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PAPER RECYCLING FRAMEWORK, THE “WHEEL OF FIBER”

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ABSTRACT

At present, there is no reliable method in use that unequivocally describes paper industry material flows and makes it possible to compare geographical regions with each other. 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 article, stress the importance of input and output flows but do not provide a uniform picture of *material recycling*. 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 time. Thus, reliably comparing material recycling activity between geographical regions or calculating any regional summaries is difficult or even impossible. The objective of this study is to give a partial solution to the problem of not having a reliable method in use that unequivocally describes paper industry material flows. This is done by introducing a new material flow framework for paper industry in which the flow and stage structure supports the use of uniform definitions for terms related to paper recycling. This new framework is termed the Detailed Wheel of Fiber.

HIGHLIGHTS

- There is no reliable method in use to unequivocally describe paper material flows
- A new material flow framework, called the Detailed Wheel of Fiber, was introduced
- Uniform terminology and standard definitions for terms and structures was developed
- A new formula for calculating the paper recycling rate was proposed

Keywords: materials flow analysis (MFA); paper industry; paper recycling; recycling rate; recovered paper

1. INTRODUCTION

A detailed description of industry material flows is essential, for example, for analyzing and forecasting demand, for establishing recycling targets by policy makers, as well as for analyzing the trade of different raw materials. The world is rapidly becoming more globalized, thus the interrelationships between the production of products, the use of materials, and the generation of waste are becoming increasingly more complex and geographically dispersed (Sevigné-Itoiz, 2015). For example, climate change, which is closely connected to raw material and energy use, is a global issue. It is essential to have a uniform framework that makes it possible to compare the raw material use and recycling activities in different geographical regions with each other.

If the sender of a message does not use the same definitions as the receiver, then communication becomes obscure, misunderstandings can occur, or messages may not be understood at all by the receiver. Every sector of society and science needs to build a systematic terminology with generally accepted, uniform definitions and terms (Christensen, 2006; van de Ven, 2007).

A great deal of work has been done at the society level, especially by policy makers and non-governmental organizations, to describe the supply side of environmental accounting (Waller-Hunter, 2000). Attention has been paid to developing practical applications, including accounting tools for natural resources like water, forests, and energy as well as the associated availability of statistical data, sophisticated accounting systems, and indicator development at the national and international level. Materials Flow Analysis (MFA; called framework in this article) is a tool that can provide relevant, analytically sound, and measurable indicators for decision makers at different levels.

Resource efficiency is one of the most important challenges presently faced by the European Union and other geographical communities as well as private enterprises. The resource-efficient utilization of raw materials is needed for sustainable growth (EC,

2013). Easily understandable and robust indicators are essential for improving the way in which resource efficiency is measured. Consistent definitions between nations, business sectors, and the disciplines related to resource efficiency are essential. Standardization amongst nations and business sectors is necessary for comparison purposes.

According to the European Waste Directive (Directive 2008/98 EC), a *recycling rate* of 50% for household waste needs to be achieved throughout Europe by 2020. Additionally, the European paper industry, together with several stakeholders, has published a voluntary declaration on paper recycling that calls for a *recycling rate* of 70% by 2015 (ERPC, 2011). Furthermore, the European Commission recently adopted (EC, 2014) a legislative proposal to review recycling and other waste-related targets in the EU in which the recycling and re-use of municipal waste should be increased 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 important to reliably define recycling rate and the formula for calculating it.

Material flow accounts (MFAs) are frameworks generally used to describe the amount of physical inputs into an economy, the material accumulation in the economy, and the outputs to other economies or those returned to nature (Eurostat, 2001). In this context, the economy in question can be either an individual country or a geographical region. Economy-wide frameworks and the indicators derived from them provide information on the material and energy that enter into the economy and exit the economy (Eurostat, 2001). A material balance principle assumes that total inputs = total outputs + net accumulation.

To be able to reliably calculate the values for resource-related indicators that measure paper industry recycling activity, it is necessary to form a clear picture of material flows in the material loop. Essential stages should be identified and the material flows between different stages should be defined and quantified. The ratio between different material flows needs to be measured in a uniform manner. For such analyses a uniform material flow framework needs to be developed.

The objective of this study is to give a partial solution to the problem of not having a reliable method in use that unequivocally describes paper industry material flows. This is done by introducing a new material flow framework for paper industry in which the flow and stage structure supports the use of uniform definitions for terms related to paper recycling. This new framework is termed the Detailed Wheel of Fiber. With a uniform framework, comparable calculations of material flows can be made, ultimately enabling comparisons between different geographical regions.

In this study, the term *paper* includes both *paper* and *paperboard*. Furthermore, the raw material utilization in paper manufacturing consists of four main raw materials: *recovered paper*, *wood pulp*, *pulp other than wood*, and *non-fibrous components*. Therefore, *paper grades* and, thus, the different *recovered paper grades* that are collected, may consist of varying shares of *virgin pulp* (wood pulp from several different wood species and pulp from other plants), *recovered paper*, and *non-fibrous materials*, including minerals and additives such as calcium carbonate and clay.

2. METHODOLOGY

2.1. Frameworks and material flows

A detailed description of industry material flows is essential to be able to, for example, analyze and forecast demand and the trade of different fiber raw materials. The world is changing rapidly and regional differences do occur. Besides, supply and demand and the balances of different raw materials change. The standard of living in Asian economies and especially in China is expected to grow more quickly than in Western economies. This will further increase the demand for raw materials in Asia.

A measurement of secondary, that is to say, *recycled or re-used, material flows* is highly relevant (OECD, 2004). This, however, will require long-term measurements and sound methodological efforts (OECD, 2004). The development work that is required can be done, for example, by countries that wish to establish more detailed sector- or substance-specific accounts. Progress can be achieved through specific national efforts or through case studies done in collaboration with countries sharing common interests and other

forms of co-operation. There are natural variations between different material sectors. Different flow accounts for different materials are needed (OECD, 2004).

By using an economy-wide material balance framework, it will be possible to derive sufficient input, consumption, and output indicators. A complete material balance is difficult to achieve statistically. Not all material input and output flows are systematically monitored. Some data must be estimated (Eurostat, 2001). When different flows are quantified, it is done for a certain period of time, normally a year. Material recycling is important since the target is to re-use the same material. Through material recycling, considerable financial savings are possible (OECD, 2012).

The Statistical Office of the European Union (Eurostat) published a framework called the economy-wide material balance. It includes all relevant input and output flows. The general framework is shown in figure 1 (Eurostat, 2001). The framework includes indirect flows associated with imports and exports through the economy, excluding water and air. The domestic extraction of materials can be further disaggregated into, for example, fossil fuels, metal ores, minerals, and biomass. Each of these broad material groups can further be subdivided into biomass, timber, agricultural harvest, and so forth.

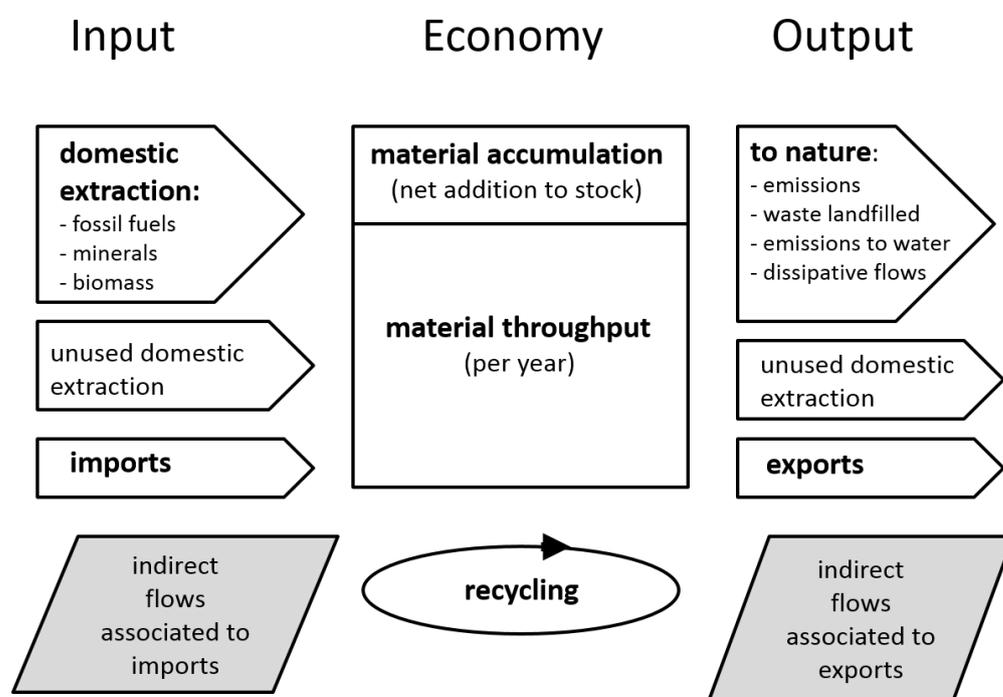


Figure 1. Framework for an economy-wide material balance (excluding air and water flows) (Eurostat, 2001).

In the Eurostat material balance scheme, recycling is understood as a domestic material flow. However, in the paper industry *recycling* is treated as more than just a regional material flow. For example, millions of tons of *recovered paper* are exported from Europe to China. According to the current definition adopted by the European Recovered Paper Council, such an export of *recovered paper* is considered to be European *recycling* (ERPC, 2011).

Europe, the United States, and Japan are the largest exporters of *recovered paper* in the world. The net trade of *recovered paper* in 2013 was 19.9 million tons for United States, 8.0 million tons for CEPI countries, and 4.9 million tons for Japan. Most of the exports go to China, which is annually importing approximately 30 million tons of *recovered paper* (AF&PA, 2015; CEPI, 2014; PRPC, 2014).

Another important issue to consider is the terminology related to *paper recycling*. The terminological inconsistencies between different regions are complicated and need to be addressed (Ervasti et al., 2016). It is difficult to compare different regions and different periods of time. For example, terms like *recovered paper*, *paper for recycling*, *collected paper*, *paper stock*, *recycled paper*, *recycled fiber*, *scrap paper*, and *discarded paper* have been used to define same material (Ervasti, 2015).

Many literature sources have used case-specific symbols for select terms differently. Examples of different calculation formulas and symbols for different terms related to *paper recycling* are shown in Table 1. These examples show that there is a great deal of variation when defining terms, formulas, and their symbols. It is important that the different terms related to *recycling* have defined and uniform symbols. This would make it easier for different players in the field to explain what they really mean when using different terms, as is already done in physics and chemistry.

Table 1. Paper industry material recycling related terms. Different calculation formulas and symbols used in literature.

Authors	Term	Formulas and corresponding symbols
Berglund and Söderholm (2003)	Recovery rate (RR)	$RR = ((WP\ cons) + (WP\ ex - WP\ im)) / PB\ cons$ In formula: WP cons = waste paper consumption, WP im = waste paper imports, WP ex = waste paper exports, PB cons = paper and board consumption
AF&PA (2008) ¹	Recovery rate (7)	(Recovery rate, 7) = (total recovered paper recovery, 6) / (new supply of paper, 2) In formula: (total recovered paper recovery, 6) = (recovered paper consumption at paper mills) + (other uses, 4) + (recovered paper exports, 5) – (recovered paper imports) – (paper exports), excluding hard pressed board. Imports and exports of paper include paper-converted products.
PRPC (2013)	Recovery (H)	$H = (G + G' - E + F)$ In formula: 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)	Waste disposed (W)	$W = (Q - R)$ In formula: W = waste disposed, Q = total consumption of goods, and R = recycled volume
Klimek (2011)	Utilization rate (%)	$100 \times (D / A)$ In formula: A = paper production, D = waste paper utilization
	Recycling rate without trade	$100 \times ((D / B))$ In formula: B = paper consumption, D = waste paper utilization
	Recycling rate with trade	$100 \times (C / B)$ In formula: B = paper consumption, C = waste paper collection
Barrio (2006)	Recycling rate (%)	$100 \times ((B + C) / A)$ In formula: A = packaging placed on the market, B = material recycling, and C = organic recycling and use for other purposes
CEPI (2013a)	Utilization rate (%)	$100 \times (E / G)$ In formula: E = total use of recovered paper, and G = total paper production

1) The numbers after the terms are related to AF&PA's (2008) definitions

2.2. Paper industry material flows

Paper industry material flows include different material elements, such as *virgin fiber*, *recovered fiber*, *recovered paper*, *water*, *non-fibrous components*, as well as the final product, *paper*. *Non-fibrous components* consist of *fillers*, *coating pigments*, *adhesives*, and *printing ink*.

The paper industry material flow framework can be described as a wheel in which there is no exact starting point or end point. Material input and material output occur continuously at different stages of the framework as material flows through the system. The circle can be divided into relevant stages. There are also inflows and outflows of material moving throughout the various stages. Additionally, the flows may also lead to a point outside the wheel (for example, another region), or flows can come from outside the wheel into the system.

Material flows related to the paper industry, including *paper recycling*, offer an interesting sector for material flow analysis. Fibers are part of the biomass flow and originate from forests and annual plants. After having been *utilized* for the first time in *pulp and paper production*, the fibers acquire a new life through *recycling*. Nevertheless, continuous injection of *virgin fiber* and other materials into the system is necessary in order to replace the material lost during each *recycling round*.

Consumed paper changes form to become *waste paper*, which is then converted into *recovered paper* after collection and sorting. After pulping, *recovered paper* is converted into *recycled fiber*, which is then used as raw material in *paper production*. For example, after paper production the *paper flow* consists of several different *paper grades*, each of which has a raw material furnish of its own, including a different combination of *virgin fibers*, *recycled fibers*, and *non-fibrous components*.

The material framework for the paper industry can be divided into five main stages based on a method proposed by Ervasti and Kauranen (2011). The general structure of the stages and material flows is called the general-level Wheel of Fiber, and it is shown in figure 2.

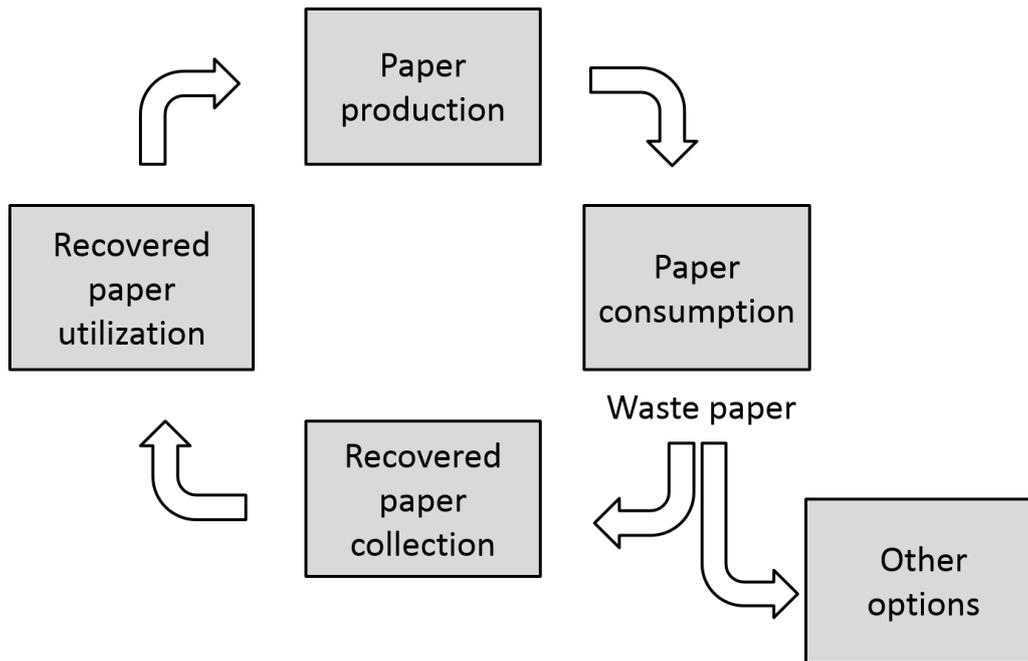


Figure 2. General-level framework for the “Wheel of Fiber”: material recycling flows and different stages of the framework (Ervasti and Kauranen, 2011).

In this article, the authors have selected different terms to represent various stages of the paper recycling chain. For quantitative analyses, the stages and flows in the framework must be quantified. The five-stage framework, presented in Figure 2, can be used to describe the paper industry material recycling at a general level. The main stages are as follows:

- *Recovered paper utilization* in paper production;
- *Paper production*;
- *Paper consumption*;
- *Collection (or recycling) of recovered paper*, including both *domestic utilization* and *net trade*;
- *Other options*: This includes all material flows except for those being *collected* and *used for paper manufacturing* domestically or as *exported paper*. Other options include *recovered paper material use outside the paper industry*, *energy use*, *uncollected paper*, *sourcing losses*, *manufacturing losses*, and *disposed paper*.

The stages in the framework can be quantified. The stages are connected to one another via material flows. For example, the term *waste paper*, which falls between *paper consumption* and *recovered paper collection* in the process, describes some unspecified

material that cannot be reliably quantified. In the framework, *waste paper* is not an individual stage; rather, it is a material related term that falls between *paper consumption* and *recovered paper collection*.

3. RESULTS AND DISCUSSION

3.1. Development process for the Detailed Wheel of Fiber model and existing frameworks

The creation process used to develop the Wheel of Fiber is based on iteration. In the first iteration, the general-level Wheel of Fiber was used. The five-stage approach was selected to be used as the basis for a general structuring of the stages. In addition to stages, material flows between the different stages were also identified.

Several organizations and authors have published their own paper industry frameworks and use their own names for them. For the purposes of this article, ten different frameworks related to paper recycling were selected and analyzed in detail (Table 2).

Table 2. Different paper industry frameworks and their names.

Source	Name of the framework
European Recovered Paper Council (ERPC, 2013)	Paper recycling – Who does what?
Villanueva et al. (2007)	The Paper System
Indufor (2013)	Wood raw-material flows within and between the EU forest-based industries subsectors
EcoPaperLoop (2014)	Recovered Paper Balance
CEPI (2008)	Paper Recycling Loop
CEPI (2013a)	The European Fiber Flow Chart
Schmidt et al. (2007)	Paper Flow in Product System
PRPC (2010)	Recovered Paper Generation / Distribution route
Daividsdottir et al. (2005)	System Boundaries for Pulp and Paper Production
Pento (1994)	Material Flows of Printing Papers in Germany

These frameworks have been called, for example, *accounts*, *diagrams*, *models*, *charts*, *material flow accounts (MFA)*, and *substance flow analysis (SFA)*. Additionally, specific names have been given to the frameworks. For example, the European Recovered Paper Council (ERPC, 2013) calls its framework *Paper recycling – who does what?* In this

article, the term *framework* is used to cover all of the different names used for the *material recycling chain* by different sources.

Even though the analyzed frameworks related to paper recycling use different terms when describing different stages, the five main stages and material flows between the stages could be identified in all of the frameworks. Additionally, all of the selected frameworks except one, the framework used by EcoPaperLoop (2014), take the form of a wheel. All of the stages and material flows that were identified in the selected ten frameworks were grouped using the general-level Wheel of Fiber structure. During the first iteration, a comprehensive stage structure list of all the stages and flows identified in the selected frameworks was produced.

The accuracy of the stage and material flow structure that had been created was tested by iteration. The testing process included the use of symbols that had been created to define selected types of *paper recycling* with respect to the definitions proposed by different organizations from different geographical regions. The aim of this iteration was to test whether or not it is possible to define different definitions related to *paper recycling* with formulas when using the letter symbols and the basic structure of the Detailed Wheel of Fiber. For example, the definitions for *paper recycling* used by the following organizations were tested:

- American Forest and Paper Association (AF&PA, 2008).
- Food and Agricultural organization of the United Nations (FAO, 2010).
- Villanueva and Eder (2011).
- Paper Recycling Promotion Centre, Japan (PRPC, 2013).
- Paper Recycling Association of South Africa (PRASA, 2013).
- Confederation of the European Paper Industries (CEPI, 2003; 2006; 2013)
- European Recovered Paper Association (ERPA, 2000).
- European Recovered Paper Council (ERPC, 2011).

In the case of any discrepancies, the definition of the term with respect to the particular stage or material flow was checked and possibly repositioned in the stage structure list.

During the following iteration, the stage structure list, the Detailed Wheel of Fiber, and the letter symbols were compared with each other. After a final match had been achieved, and when no more checks were needed, the final form of the Detailed Wheel of Fiber and corresponding letter symbols for stages and material flows was produced. The iterations are shown in figure 3.

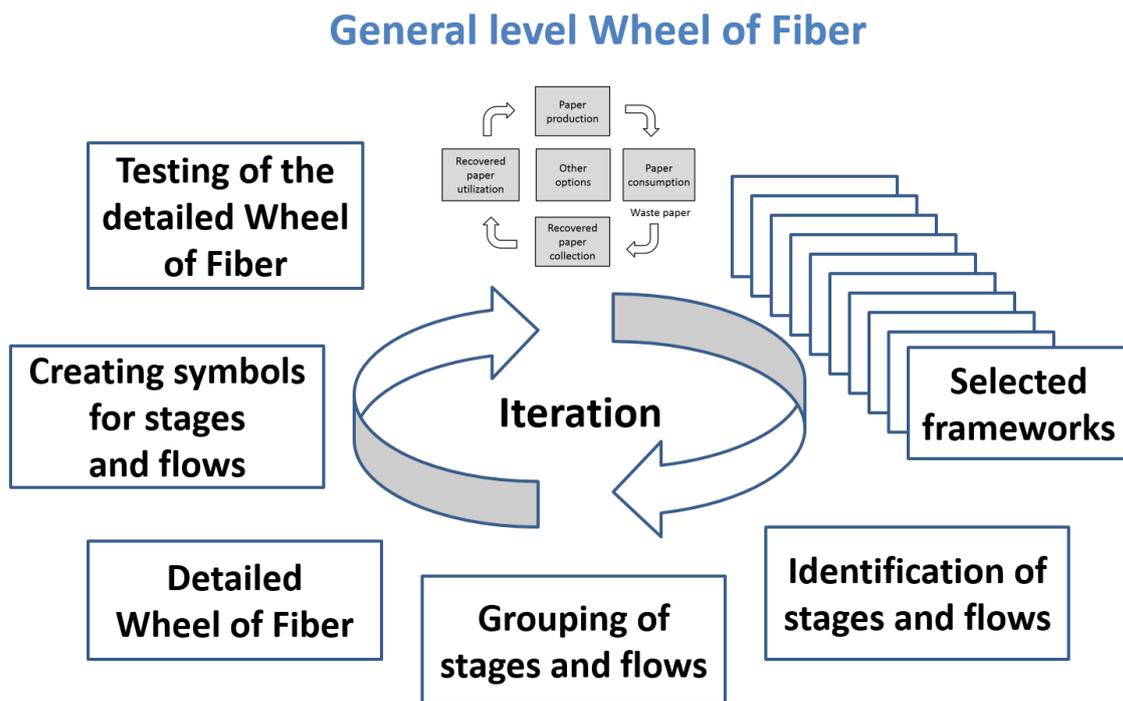


Figure 3. Iteration processes used when developing the Detailed Wheel of Fiber.

In this study, frameworks that had been developed especially to take into account the characteristics of material flows within the paper industry were analyzed.

Generally, a framework to reliably define material flows, including *recycling*, in paper industry should include all of the stages and material flows needed to calculate the most common indicative terms related to *recovered paper recycling*. This can be done by comparing the statistical terms with each other. Usually, statistical terms quantify the different stages and/or material flows between the stages. For example, the ratio between *recovered paper recycling* (*recovered paper utilization* + *recovered paper net trade*) and *paper consumption* is called the *recycling rate* (CEPI, 2013a), whereas the ratio between *recovered paper utilization* and *paper production* is the *utilization rate* (CEPI, 2013a). Furthermore, the *collection rate* is the ratio between *recovered paper collection* and *paper*

consumption (Miranda & Blanco, 2010), and similarly, the *recovered paper recovery rate* is the ratio between *recovered paper recovery* and *paper consumption* (PRPC, 2013).

Even when the statistical terms describing the various stages and flows in the different frameworks were the same, they still do not necessarily refer to the same issue. For example, great differences occur between the frameworks when it comes to defining the stage-related term *paper consumption*. The definition for *paper consumption* varies depending on the framework being used, and it does not necessarily contain the same elements. Such elements as *trade of converted paper products*, *packaging material traded together with goods*, *added inks*, and *additives used during the printing and converting process* are used only in some frameworks. Additionally, the terms used for the stages and flows are sometimes referred to differently, even though they may describe the same issue. For example, in different frameworks terms related to material flow, such as *paper recovery*, *recovered paper recovery*, *waste paper recovery*, *recovery*, *waste paper to recycling*, *collection*, *used paper collection and sorting*, and *collection and sorting*, are used interchangeably.

Analysis of the ten selected frameworks has led us to the conclusion that there is no generally accepted uniform terminology or framework that can be used uniformly to describe the various stages and material flows within the paper industry. Terms defining the different stages and flows as well as other material-related terms vary considerably between the different frameworks. The existing frameworks do not solve the need for being able to compare and combine regional frameworks with one another at an international level.

3.2. Creating symbols for stages and material flows

After the first iteration, letter symbols were assigned for all of the stages and flows. During the subsequent iteration, letter symbols from A to Z were attached to the different stages and material flows discussed in the analyzed frameworks. These letter symbols are shown and defined in table 3.

In this study, the letter symbols for stages and flows are used only to distinguish between the various stages and flows. In the future, it is possible and recommendable to change the letter symbols to better describe the various stages and flows. For example, R could describe *recycling*, U could describe *utilization*, and E could describe *exports*.

Table 3. Letter symbols, and definitions for the different stages and material flows used in the Detailed Wheel of Fiber.

Term symbol	Term description	Category: stage / flow
A	paper production	stage
B	domestic deliveries of paper inside the region	flow
C	imports of paper	flow
D	exports of paper	flow
E	consumption of paper	stage
E'	paper consumption that is non-collectable or non-recyclable	flow
F	net trade of paper packages traded together with goods	flow
G	net trade of converted paper products	flow
H	other recycling, recovered paper utilization outside the paper industry	H, I, and J are flows. (H+I+J) = other options stage (Z). (H+I+J) = (E'+P1+P2)
I	recovered paper used for energy (energy recovery)	
J	recovered paper disposal, not recycled	
K	recovered paper collection. Material that fulfills the definitions set for recovered paper (N-L+M)	stage
K'	paper recycling (N-L+M). K' is not considered a stage in its own right because the calculation formula and value for K' is the same as for K (collection)	flow. K' = K
L	recovered paper imports	flow
M	recovered paper exports	flow
N	recovered paper utilization in paper manufacturing within a region	stage
O1	non-fiber components, such as fillers and coating pigments, put into paper during the paper manufacturing process	flow
O2	non-paper components, such as adhesives, inks, films, and laminates, used during printing and the converting of paper	flow
O3	non-paper components, such as plastic, wires, and waste in general, which may enter the material flow at collection sources and during baling	flow
P1	material losses during sourcing, collection, and sorting	flow
P2	material losses at paper mills, including sorting and process losses	flow
Q	production of recycled fiber pulp at a pulp and paper mill to be used as raw material in paper manufacturing	flow

R	use of virgin wood fiber pulps	flow
S	use of virgin fiber pulps other than wood fibers, such as annual plants. It includes local and imported pulps	flow
T1	moisture absorbed into paper material when the consumed paper turns into waste paper	flow
T2	moisture that evaporates from virgin pulp and recovered paper during the paper manufacturing process	flow
U	local raw wood material used for pulp production	flow
V	imported wood raw material used for pulp production	flow
WP	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	waste paper can be regarded as a material-related term because it is a material whose contents and volume cannot exactly be defined
X	local wood pulp production used for paper manufacturing	flow
Y	net trade of wood pulp	flow
Z	other options	stage (H+I+J)

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

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

Both *recovered paper utilization* (N) and *paper production* (A) are statistical figures sourced from national paper industry associations. In the *raw material utilization* stage, the *total raw material consumption* is calculated by using the formula (N+R+S+O1). In *paper production*, *recovered paper* is used first to produce *recycled fiber pulp* (Q), such as *deinked pulp*, which is then used as raw material in *paper production*. In *recycled fiber pulp* manufacturing, process losses (included in P2), such as rejects and sludge, can vary between 15 and 45 percent depending on the quality and grade of the *recovered paper grade* and end product being manufactured (Hamm, 2010).

The term *re-use* means any operation by which products or components that are not waste are used again for the same purpose for which they were originally conceived (Directive

2008/98 EC). It is possible to interpret the term re-use in two different ways. First, if it refers to the re-use of boxes for packaging purposes as such, then it is only a material loop inside the paper consumption stage. Second, if it refers to material use, then re-use refers to recycling.

3.3. Detailed Wheel of Fiber

In *paper production*, in addition to *utilized recovered paper*, other fibers, such as *wood pulps*, are also used as raw materials. Additionally, *paper produced* in Europe is *recycled* both in Europe, after *paper consumption* and *collection*, and outside Europe, as *exported paper*, as *exported converted products*, and as *exported packaging material traded together with goods* like *boxes exported with goods*. These different types of materials can be *collected* in the destination region. In order for material to flow and circulate continuously throughout a region, both the *virgin fiber pulp* and *recycled fiber pulp* input flows and output flows have to be in balance over the long run.

Forests can be understood as a source of *wood fiber*, and *paper consumption* can be understood as a potential source for *waste paper*. *Waste paper* turns into *recovered paper* after collection and sorting, and it is used as raw material for *recycled fiber pulp*. Finally, *recycled fiber pulp* is used as raw material in (*recycled*) *paper production*.

Material flows between the different stages. Additionally, material can either flow out of the system or into the system. The different stages and material flows are shown in Figure 4. For example, moisture is mentioned in the figure 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 describes regional material stages and material flows. The different stages and flows are indicated with letter symbols.

defining different terms using the Detailed Wheel of Fiber Framework structure and the corresponding letter symbols.

Terms related to *recovered paper* used in the different sources, such as *collection rate*, *recycling rate*, *recovery rate*, and *utilization rate*, were selected and defined. The analyzed sources were from the following organizations and researchers: AF&PA (2008), FAO (2010), Villanueva et al. (2011), PRPC (2013), PRASA (2013), CEPI (2003, 2006, 2013a), ERPA (2000), and ERPC (2011). The selected terms defined by the above-mentioned sources were tested as to whether or not they could also be defined using the Detailed Wheel of Fiber's stages, flows, and corresponding letter symbols. This testing was carried out successfully, as shown in table 4.

Table 4. Definitions of terms used by different sources and defining these terms using the Detailed Wheel of Fiber's stages, flows, and corresponding letters.

Source	Term	Definition	Formula
AF&PA (2008)	recovery rate	the ratio of total recovered paper collected to the new supply of paper and paperboard.	$(N+H-L+M) / (A+C-D+G)$
	utilization rate	the ratio of recovered paper consumption to the total production of paper and paperboard.	(N / A)
CEPI (2003)	recycling rate	(recovered paper utilization in CEPI) / (paper and board consumption).	$(N)/(E)$
	collection rate	(apparent collection of recovered paper and board) / (paper and board consumption). Apparent collection of recovered paper = (utilization of recovered paper) + (trade balance of recovered paper and board). If a country is a net exporter of recovered paper, then the net trade figure is positive.	$(N+E-L)/(E)$
CEPI (2006)	recycling rate	(recovered paper utilization) / (total paper consumption). Paper consumption = (internal deliveries of paper and board) + (imports from outside CEPI). Recycling = reprocessing of recovered paper in a production process for the original purpose or for other purposes, including composting but excluding energy recovery	$(N+H)/(B+C)$
	collection rate	the ratio of apparent collection to total paper consumption. Apparent collection = utilization plus exports minus imports of recovered paper.	$(N+M-L)/(E)$, $(E) = (B+C)$
	utilization rate	Relation between recovered paper utilization and paper production.	$(N) / (A)$
CEPI (2013a)	recycling rate	(utilization of paper for recycling + net trade) / (paper and board consumption).	$(N+M-L)/(E)$, $(E) = (B+C)$

	paper consumption	(paper production) + (paper imports) – (paper exports) or (domestic deliveries) + (paper imports).	$(A)+(C)-(D)$ or $(B) + (C)$
	utilization rate	(utilization of paper for recycling within paper & board production) / (paper & board production).	$(N)/(A)$
	collection of paper for recycling	(utilization of paper for recycling within paper & board production) + (net trade of paper for recycling).	$(N) + (M-L)$
ERPA (2000)	recycling rate	the ratio of recovered paper utilized for recycling to paper and board consumption. Recycling = reprocessing of recovered paper in a production process for the original purpose or for other purposes, including composting but excluding energy recovery.	$(N+H)/(A+C-D)$
ERPC (2011)	paper consumption (apparent)	internal deliveries within the defined countries (according to the given list) plus imports from countries outside this area.	$(B)+(C)$
	recycling rate	the ratio of recycling used paper, including net trade of paper for recycling, to paper and board consumption.	$(N+M-L)/(E)$, $(E) = (B+C)$
FAO (2010)	Waste paper net recovery rate	the ratio of waste paper collected for re-use to adjusted paper and board consumption.	$(K)/(E+G)$, where $(K) = (N+H-L)$
	Adjusted waste paper net recovery rate	the ratio of waste paper collected to adjusted paper and board consumption, from which the non-recoverable paper and paperboard is deducted.	$(K)/((E-E')+G)$
	Recovered paper utilization rate	the ratio of recovered paper used for paper and paperboard to paper and paperboard production.	$(N)/(A)$
	recovered paper in fiber use rate	the ratio of recovered paper used for paper and paperboard to the total amount of fiber used for paper and paperboard.	$(N)/(N+R+S)$
PRASA (2013)	recycling rate	(consumption of recovered paper + recovered paper exports – recovered paper imports) / (paper consumption – exported in agricultural products – unsuitable for recovery).	$(N+M-L) / (E-E'+G)$
PRPC (2013)	recovery rate	the ratio of total paper and paperboard recovered to the total amount of consumed paper and paperboard. The use of terms refers exclusively to consumption and recovery within Japan.	$(K)/(E)$ within Japan
	recovery rate (formula)	(recovered paper recovered in Japan) / (paper and paperboard consumed in Japan) Note: Recovered paper recovered = (recovered paper supply, i.e. shipments to mills) + (that used for market deinked pulp) + (exported recovered paper) – (imported recovered paper).	$(N+M-L) / (B + D - C)$

		Note: Consumed paper and paperboard (P&PB) = (sold P&PB to manufacturers) + (exported P&PB) – (imported P&PB).	
	utilization rate	(amount of recovered paper consumption and deinked pulp from recovered paper that is used in paper production) / (total fiber used in paper production, including wood pulp + recovered paper + deinked pulp from recovered paper + other fiber*). Note: Other fiber* refers to fiber that does not originate from wood pulp. It accounts for less than 1% of the total figure used and includes viscous staple fiber, knot screen waste, manila fiber, and mitsumata fiber.	(N) / (R+N+S) where (N) includes the utilization of recovered paper and market pulp (DIP)
Villanueva et al (2011)	recovery rate or collection rate	the ratio of waste paper collection to total paper consumption. Waste paper collected in a country but exported for recycling in another country is included. Waste paper imported from other countries and recycled in a particular country is not included. Collection refers to (according to Waste Framework Directive 2008/98/EC) the gathering of waste, including the preliminary sorting and preliminary storage of waste, for the purposes of transport to a waste treatment facility. Paper consumption refers to paper that is delivered (purchased) and used within a list of countries plus imports from countries outside the list of countries	(K-L)/(B+C)

Note: Letter symbols refer to letters used in the Detailed Wheel of Fiber.

As the Table 4 indicates, it is possible to define recycling terms of different literature sources by using the introduced framework. By quantifying selected stages and related flows, it is possible to quantify the surrounding stages. In this respect, for example, there is no aggregated statistical data about collected recovered paper volumes from collectors' organizations. That is why, in most cases, the *collection* (K) and *recycling* (K') volume is calculated by summing the *recovered paper utilization* stage value (N) with the *recovered paper net trade* flow values (M – L). Additionally, there is no reliable data about *paper consumption* volumes. That is why the *paper consumption* stage volume (E) is calculated either by summing the *domestic deliveries of paper* flow volume (B) with the *paper imports* flow volume (C) or by summing the *paper production* stage volume (A) with the *paper trade* flow volumes (D–C).

By using the letter symbols, it is possible to define recycling related terms accurately. As an example, a more detailed calculation formula for *recycling rate* can be developed.

According to the ERPC (2011), by using the introduced letter symbols, the *recycling rate* (K' %) can be expressed as $((N+M-L) / (E)) \times 100$, where $(E) = (B+C)$ or $(A+C-D)$.

When comparing the European definition of *paper recycling rate* (ERPC, 2011) to the Detailed Wheel of Fiber, it is clear that several such material flows, 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 must be paid to issues that take into account those stages and flows describing a closed loop and material that proceeds to the subsequent round. In this respect, it is possible to take into account the following additional material flows in *recycling rate* calculations:

- *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* (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*, i.e. *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 findings mentioned above, the detailed calculation formula for *recycling rate* could be, for example, as follows:

$$(N+(M-P2 \text{ {overseas}})+H-T1-P2) / ((E+F+G+O2)-E')$$

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*. This calculation formula gives a more exact picture of the recycling activity than the formula that is presently used (ERPC, 2011). This formula would also provide a reliable picture of the closed loop because it shows the material that returns to the final product itself as well as to the next round at the *paper production* stage (A). The presently used *recovered paper utilization* (N) 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*.

However, it is difficult to calculate the *recycling rate* formula introduced above due to a lack of reliable information about some of the terms, such as those expressed with the letter symbols H, T1, P2, G, F, O2, and E'. At present, these material stages and flows can only be quantified based on rough estimations.

It must be noted that these formulas and letter symbols are used for total *recovered paper* related terms. It would be possible to also adopt these letter symbols to define the material steps and material flows for individual recovered paper grades. Select stages, such as collection volume, and utilization volumes and flows, such as exports and imports for individual *recovered paper* grades, could be expressed with letter symbols. It has to be noted that different regions have their own specifications for recovered paper grades. For example, Australia uses AuRPS specifications, Europe uses EN 643 specifications, Japan uses PRPC specifications and the USA uses ISRI specifications.

For example, the collection volume for *old corrugated containers (OCC)*, which is a globally specified *recovered paper* grade, could be expressed with the following formula

$$(K^{OCC}) = (N^{OCC} + M^{OCC} - L^{OCC}).$$

According to Keränen and Ervasti (2014), the presently used calculation formulas for *utilization rate* and *recycling rate* tend to provide an overly optimistic picture of recycling activity. For example, according to their findings only about 41% of *fiber used in paper production* came back into circulation through recycling in Europe (EU) in the year 2010. CEPI's (2011) statistics show that during the same year, the European (EU + Norway and Switzerland) *recycling rate* was 68.9%. The differences between these two percentages can be explained by the different calculation methods used. Thus, official statistics do not exactly describe *fiber recycling*, but only give an average picture of *paper rotation*, as recognized by Bajpai (2013). The structures of the different countries do not have an important effect on the differences.

For example, a great volume of *packaging material* travels together with traded goods imported from one geographical region to another, say increasing amounts of packaging material travels from China to other geographical regions. According to existing statistical systems, these recorded volumes will be consumed in the country of origin. In reality, the volumes are being recycled in the destination countries. Quantification of the recycling process is done with a low degree of transparency. This type of statistical recording system increases the recycling rates in the destination countries but decreases the recycling rates in the country of origin. Accordingly, Zhao and Jiang (2014) estimate that the real collection rate (recovered paper collection) / (potential supply of recovered paper) would be approximately 65% in China, whereas the official collection rate (recovered paper collection) / (apparent paper and board consumption) is 45%.

Many theoretical studies have been carried out to determine how many times paper can be recycled. The estimates range from four to eight times on average. The limiting factor is how much the fiber has deteriorated during the previous cycles. According to CEPI (2013b), the current average number of recycling rounds in Europe is 3.5. This figure is called *velocity*. *Velocity* indicates the number of times the same fiber returns for another round of production within a certain period of time (Ringman, 2014). *Velocity* (V_t) is calculated using the following formula:

$$V_t = 100 / (100 - \text{collection rate } [\%])$$

So, if the *collection rate* is, for example, 50%, then the *velocity* value is 2.

The perception of the authors of this study is that a *velocity* figure of 3.5 is too optimistic. The formula does not fully take into account all of the material exits from the loop and the material losses at different stages of the recycling chain.

4. CONCLUSIONS

The use of terms and their definitions vary depending on the author, region, and period of time in question. There are several different terminological systems in use currently. In addition, many authors misleadingly use terms from more than one discipline together with each other without explaining it in the text.

A new, functioning material flow framework for the paper industry called the Detailed Wheel of Fiber was introduced in this study. With this kind of a framework, it will be possible to form a clear picture of material flows and recycling activity. The authors of this article introduced a new formula for calculating the *recycling rate*. Due to fixed *recycling activity targets*, both the European Commission and the European paper industry must consider how to measure the extent to which the set targets are met.

This new framework can also be used as a foundation for developing a new uniform terminology related to paper recycling. This article shows that any terminology and corresponding framework depend on one another. To be able to univocally define material flows in paper manufacturing, it is essential to have the following:

- a uniform framework that can be used to describe the closed material loop in the paper industry;
- a way to define and quantify stages and material flows in the framework.
- a uniform terminology to uniformly define terms in the paper industry related to *recycling*;
- a uniform system of symbols that can be used to define terms;

A common framework and uniform terminology is also necessary for other types of recycling in addition to paper recycling. Voluntary and compulsory material *recycling*

targets for different materials, such as metals, glass, plastics, and wood, are currently being set for different regions. With sophisticated versions of the framework, the Wheel of Fiber introduced here could perhaps be used to define energy flows and regional economies, too.

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