily refer to the same process in each framework. Additionally, the terms used for the various streams and stages were sometimes referred to differently, even though they may in fact be referring to the same process.

Analysis of the ten selected frameworks leads to the conclusion that there is no generally accepted uniform framework that can be used to describe material streams, including recycling, within the paper industry. In particular, the existing frameworks do not solve the need to compare and combine regional frameworks with each other in order to form a usable network of streams globally. The terms defining the different streams and stages as well as other terms related to recycling vary considerably between the different frameworks.

6.3.2 General level material recycling framework – the Wheel of Fiber

The material stream framework for the paper industry has to be understood as assuming the form of a circle or a wheel, whereby there is no exact starting point or end point (Ervasti et al., 2016b). Material input and material output occur continuously at different stages of the framework as the material moves through the system. This circle can be divided into five relevant stages. There are also inflow streams and outflow streams of material that move between the stages. Additionally, these material streams may also lead outside the wheel (for example, to another region) or else material streams can come from outside the wheel into the system.

Even though the analyzed literature sources used different terms to describe the different stages, a basic five-stage structure could be identified in all of the frameworks. Additionally, all of the selected frameworks except one, namely the EcoPaperLoop (2014), take the form of a wheel.

Based on an analysis of the frameworks, five common stages of material movement were identified. Consumed paper changes its form to become waste paper, which then becomes recovered paper during collection and sorting. After the collection stage, recovered paper is utilized in paper production. Other options include material use outside the paper industry, sorting residues, and non-collected material. Additionally, the paper stream consists of several different paper grades, each having a raw material furnish of its own, including a different combination of fibers and fillers. The structures of all of the different frameworks can be grouped using the identified five-stage approach shown in figure 11. The arrows between the stages indicate material streams.
6.3.3 Detailed material recycling framework – the Detailed Wheel of Fiber

In the framework, material flows between the different stages. Additionally, material can either flow out of the system or into the system. The different stages and material streams are shown in figure 12. For example, the figure mentions moisture in particular to indicate that changes in the moisture content between the various stages may cause variations in the expressed weights. This framework is called the Detailed Wheel of Fiber. It can be used to describe regional material streams and stages.
In this study, the letter symbols for the streams and stages are used only to distinguish between the different stages and streams. In the future, it will be possible and recommendable to change the letter symbols to better describe the various stages and streams. For example, R could describe recycling, U could describe utilization, and E could describe exports.

Descriptions of different material streams and stages in the Detailed Wheel of Fiber framework are marked with letter symbols and shown in table 8.

<table>
<thead>
<tr>
<th>Term symbol</th>
<th>Term description</th>
<th>Category: stage / stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>paper production</td>
<td>stage</td>
</tr>
<tr>
<td>B</td>
<td>domestic deliveries of paper within the region</td>
<td>stream</td>
</tr>
<tr>
<td>C</td>
<td>imports of paper</td>
<td>stream</td>
</tr>
<tr>
<td>D</td>
<td>exports of paper</td>
<td>stream</td>
</tr>
<tr>
<td>E</td>
<td>consumption of paper</td>
<td>stage</td>
</tr>
<tr>
<td>E'</td>
<td>paper consumption that is non-collectable or non-recyclable</td>
<td>stream</td>
</tr>
<tr>
<td>F</td>
<td>net trade of paper packages traded together with goods</td>
<td>stream</td>
</tr>
<tr>
<td>G</td>
<td>net trade of converted paper products</td>
<td>stream</td>
</tr>
<tr>
<td>H</td>
<td>other recycling, recovered paper utilization outside the paper industry</td>
<td>stream</td>
</tr>
<tr>
<td>I</td>
<td>recovered paper used for energy (energy recovery)</td>
<td>stream</td>
</tr>
<tr>
<td>J</td>
<td>recovered paper disposal, not recycled</td>
<td>stream</td>
</tr>
<tr>
<td>K</td>
<td>recovered paper collection. Material that fulfills the definitions set for recovered paper (N-L+M)</td>
<td>stage</td>
</tr>
<tr>
<td>K'</td>
<td>paper recycling (N-L+M). K’ is not considered a stage in its own right because the calculation formula and value for K’ are the same as for K (collection)</td>
<td>stream, K’ = K</td>
</tr>
<tr>
<td>L</td>
<td>recovered paper imports</td>
<td>stream</td>
</tr>
<tr>
<td>M</td>
<td>recovered paper exports</td>
<td>stream</td>
</tr>
<tr>
<td>N</td>
<td>recovered paper utilization rate in paper manufacturing within a region</td>
<td>stage</td>
</tr>
<tr>
<td>O1</td>
<td>non-fiber components, such as fillers and coating pigments, put into paper during the paper manufacturing process</td>
<td>stream</td>
</tr>
<tr>
<td>O2</td>
<td>non-paper components, such as adhesives, inks, films, and laminates, used during printing and the converting of paper</td>
<td>stream</td>
</tr>
<tr>
<td>O3</td>
<td>non-paper components, such as plastic, wires, and waste in general, which may enter the material stream at collection sources and during baling</td>
<td>stream</td>
</tr>
<tr>
<td>P1</td>
<td>material losses during sourcing, collection, and sorting</td>
<td>stream</td>
</tr>
<tr>
<td>P2</td>
<td>material losses at paper mills, including sorting and process losses</td>
<td>stream</td>
</tr>
<tr>
<td>Q</td>
<td>production of recycled fiber pulp at a pulp and paper mill to be used as raw material in paper manufacturing</td>
<td>stream</td>
</tr>
<tr>
<td>R</td>
<td>use of virgin wood fiber pulps</td>
<td>stream</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>use of virgin fiber pulps other than wood fibers, such as annual plants. It includes local and imported pulps</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>moisture absorbed into paper material when the consumed paper turns into waste paper</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>moisture that evaporates from virgin pulp and recovered paper during the paper manufacturing process</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>local raw wood material used for pulp production</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>imported wood raw material used for pulp production</td>
<td></td>
</tr>
<tr>
<td>WP</td>
<td>waste paper. This material makes up the recovered paper collection potential; it consists of consumed paper material from different sources. This particular material may be mixed with non-paper components, waste, and different paper grades</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>local wood pulp production used for paper manufacturing</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>net trade of wood pulp</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>other options</td>
<td></td>
</tr>
</tbody>
</table>

Each of the stages can be defined by using the selected letter symbols for the Detailed Wheel of Fiber framework as follows:

- paper production (A)
- paper consumption (E) = (A+C−D) or (E) = (B+C)
- recovered paper utilization in paper production (N)
- recovered paper collection (K) = (N-L+M)
- other options Z = (H+I+J)

### 6.4 Recycling rate: definition of terms and calculation

The importance of selected terms may vary considerably. For example, the term recycling rate can be regarded to be perhaps the most important term related to paper recycling in Europe today. A reason for this is that the European paper industry has three times issued a voluntary declaration on paper recycling, including exact recycling rate targets.

Furthermore, the European Commission recently adopted a legislative proposal (EC, 2014) to review recycling and other waste-related targets in the EU, in which it recommended increasing the recycling and re-use rates for municipal waste to 70% by 2030. It also set the recycling and re-use target for packaging paper at 90% for 2025. This means that recycling rate is a central term when describing material recycling activity in Europe. It is thus important to reliably define recycling rate and the formula for calculating it.

When comparing the European definition for paper recycling rate (ERPC, 2011) to the Detailed Wheel of Fiber, it is clear that several such material streams, which could be included in the recycling rate definition according to the analyzed frameworks, are missing from the presently used definitions. To obtain a general picture of material recycling, attention should be paid to issues
that take into account those stages and streams describing a closed loop and material that proceeds to the subsequent round. In this respect, it is important to take into account the following additional material streams when calculating the recycling rate:

- non-paper component input, such as adhesives and inks (O2), in printing and converting should be taken into account (Schmidt et al., 2007; CEPI, 2008; EcoPaperLoop, 2014);
- non-collectable and non-recyclable papers (E) could be excluded from paper consumption (EcoPaperloop, 2014; Schmidt et al., 2007);
- net trade of packages traded together with goods (F) and converted paper products (G) should be taken into account when defining paper consumption (CEPI, 2013; Pento, 1994);
- water content variation (T1) between different stages should be taken into account (Schmidt, 2007);
- other recycling options outside the paper industry, such as composting (H), should be included in the recycling volume (CEPI, 2013a; Indufor, 2013; ERPA, 2000, Villanueva and Wenzel, 2007);
- process losses in paper production, that is to say, pulping rejects and different sludges from various stages (P2), should also be taken into account (Pento, 1994; CEPI, 2013a).

By combining the ERPC’s (2011) calculation formula with the additional material streams and stages mentioned above, a detailed calculation formula for recycling rate would be as follows:

\[
\text{Detailed recycling rate} = \frac{N+(M-P_{\text{overseas}})+H-T1-P2}{(E+F+G)-E'}
\]

All the letter symbols used in the formula are explained in table 8. It must be noted that F = (net trade of packages together with goods) and G = (net trade of converted paper products) can be either negative or positive figures. If a region is, for example, a net importer of packages together with goods, then the net trade of packages (F) will be positive and it must be added to the paper consumption because it increases the paper collection potential. The letter symbol P_{overseas} refers to pulping process losses of exported recovered paper in the destination country. The calculation formula above gives a more exact picture of the recycling activity than the formulas that are presently used (ERPC, 2011). The suggested new formula also provides a more reliable picture of the closed loop because the new formula shows the material that returns to the final product itself as well as the material that passes to the next round at the paper production stage (A). The presently used recovered paper utilization (N) rate shows only the recovered paper that is fed into the pulping process without taking into account the process losses that occur before the material goes into the final product, paper.
Depending on the calculation formula used to obtain the recycling rate, the results may differ considerably. The presently used European calculation formula (ERPC, 2006) is as follows:

\[
\text{Recycling rate} = \frac{(N-L+M)}{(E)}.
\]

This formula gives a paper recycling rate of 69% for 2010. However, Keränen and Ervasti (2014) have determined that only about 41% of the fiber used in the paper production phase comes back into circulation through recycling in Europe. In this respect, the author of this study stresses that it is important to define the purpose for which the term is being used. The author of this study divides terms into two different categories, namely techno-regional and enviro-political. If the recycling rate is techno-regional in nature, then it defines only regional material recycling activity during a given period of time. The external trade of recovered paper is excluded from the recycling rate calculation formula. However, if the recycling rate is enviro-political in nature, then it means that the volume of collected material that is being recycled in another region can be added to the volume of local recycling. The volume of exported recovered paper is included in the calculation formula because that recovered paper volume is utilized somewhere globally, but outside the region in question.

When calculating, for example, the European Commission’s recycling rate targets, the author of this study understands the need to use an enviro-political term. For instance, when estimating the effects of recycling on climate change it is essential to use enviro-political terms. The expressions techno-regional and enviro-political are introduced and used by the author to stress the importance of also defining the purpose for which the term in question is being used. For the detailed calculation formula for recycling rate, the external trade of recovered paper has been included from the formula.

In practice, it is difficult to calculate the detailed recycling rate based on the formula shown above due to a lack of reliable information regarding some of the terms, such as those expressed with the letter symbols H (other recycling), T1 (moisture), P2 (sorting losses), G (net trade of converted paper products), F (net trade of packages together with goods), and E’ (non-collectable and non-recyclable paper). At present, these stages and streams can only be quantified based on rough estimations. It must be noted that the formulas and letter symbols discussed here are used for terms related to the total recovered paper. It would also be possible to present corresponding formulas for different individual recovered paper grades. However, it would be even more problematic to reliably quantify the material volumes for individual recovered paper grades at different stages and streams in paper recycling because of the lack of uniform data.

### 6.5 Comparison of virgin fiber chain and recycled fiber chain

The terms used for materials related to recycling are closely connected to the recycling framework. When material moves from one stage to another within the framework it changes form, and the terms used to define these materials
should change accordingly. This issue can be illustrated by using an analogy from the recycled pulp and wood pulp industry (Ervasti, 2015). In wood pulp manufacturing, the material chain starts with forests and trees. After the trees have been cut, they are turned into pulpwood. After the pulping process, wood becomes wood pulp. Wood pulp is used as raw material in paper production. In the wood pulp industry, the above-mentioned terms clearly define different materials. In recycled pulp manufacturing, the material chain starts with paper consumption. Paper is collected and sorted into recovered paper, which is used as raw material for recycled pulp production.

The virgin fiber analogy is illustrated in figure 13, where the virgin fiber chain (wood pulp chain) and the recycled fiber material chains in the paper industry are compared with each other. Both chains have been divided into different stages and corresponding processes. It should be noted that the stage structure in the figure is not the same as in the Detailed Wheel of Fiber framework because figure 13 describes the metamorphosis of the material itself. Figure 13 illustrates that corresponding material to be compared with, for example wood pulp, is not recovered paper, but rather recycled fiber or recycled pulp, such as de-inked pulp. In this respect, recovered paper is used as raw material in recycled fiber production and it should be compared with wood raw material (pulpwood).

![Figure 13](https://example.com/f13.png)

Figure 13. Comparison of two raw material chains (virgin fiber chain and recycled fiber chain) in the paper industry and corresponding material streams within the chain (intra-chain streams) as well as streams flowing into the chain and out from the chain (inter-streams). The abbreviation NT (Net Trade) indicates the material trade with other regions. (Ervasti 2015)

Figure 13 indicates that two different primary raw material chains feed paper production. First, the virgin fiber chain starts with the forest. After cutting, the...
material turns into pulpwood, which is used as raw material in wood pulp production. Wood pulp is then used as raw material in paper production. After production, paper is converted, printed, and consumed.

Second, paper consumption can potentially be used as waste paper. In fact, waste paper does not actually constitute a stage and its volume cannot be reliably quantified. The term waste paper has not been clearly defined and the material itself is a mixture of different materials, such as paper, moisture, contaminants, and so forth. Only after sorting and collection does this material become recovered paper, which is then used as raw material in recycled fiber (pulp) production. Recycled pulp is then used as raw material in recycled paper production, which, after the converting and printing stages, is consumed by consumers. Figure 13 shows how the different stages and corresponding material terms for the virgin fiber and recycled fiber chains should be compared:

- forest corresponds to paper consumption
- trees correspond to waste paper
- timber and pulpwood correspond to recovered paper
- wood pulp corresponds to recycled pulp (recycled fiber)
- paper corresponds to recycled paper.

It is important to note that there is no actual difference between paper and recycled paper. When producing the various paper grades, recycled pulps are used together with wood pulps as raw material.

### 6.6 Quantification of different material streams related to paper recycling

So far, it has been challenging to compare the volumes of different material stages and streams, such as paper, wood pulp, recovered paper, and pulpwood, with each other based on their wood fiber contents.

In general, it is important to find a common denominator when comparing different materials and different forms of energy with each other. According to Martin (2009), when using process costing to calculate a cost per unit, it is necessary to state all material units in terms of a common denominator. For example, in energy calculations a ton of oil equivalent (toe) is used to convert the energy values of different forms of energy into the amount of energy corresponding to burning one ton of crude oil (OECD, 2015; Eurostat, 2015).

In this study, RWE was selected as the common denominator for comparing different paper recycling-related materials with each other (Ervasti, 2016). To reliably calculate the RWE volume at different stages of the paper industry material chain, it is important to define the RWE content reliably not only with respect to wood pulp but also paper and recovered paper.

To quantify the volume of wood fiber, expressed in RWEs at different stages of the material chain, it was necessary to obtain quantitative data from several different sources. These sources include CEPI (2011), COST E-48 (2010), FAO (2010), FAO / UNECE (2010), the Forest Legality Alliance (2014), the Global

Paper production in Europe (EU-27) was 94.2 million tons in 2010. During the same year, wood pulp consumption was 43.6 million tons, recovered paper consumption 48.3 million tons, and non-fiber material consumption 14.0 million tons. The total wood pulp and recovered paper consumption rate with respect to the paper industry was 91.1 million tons (see table 9). The data in this table is based on statistics from Indufor (2013) and CEPI (2011). This data is unique and was collected for a specific European Commission study, and it covers all 27 European Union countries in 2010.

The total consumption of raw materials, namely wood pulp, recovered paper, and non-fiber materials, was approximately 13 percentage points higher than for paper production. This higher volume of raw material’s consumed compared to that of paper production can mainly be explained via the moisture differences between paper and raw materials as well as production losses. The high rate of raw material consumption can be regarded as a normal situation.


<table>
<thead>
<tr>
<th>EU TOTAL - 2010 1000 tons</th>
<th>Paper Production</th>
<th>Consumption of raw virgin materials (pulps)</th>
<th>Consumption of recovered paper</th>
<th>Grand total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Paper</td>
<td>Mech.</td>
<td>Bld sa sw</td>
<td>Bld sa hw</td>
</tr>
<tr>
<td>Newsprint</td>
<td>9006</td>
<td>2288</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Printing &amp; writing</td>
<td>32802</td>
<td>5763</td>
<td>5907</td>
<td>9027</td>
</tr>
<tr>
<td>Tissue</td>
<td>6802</td>
<td>262</td>
<td>1538</td>
<td>2129</td>
</tr>
<tr>
<td>Packaging</td>
<td>34417</td>
<td>2651</td>
<td>1390</td>
<td>2062</td>
</tr>
<tr>
<td>Other paper</td>
<td>11219</td>
<td>555</td>
<td>1858</td>
<td>1489</td>
</tr>
<tr>
<td>Total paper</td>
<td>94246</td>
<td>11519</td>
<td>10712</td>
<td>14718</td>
</tr>
</tbody>
</table>

Note:
The term paper refers to total paper and paperboard:
Mech. (mechanical wood pulp) also includes semi-chemical wood pulp
Bld sa sw (bleached sulphate softwood wood pulp)
Bld sa hw (bleached sulphate hardwood wood pulp)
Ubl sa (unbleached sulphate wood pulp)
Sulphite (sulphite wood pulp, unbleached + bleached).

While there is no reliable data to show the recycled fiber consumption volumes by paper grade, the consumption figures for different recovered paper grades are shown instead:
Mixed (mixed recovered paper grades)
OCC (old corrugated containers)
ONP (old news and magazines)
HG/PS (high grade de-inking and pulp substitutes).

When quantifying the RWE contents of different material stages and material streams, it was necessary to divide these materials into three different material components: (dry) fiber, non-fiber, and water components. Table 10 shows the shares of the different material components based on the principal material categories for Europe. The volumes of the different material components are based on an analysis done by Keränen and Ervasti (2014). While water is treated as a
separate component, it is possible to define the share of the dry fiber component (0% water) in the different material categories in the same manner and avoid possible sources of error, which are based on moisture differences between wood pulps, recovered paper, and paper.

Table 10. Volumes of different paper industry materials and shares of the raw material components in Europe in 2010 (Keränen and Ervasti, 2014)

<table>
<thead>
<tr>
<th>Paper industry materials (million tons)</th>
<th>Total volume1</th>
<th>Dry wood fiber2 component</th>
<th>Non-fiber component</th>
<th>Water component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper production</td>
<td>94.3</td>
<td>67.1</td>
<td>21.9</td>
<td>5.4</td>
</tr>
<tr>
<td>Paper consumption</td>
<td>81.4</td>
<td>58.3</td>
<td>18.3</td>
<td>4.7</td>
</tr>
<tr>
<td>Paper net exports</td>
<td>12.9</td>
<td>8.7</td>
<td>3.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Recovered paper collection</td>
<td>56.2</td>
<td>38.3</td>
<td>12.3</td>
<td>5.6</td>
</tr>
<tr>
<td>Recovered paper net exports</td>
<td>7.9</td>
<td>5.5</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Recovered paper utilization</td>
<td>48.3</td>
<td>32.8</td>
<td>10.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Wood pulp consumption</td>
<td>43.6</td>
<td>39.3</td>
<td>-</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Note:
1) The dryness of paper is 95%, whereas the dryness of wood pulp and recovered paper is 90%.
2) The (dry) wood fiber dryness is 100%.

For example, the European recovered paper collection rate was 56.2 million tons. This volume consists of 38.3 million tons of (dry) fiber, 12.3 million tons of non-fiber components, and 5.6 million tons of water.

When the impact of moisture differences in pulp and recovered paper (10%) is eliminated, the results of this study demonstrate that an average ton of dry wood fiber material (moisture 0%) consumed during the paper production process corresponds to 4.4 RWEs in Europe. This conversion factor can be calculated using the following formula: (4.0 RWEs x 1.1 = 4.4 RWEs). It is assumed that the shares of different types of fibers (hardwood / softwood and mechanical and chemical) will remain the same at the different stages of the material framework. This assumption relates to the materials present at different stages: paper production, paper exports, paper consumption, recovered paper collection, recovered paper exports, and recovered paper utilization. For all of the above-mentioned stages, it is assumed that one ton of dry fiber component (dryness 100%) corresponds to 4.4 RWEs of wood. The shares and volumes of different fibers may vary at different stages, but the assumed conversion factor gives an average picture of the ratio of dry fiber component in material to wood raw material content, as expressed in RWEs.

The average wood raw material consumption rate used to define an average ton of wood pulp (dryness 90%) consumed in Europe corresponds to 4.0 RWEs of wood per ton of wood pulp.

The total European input of wood fiber from outside the region was 60 million RWEs. This figure consists of net imports of wood fiber in wood pulp (30 million RWEs) and 30 million RWEs of imported pulpwood.
When combining the conversion factor of 4.4 to convert dry fiber (0%) into RWEs with the dry fiber contents of paper and recovered paper, it is possible to also calculate RWE conversion factors for one ton of paper or recovered paper, as shown in table 11.

Table 11. Roundwood equivalent contents in paper and recovered paper (RWE / ton paper and recovered paper) (Ervasti, 2016)

<table>
<thead>
<tr>
<th>Paper:</th>
<th>(295(^1) Million RWEs) / (94.3 Mt)) = 3.1 RWE / ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovered paper:</td>
<td>(144(^2) Million RWEs) / (43.8 Mt)) = 3.0 RWE / ton</td>
</tr>
</tbody>
</table>

Note:
1) \((67.1 \times 4.4 \text{ RWEs}) = 295 \text{ RWEs}.
2) \((32.8 \times 4.4 \text{ RWEs}) = 144 \text{ RWEs}.

Figure 14 shows the wood fiber material inputs and exits (expressed in millions of RWEs) of the European paper industry material chain in a balanced situation for the year 2010. The total RWE net value of both the input and exit streams is 173 million RWEs annually. The wood fiber input consists of different wood pulps.

Annual paper production for the European paper industry corresponded to 295 million RWEs in 2010. A volume of 122 million RWEs returned to circulation during the paper production stage. This is the volume of recycled fiber used as a substitute for virgin fibers (see figure 14).

Figure 14. The material framework for the European paper industry in 2010 and the wood material content of different materials expressed in millions of RWEs annually (Ervasti, 2016)
The findings presented in this study clearly indicate that both the terminological system related to paper recycling and the several material frameworks presently being used are not capable of unequivocally defining material streams in the paper industry.

One of the main reasons behind the terminological chaos with respect to material terms is that waste paper has been understood as a real material stage. Instead, waste paper is a redundant term for the material in the recycling chain between the paper consumption stage and the recovered paper collection stage. In this respect, waste paper is also unclearly defined. Recovered paper is not pulp but it is used as raw material in recycled pulp production.

Another reason for the confusion is that recovered paper used to be a local raw material and the related terminology was developed to serve local terminological needs. Today, when recovered paper has become a global raw material and trade commodity, a uniform, international terminology is necessary.

Further efforts are needed to improve statistical systems to reliably quantify material in the stages and streams in the material chain. This study suggests that a new uniform material framework should be created for the paper industry. The developed Detailed Wheel of Fiber framework has a great novelty value and it can be used as foundation for developing material frameworks for different recyclable materials at the global level.

At present, there is no system in place that can uniformly define symbols for different terms related to material recycling. Such a commonly used system is sorely needed. Uniform definitions for terms and symbols would also make it possible to define uniform formulas for the relations between the various terms.

However, creating and adapting a new terminological system would also create problems. If a new terminology were introduced, this would make it difficult to build a comparable time series. To a certain extent, the new statistics would be based on different definitions than those used for the existing statistics.

The paper industry is not the only user of recovered paper. By definition, other uses outside the paper industry should be included in the recycling volume (EU, 2008; ERPA, 2000). At present, this volume of paper is not included in the recycling volume. There is no reliable data about this volume of paper. Presently, the European Declaration on Paper Recycling (ERPC, 2006, 2011) has changed its definition and simply states that the term paper recycling includes only the reprocessing of used paper in a production process into new paper plus the net trade of recovered paper. However, the author of this study suggests that other
uses of recovered paper outside the paper industry should be included in the recycling volume. For example, terms like recycling, which at present is not defined in a uniform way, may include or may not include packages traded together with goods, trade of converted paper products, and other uses of recovered paper outside the paper industry.

The paper industry, especially in Asian countries, has plans to increase recovered paper-based paper production considerably (Levlin & Grossmann, 2008). The system needs a continuous inflow of virgin fibers in order to keep the system running. According to CEPI (2013b), paper can in theory be recycled up to six or seven times. The current average number of rounds, according to CEPI, is currently 3.5 in Europe. This figure is called velocity. Velocity means that during a particular period of time, the same fiber returns for another round of production (Ringman, 2014). Velocity is calculated via the following formula:

\[ Vt = \frac{1}{1-0.x} \], where 0.x = collection rate.

So, if the collection rate is, for example, 50%, then the velocity value would be 2. The opinion of the author of this study is that CEPI's figure of 3.5 is too optimistic. The formula does not fully take into account all material exits from the material chain and material losses at different stages of the chain.

The difference between the values of the presently used European (ERPC, 2006) recycling rate and the recycling rate introduced in this study is considerable. However, it has to be noted that these two recycling rates describe different phenomena. Due to exit of fibers from the system, the actual fiber amount back into the loop is considerably lower than the presently used recycling rate indicates. Continuous injection of virgin fiber into the system is necessary to replace the lost fiber material.

In most countries that have records about recovered paper use and material recycling, the recovered paper utilization volume for paper production has usually been reliably quantified. However, what is not well known is how much of the fiber in recovered paper stock goes back into circulation during the paper production stage after the pulping process. The real regional fiber volume that goes back into circulation is considerably lower than the current European recycling rate indicates (ERPC, 2006). Five main reasons for this can be listed:

- the moisture content of recovered paper is, on average, 4–6 percentage points higher than the moisture content in paper, with which it is compared;
- the share of unusable materials in recovered paper stock collected from households and sorted in material recovery facilities (MRFs) may vary by as much as 5 to 20 percentage points. In recovered paper classification systems, such as the PS-2012, EN 643, and Kirpa Impex, the allowed share of unwanted materials and outthrows varies by as much as 1 to 10 percentage points;
- in the recycled fiber pulping process, the material losses may vary by as much as 15 to 45 percentage points. This figure of losses includes such
materials as rejects, sludge, and inks. The high percentage of losses in this context refers to the production of graphic papers and tissue papers. In the production of packaging papers, the material loss percentages are usually lower;

- the exported recovered paper volume from the region is included in the regional recycling volume, even though the material is utilized in the destination country;
- the regional net trade volumes of packages traded with goods are part of the collection potential, but these volumes are not included in the statistical paper consumption volume. For example, Europe is a net importer of these traded packages.

This study points out that though several material streams, such as the trade of packaging materials together with goods, recovered paper utilization outside the paper industry, trade of converted products, and real fiber volume back to circulation, have been identified, they have not been quantified. To be able to achieve a clearer picture of the level of fiber recycling, all identified material streams should also be reliably quantified.

In addition to paper recycling, voluntary and compulsory material recycling targets for different materials, such as metals, glass, plastics, and wood, are being set for different regions. Different sectors can learn from each other when developing a recycling terminology and recycling practices in general. The results of this study can be utilized in other recycling material sectors, too.
8. Validity, reliability, and generalization

8.1 Validity

The validity of a research study refers to the degree to which the study measures what it is supposed to measure. Validity depends on the qualifications of the methodology used in the research process (Scandura & Williams, 2000). Validity requires that the theories, models, and constructs used in the study match with reality. A basic criterion of validity is a rich and strong description of the study phenomena.

When considering the validity of this study, issues that should be taken into account include the selection of data sources, analysis methods, identification of term definitions, and conclusions. With respect to selecting literature sources for this study, the literature sources all have been written by individual experts or organizations that have close relations with the paper industry. It was possible to identify several different terms and definitions related to recycling in the paper industry. In several cases, though the terms were the same, their definitions differed considerably from each other.

Two types of approach categories were used: descriptive research and document analysis. Listing the terms used and comparing the different selected frameworks and definitions can be regarded as a suitable means of analysis with respect to fulfilling the demands related to the study objective.

A comprehensive review of the terms being used and frameworks related to paper industry recycling was conducted. This study identified a great number of different terms and frameworks and their relations. The means to trace the definitions for the terms used in the study has been provided for the reader.

Furthermore, all literature sources used in this study were carefully documented. Several direct citations and definitions from the literature sources were used. This ensures that the subjective influence of the author has been minimized. Some terms proved to be equal to one another by comparing their calculation formulas. For example, if the formula for two different terms is the same, then these terms define the same matter.

The grouping of different stages of the selected frameworks proved to be successful. After disaggregation of the different frameworks, they were reconstructed using their components based on Ervasti and Kauranen’s framework. All the components of all the frameworks that were taken from literature sources (terms, stages, and material streams) could be grouped following the framework developed for the present study.
8.2 Reliability

Reliability refers to internal consistency, and it measures the amount of error in the measurement of a construct. Measuring the same phenomenon with different variables can increase reliability (Scandura & Williams, 2000). Reliability also relates to the investigator’s bias (Yin, 2009). Accordingly, high reliability means that using another researchers with the same skills would presumably not affect the results and conclusions of the work. In a research report, it is important to provide a complete, documented trail of what has been done. This is necessary in order to be able to replicate the study if so desired. This entails that there is a study protocol and references to data sources. Comparisons and calculations must be transparent.

According to Kauranen et al. (1992), one characteristic of a strong research paper is that the information has been obtained from several different sources, that items from different sources have been compared critically, that comparisons have also been made with the writer’s own results, and that comparisons have been made at an international level, whenever possible.

In this study, several relevant sources related to paper recycling were identified during the data collection process. Many of the sources are official and semi-official international organizations or regional organizations covering more than one country. Data collection had two main purposes: first, to identify sources that have used terms related to paper recycling and, second, to identify the frameworks that define material streams in the paper industry.

Data concerning the use of different terms related to recycling deals with several different regions, including Europe, North America, Japan, Russia, South Africa, India, and Australia. Additionally, four global organizations, namely the Bureau International Recycling (BIR), FAO, International Energy Agency (IEA), and OECD, were consulted.

In the analysis phase, the identified terms were listed in tables. This makes it possible for the reader to easily compare the different uses of the terms by different sources. At the analysis stage, the frameworks were compared with each other and a short description of each of the frameworks was given. Additionally, when comparing the frameworks with each other, the structures of each of the frameworks were described and analyzed in detail. All of the stages and streams as well as the terms used in the frameworks were restructured using Ervasti and Kauranen’s framework as a basic model. However, this framework, which has been used as a model to represent the general framework provided in this study, may introduce a certain amount of subjectivity to the study. Earlier versions of this framework have been introduced in literature pertaining to the field and at conferences (COST E48, 2010; Ervasti and Kauranen, 2011).

The three above-mentioned regions, namely Europe, North America, and Japan, form a representative sample of overall recovered paper collection at the global level. These regions correspond in total with 60% of the global recovered paper collection and give a clear global picture of the matter being studied.
9. Conclusions

The objective of this study was to create guidelines for a uniform terminological system for paper recycling. A comprehensive analysis of existing terminological systems used for paper recycling was carried out. Different terminological systems related to material recycling in the paper industry were compared with each other. Their deficiencies were revealed. Severe inconsistencies between different terminological systems were found. It became obvious that a state of chaos exists with respect to how terminology is used in the paper recycling industry. There are several terminological disciplines in use. Often, different terms are being used for the same matter; and often, the same term is being used to refer to different matters depending on author, region, and time.

A comprehensive analysis of ten existing frameworks dealing with the material streams related to paper recycling was done. Different frameworks were compared with each other. Their deficiencies were revealed. Four of the ten identified frameworks quantified the material contents of different stages and streams.

A comprehensive uniform framework for materials streams and stages in the paper recycling industry was developed. This framework is called the Detailed Wheel of Fiber. After developing this framework, it was possible to lay a foundation for a new terminological system related to material recycling in the paper industry.

A method for quantifying the different material streams and stages in the material system of the paper industry was developed. The materials involved in material recycling consist of different components, such as fiber, water, and non-fibrous components. In this study, these different material streams and stages were quantified using a common denominator, the roundwood equivalent (RWE).

The main reason for the existing chaos in terminology is that there is no uniform terminological system to univocally define terms related to material recycling in the paper industry.

The findings of this study are based on a vast number of sources using recycling terms, their definitions, and different frameworks, all of which were identified and analyzed. Even though these frameworks try to define the same matter, material recycling in the paper industry, they nonetheless vary greatly. At the same time, there are several terminological disciplines in use. In addition, many authors misleadingly use terms from more than one discipline together with each other without mentioning it in the text. Surprisingly, even the most
common terms in the field of paper recycling are generally used without uniform definitions. Most of the analyzed frameworks cover only total recovered paper, without dividing it into individual recovered paper grades.

Defining the terms recycling and recycling rate seems to be a European phenomenon. In Europe, these terms have several definitions depending on source. However, in other geographical regions the term recycling refers mainly to material recycling at a general level, meaning that material moves through a recycling system. A new detailed calculation formula for obtaining the recycling rate was provided. This new calculation formula includes additional material streams, which are not taken into account in the calculation formula currently used. However, the term recycling rate is not generally in use outside Europe.

In this study, different material streams and stages in the material framework were described. These material streams and stages were given letter symbols. This makes it possible to define different terms from different regions using formulas and to compare them with each other. Uniform symbols for recycling related terms should be defined at the same time that a uniform terminological system is developed.

An extensive table of terms is presented in this study together with the definitions that have been used for these terms in the existing literature. The terms are listed in an all-inclusive manner. The different definitions provided in the literature can easily be compared with each other.

The use of the term waste paper has also caused confusion. When this term is used to define recovered paper, the different materials and stages can be quantified. However, if the term waste paper relates to material that makes up the recovered paper collection potential, which consists of consumed paper material from different sources, the related material streams cannot be reliably quantified. Additionally, this particular material may be mixed with non-paper components, waste, and different paper grades.

One reason for the terminological confusion is that previously no distinction was made between several terms related to the material when it moves through the material chain. In virgin wood pulp production, there is a clear difference between terms like tree, pulpwood, wood pulp, and paper, for example. In recycled pulp production, corresponding terms at different stages of the material chain, such as paper, waste paper, recovered paper, recycled pulp, and recycled paper, have not generally been understood to define different materials at different stages of the material chain. Additionally, material-related terms like recovered paper can be divided into hundreds of individual recovered paper grades by using the classification systems of different organizations. Globally, these individual grades can be separated into four main groups based on their technical quality. These main groups are as follows:

- mixed grades
- old corrugated containers and kraft grades
- old newspapers and magazines
- high grade de-inking and pulp substitutes
A new global, fully functional material framework for the paper industry is desperately needed. Only after developing this kind of a framework will it be possible to have a clearer picture of the global material streams and recycling as well as their effects on regional and global material chains. Additionally, a uniform global recovered paper grade classification system is needed.

The author of this study suggests that the developed framework presented here, the Detailed Wheel of Fiber, could be used as the basis for developing a new global framework for the paper industry. A global material framework could be used to estimate the amount of virgin fiber that should be input into the system both regionally and globally in the long run with respect to different fiber recycling levels and different paper industry structures. Additionally, a uniform material framework for defining terms and reliably quantifying material streams would make it possible to estimate and forecast greenhouse gas emissions related to the paper industry.

This developed framework for paper recycling can be used to analyze the frameworks currently being used by different organizations and researchers. This new framework includes all of the stages and material streams that could be discovered when analyzing the ten identified frameworks. Even though the developed framework may not be perfect and may include some researcher-related subjective weaknesses, it can still be used as the basis for developing a new uniform recycling framework. This framework can be used as a tool for quantifying the different stages and material streams related to paper industry.

This study makes a contribution to the scientific community by identifying the fact that the terminology currently being used in the paper recycling industry is in a state of chaos. This study gives useful advice for how to deal with and overcome this chaos. Additionally, this study introduces new ideas that should be researched further.
10. Ideas for future research

It is important to have a universal, generally accepted material stream framework and a uniform terminology for the material stages and streams and recycling in the paper industry. For this development, a comprehensive research project is needed. This project should be supported by all stakeholders, including industry, trade, authorities, environmental groups, researchers, and consumers organizations. The findings presented in this study can be used to achieve the set targets for a future research project. This future research project should have a clear target in order to create a uniform global material framework and a uniform material recycling terminological system, which could be used globally. The following issues should be considered:

- this study suggests that there is a research problem and a research gap in developing a global, uniform material framework and a terminological system related to paper recycling. Other recyclable materials could be included, too;
- now that a research gap has been identified in this study, a clear target for the research project should be defined and research design should be created accordingly;
- the author of this study has concentrated on utilizing desk research sources, such as articles, definitions, statistics, and regulations. It is important that when, for example, designing a data collection process for an actual case study, cooperation between experts from different countries should be encouraged;
- in this study, the collected data was analyzed only partially. For example, when grouping individual recovered paper grades, only European (EN 643, 2002, 2013) grades were analyzed in detail. In future studies, all corresponding grade definitions for other regions should be analyzed and grouped together in order to create a uniform, global recovered paper classification system;
- this study suggests that some material streams, such as packages traded with goods, recycling of recovered paper outside the paper industry, and waste paper / recovered paper used for energy uses, need to be reliably quantified.

A body of experts representing various stakeholders and geographical regions and with in-depth insights into the field should be formed to devise a new and
Ideas for future research

A uniform framework for paper recycling and a uniform system for related terms, including a list of recovered paper trade grades.

To be able to reliably quantify such terms as recycling rate, collection rate, and utilization rate, it is necessary to assign quantitative values to materials at different stages and to the material streams of the material framework.

At present, the recycling rate in Europe does not give a clear picture of recycling activities in the region. According to the definition, this indicator shows only the share of a defined paper potential that is fed into the pulping system. By using the findings from this study, it will be possible to create a new and more accurate calculation formula for the recycling rate.

Additionally, reliable methods for quantifying the use of paper and recovered paper for energy production should be developed.

The moisture contents of the material may differ at different stages of the material stream. This has not been taken into account in the recycling rate calculations. For accurate recycling rate calculations, it is necessary have a reliable picture of the moisture contents of the material at different stages of the material chain.

This study and the introduced Detailed Wheel of Fiber framework will strengthen the paper industry’s role as the leading sector in defining and understanding matters related to material recycling. In addition to paper and related products, the Detailed Wheel of Fiber framework can also be used to describe the material streams of other recyclables, such as glass, metal, plastics, and wood. To be able to optimize material recycling globally, it is necessary that we have common understanding of the matter. Additionally, we need a better means of communication for understanding each other. This study provides a foundation to both describe material streams related to the paper recycling industry and a basis for developing a uniform, global terminological system related to recycling.
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This dissertation introduces guidelines for a uniform terminological system for paper recycling. Different terminological systems related to material recycling in the paper industry were compared with each other. It became obvious that a state of chaos exists with respect to how terminology is used in the paper recycling industry. Globally, there are several terminological disciplines and material stream frameworks in use. Often, different terms are being used for the same matter; and often, the same term is being used to refer to different matters depending on author, region, and time.

A comprehensive uniform framework for materials streams and stages in the paper recycling industry was developed. This framework is called the Detailed Wheel of Fiber. A method for quantifying the different material streams and stages in the material system of the paper industry was developed. In this study, different material streams and stages were quantified by using a common denominator, the roundwood equivalent.